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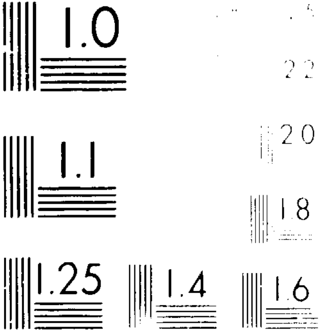
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Essays on the application of plastics — R S Lenk 1981

I. Material selection, materials classification and the place of plastics among the materials

The cultural and social evolution of Man is the direct consequence of technological advances made possible as a result of discovering and exploiting fresh material resources, starting with stone, its conversion to simple implements and its employment as a constructional element, the use of timber for major loadbearing structural and domestic purposes, the discovery that shaped clay can be fired and converted to brick and pottery, the realisation that animal and vegetable fibres can be used as hides, tanned to leather, spun and woven into textiles for the manufacture of garments, and the art of extracting metals from ores.

The discovery of each of these groups sparked off inventions which provided the seedcorn for new technologies. Supplementing and/or superseding earlier technologies, these transformed the brutish existence of the primitive hordes of savages, bringing about the changes which eventually resulted in the emergence of civilised communities which were able to enjoy a longer life span of better quality and enhanced security.

The main points of the consequences of this progression may be summarised as follows:

(i) A greater independence from the vagaries of the immediate environment and the ability to survive under otherwise hostile climatic conditions;

(ii) A progressive reduction in the drudgery involved in securing a continuing supply of food and other essentials of life;

(iii) The need for specialised skills, the resulting division of labour and the evolution of larger social groups within which individuals became increasingly dependent upon co-operation with others;

(iv) A continuous improvement in productive efficiency, making it possible for people to devote an increasing proportion of their lives to pursuits other than those required to scratch a bare existence;

(v) The emergence of a successful and sophisticated social structure in place of the primitive mores of the savage. Its outward signs created wealth, a respect for the rights and a concern with the welfare of its individual members under government by law with the free consent of the majority; under such conditions of felicity- unfortunately not widely enjoyed even today- people are at liberty to engage in the pursuit of happiness such as the enjoyment of artistic, intellectual and recreational activities.

Clearly, the process of technological evolution was painfully slow, even imperceptible within the lifespan of generations of prehistory and the misty shrouds of millions of years following the emergence of our species are only sketchily illuminated by conjecture based upon a few lucky archaeological finds of primitive stone tools and detritus. However, one may be safe in assuming that each major advance, such as the invention of the wheel, produced not only a wave of adaptation throughout the totality of human activity, but also catalysed and accelerated successive developments both in scale and in scope.

However, there is a reverse side of the coin: Any major technological breakthrough (to use a well worn clichée) also generates problems to which society must adjust psychologically without becoming disoriented and destroying itself through "future shock". This requires, above all, time and therein lies the dilemma: The rate of technological progress is clearly beginning to exceed the rate at which our species can adapt to it. The "industrial revolution", the "new products revolution" based upon the availability of new materials developed by the chemical industry, the microchip and the advances in a electronics, and, above all, the awsome destructive as well as the creative capability made possible by nuclear technology have produced and are still causing traumatic adjustment spasms. It is undoubtedly time to digest, take stock and reflect rather than charge further on. There is no immediate answer, but an answer will be found, provided time is given a chance. Perhaps this is the moment when poets and dreamers hold the key to the future rather than the scientist, technologist, or social engineer.

And where do plastics come in? Plastics differ from all the other materials in that they are essentially synthetic products of the chemical industry which in its modern form is itself barely 100 years old. At present the chemical industry produces the feedstocks for plastics manufacture from fossil raw materials, principally oil and coal. These are resources which nature accumulated over millions of years and which man is using up in a matter of decades. If the stream of suitable feedstocks is to continue when fossil resources are exhausted it is necessary to develop continuous cropping methods based upon the careful husbandry of the earth's surface (both land and sea) as well as upon the continuous availability of cheap and abundant solar energy. Such methods are already outlined and include biomass fermentation for the production of ethanol and other basic starting materials, and a reappraisal of the potentialities of renewable polymeric intermediates such as cellulose, starch, lignin and proteins. Whatever the problems of tapping new resources, we may be confident that these will be solved before we run out of oil and coal altogether. The continued availability of the products of organosynthesis, including plastics, may therefore be taken for granted.

It is suggested that the entire spectrum of structural and engineering materials can, in essence, be arranged in seven categories of which plastics and rubbers constitute the most recent ones.

1 Stone and "reconstituted stone" (concrete);

2 Fired clays (brick, ceramics), enamels and glass;

3 Metals (including alloys);

4 Timber and timber products such as block- and particle board and plywood;

5 Fibres of all kinds (wool, cellulose, silk, metal wool, rock and slag wool, glass wool and synthetics) as well as all the webs derived from them such as textiles, fleeces, felt, paper and board;

6 Expanded materials, rigid and flexible foams, sponges and cork;

7 Plastics and rubbers.

Of those seven clases the first three are inorganic and all the others except some fibres are organic in nature. Ancillary groups or materials include a variety of bonding agents, as well as assorted amorphous solids and "goos" such as resins, gums, tars, pitches, waxes and greases.

Dealing briefly with each of the first six groups in turn:

1 Stone and concrete have high density, excellent heat resistance, high compression strength and considerable corrosion resistance. They are also incombustible. Stone is hard to handle and difficult to transport and its shaping and conversion into a useful form is both hazardous and wasteful. Although concrete can overcome many of these disadvantages, it has a low aesthetic rating and takes a considerable time to dry out, cure and attain its ultimate strength.

2 Brick is an old and excellent building material, unrivalled in its durability, appearance, compressive strength and ease of handling and transportation. Other products of fired clay are ceramics which make useful vessels, especially when they are glazed to become impervious to liquids such as water, oils, grease and household chemicals, but their mechanical strength is limited by poor impact resistance. Enamels are used as surface coatings for metals, especially steel, rather than as materials in their own right.

Their gloss is very attractive at first, but deteriorates in time as a result of cleaning with abrasive scourers. Glass, especially plate glass, is a fairly recent material of construction, although it has been used for artistic purposes for thousands of years. Like its group companions it is made from cheap starting materials, but its cost has increased rapidly due to its high energy content. Glass is unrivalled when a combination of strength, heat resistance, chemical inertness, weathering resistance, dimensional stability, rigidity and special optical properties (transparency, translucency or opacity) is required.

3 Metals are characterised by their high density (steel: 7.8, although aluminium is only 2.2), high temperature resistance, high tensile and impact strength and high thermal and electrical conductivity. They vary greatly in their ease of extraction and hence their cost, as well as in their corrosion and general chemical resistance.

4 Timber is a renewable resource. It is preeminently a material of construction with good tensile and compressive strength in the fibre direction and it has great aesthetic appeal. It is no longer cheap and its conversion tends to be labour intensive and wasteful. Some of its waste products can, however, be used for blockboard, chipboard and particle board manufacture in combination with suitable modern adhesives, whilst woodflour may be used as a filler for thermosetting resins such as phenolics and UF resins. Multiaxial strength may be achieved by cross-grain lamination (plywood). The main disadvantages of timber are its susceptibility to bioattack by insects, rodents, rots and fungi, its generally poor weather resistance necessitating repeated protective surface coating and/or impregnation, its tendency to burn actively in a fire and its dimensional instability under varying conditions of temperature and humidity.

5 Fibres and webs constitute a distinct class of their own, even though, chemically, they might arguably be included among cellulose-based materials, glass, wool, metals, stone, proteins and plastics. The uniqueness of fibres lies in their physical form and in their uniaxial nature. Moreover, their production history bestows special morphological and/or orientational anisotropy and this results in characteristics which are far more important than their chemical affinity with the bulk form, whatever that may be. Who can deny that wool, cotton, nylon and polyester fibres have more in common with each other than, say, cotton has with cellulose film, paper with wood, rock wool with stone, metal wool with cast iron, or a nylon stocking with a moulded nylon gear wheel?

6 Expanded plastics and solid foams, sponges and cork are all materials with extremely low density. They may be rigid or flexible and may have an open or closed cellular structure. Alternatively, the cells may have degenerated into mere struts (as in sponges) while still retaining the capacity to soak up liquids by capillary action. Closed cell structures, on the other hand, are completely nonabsorptive. The characteristics of this group are self-evident and, as with fibres, derive from their physical form rather than from their chemical composition: They all have extremely low densities and excellent thermal and electrical insulating properties. The elastomeric closed cell types are widely used for cushioning and upholstery while the more rigid ones are found in thermal insulation and in certain forms of packaging. The justification of grouping together man-made polymeric foams such as foam rubbers, PU, PS, PVC, PF and UF foam with cork and sponge into a category of its own is analogous to that given for fibres earlier on: For all practical purposes a refrigeration insulating layer of PS closed cell foam resembles cork much more than, say, a presentation container for a choice orchid moulded from clear PS moulding material; and a car washing sponge from cellulosic sponge material resembles an oldfashioned bath sponge of marine animal origin much rather than a piece of cellulose packaging film

or a cellulose acetate moulding.

7 Despite the fact that plastics and rubbers include materials which do differ considerably in their combination of properties, they do nevertheless constitute a unique and cohesive group of materials with characteristics which each member of the class possesses to a greater or lesser degree:

(i) Plastics have low densities, typically ranging from about 0.9 (polyolefines to 1.4 (PVC). Many of them occupy the range between 1.05 and 1.2; the one exception is PTFE with a density of 2.2.

(ii) On the basis of strength-to-weight ratio plastics are remarkably strong, especially in tension, but they do exhibit considerable creep under static loading.

(iii) Although plastics may be either tough or brittle (depending on the specimen geometry, the conditions of testing and the type of applied stress), most uncrosslinked or lightly crosslinked plastics may be "toughened" by compounding with suitable additives such as plasticisers, by the milling-in of suitable synthetic elastomers, or by the modification of the feedstock monomers (internal plasticisation, or copolymerisation).

(iv) Being organic materials, all plastics are combustible. But while some are readily set alight and may burn actively, others are self-extinguishing by nature or as a result of special flameproofing treatment.

(v) In general, plastics will withstand prolonged exposure to elevated temperatures up to a point defined by their chemical stability or resistance to demoulding. This may be as low as about 70°C (plasticised PVC), a little higher for LDPE, or well above the boiling point of water for PP, PMMA, polycarbonate and polyacetals. In the case of Nylon 66 it exceeds 200°C substantially and enables a moulding to maintain its mechanical properties unimpaired for long and uninterrupted periods of time, while certain polyaramides can be used at temperatures exceeding 300°C and do not decompose until the temperature exceeds 500°C.

(vi) Plastics and rubbers are poor conductors of heat and electricity and are thus eminently suitable for the purpose of thermal and electrical insulation.

(vii) Plastics may be produced in an infinite range of colours and surface finishes and many of them can be obtained in a transparent, translucent or opaque form, depending on the designer's preference or specification.

(viii) Plastics are basically inexpensive owing to the relative cheapness of feedstocks and the large and continuous nature of the unit production operations. The cost of manufactured components from the base polymers tends to be low because of the simplicity, rapidity and efficiency of standard conversion operations such as extrusion and injection moulding. It is true that some speciality grades such as PTFE and polyaramides look very expensive at first sight. But even here the cost is really small when considered in relation to performance. Savings often recoup the initial outlay many times over then a suitably designed component of the correct material choice ensures continuous troublefree running of a production line without costly interruptions or maintainance shutdowns due to the failure of a component previously made from a "cheaper" material. Higher materials costs are also easily justified where weight (and hence fuel) can be saved. This applies especially to the aircraft and aerospace industries. Lastly, a high material cost may be perfectly acceptable provided that it enables one to accomplish an essential engineering design objective which cannot otherwise be attained.

(ix) Plastics generally do not present a toxicity hazard.

(x) Plastics per se are not attacked by insects, rodents, moulds, fungi or bacteria. Some have outstanding weather and UVL resistance while others can be programmed to degrade under certain conditions within a specified time so as to avoid environmental pollution through the accumulation of litter.

Finally, it should be said that an enormous number of optimised design solutions have been developed which are based upon a combination of materials right across the spectrum of groups as well as within a given category. This can be achieved, for example, by the use of bonding agents. Plastics and metals, plastics and timber, plastics and paper plastics and plasterboard, laminates involving metals in sheet or foil form and foam sandwich structures are commonplace, while many a sophisticated gadget contains numerous components made from a variety of different materials combined in a single integrated functional unit.

Following this cursory review of materials we now need to consider what criteria are to be used in order to arrive at a sensible decision when selecting the right material for the manufacture of a component which will serve a clearly defined purpose. We shall indeed go into some detail when considering specific fields of application such as building, packaging, transport, agriculture, etc. For the present moment, however, let us examine general guidelines.

(i) We first need to be perfectly clear as to the functions which the intended product is to perform. This enables us to draw up a list of properties which the component must possess, what properties might be desirable though not absolutely indispensible, and what adverse characteristics must be avoided at all cost. Some idea of this may already be in the designer's mind, especially if a similar product is already on the market and needs improving. Is the shortfall in performance really the result of faulty material selection or is it merely a defect in engineering design? If nothing of the kind exists as yet, is this due to the nonavailability of a suitable material of construction or to the absence of any demand for the product? And if the latter, is there any likelihood that such a demand will arise naturally or can be (and should be?) stimulated? The answers to questions such as these will indicate which of the seven groups of materials enumerated above or what combination of them might be the first choice.

No prejudice should be allowed to cloud one's judgment which might either favour or discriminate against any particular group. If plastics are not the answer, then this must be honestly and gracefully acknowledged. But if it appears that a good case for plastics can be made out, then we enter upon the next phase:

(ii) Which plastic? The quick answer to this is: the one which has the highest ratio of performance to cost. It is important to point out here that anything that is better than "good enough" is often really bad, inasmuch as the consumer is made to pay for something better than he really needs. Many illustrative examples of the simple truth of this statement can be given and we shall raise the matter again when we discuss the application of plastics in packaging. If the level of performance is defined, then the acceptable cost is that which the market can bear. The customer is willing to pay for just so much mechanical strength, rigidity, flexibility, thermal or electrical properties, durability, ease of installation and maintenance, appearance, etc.; but in no one instance will all of these - and many other properties that might have been added - be required. Moreover, those that are required will not necessarily rank of equal importance. One must therefore apply weighting factors with which to multiply a rating of performance in each respect on an arbitrary scale. Supposing we wish to decide on a preference between materials A, B and C on the basis of their overall performance with respect to properties X, Y and Z. Assuming that the top quality on a 10-point scale is 10 and the respective weighting factors are 4, 3 and 1 respectively, then the following table may be drawn up:

Property;	(weighting factor)	Material; (Material x weighting factor) A		B		C	
X	(4)	9	(36)	7	(28)	5	(20)
Y	(3)	6	(18)	6	(18)	8	(8)
Z	(1).	6	(6)	7	(7)	7	(7)
Total points rating		-	60	-	53	-	51

Result: Material A is clearly the first choice, although this may yet have to be revised in the light of other considerations such as availability, processing limitations, etc.

(iii) What method of processing is indicated? In many cases there is but one answer to this, but in others there may be a choice such as moulding a gear wheel or machining it from stock, and injection moulding or vacuum forming a drinking cup. The company commissioning the review may not be able or willing to embark upon a process for which it is not equipped or in which it lacks expertise; if that company wishes to go into production nevertheless it may have to accept a process which is less efficient or consider using an alternative material which represents a second choice but which is better suited to the facilities available to that company.

(iv) Whilst it is essential to consider the properties of materials in relation to the expected performance of the end product it must also be remembered that constraints may exist not only in the primary operation, but also as regards any after-treatment and finishing. The processing constraints generally involve the chemical stability and the flow properties of the polymer which, in turn, depend on time, temperature, shear stress, applied pressure and composition (including additives, if any). After-processing such as hot- or cold drawing often have a tremendous effect on the morphology and anisotropy of the product, on the equilibrium moisture content or on the dimensional stability in service, while finishing operations may decisively affect the appearance and may be essential, yet costly.

(v) Any production hazards such as toxicity, flammability or explosion risks must, of course, be totally eliminated before even considering setting up a production line. Equally, one must consider the environment of the production site: pollution with gaseous and liquid waste products must be prevented and solid waste should preferably be recovered and reworked, or at least be safely disposable.

The site itself has to be provided with the necessary services such as water, power, effluent treatment and disposal, transport and telecommunication facilities, storage space and a supply of staff who possess or who can be taught the relevant skills. The workforce will need to have housing available within commuting distance and technical and managerial staff may need to be recruited from more distant places if necessary.

(vi) On launching the product one has to decide on the organisation of sales, product promotion and technical service.

(vi) What is the estimated time (or level of production) before

(a) the anticipated initial production loss period is at an end, and

(b) the product yields a profit equal to the average profitability of <u>all</u> the company's products?

Furthermore, what surplus profits <u>beyond</u> that point must then be made in order to enable the company to recover its research and development outlay and to provide the capital for the next venture? This is a particularly tricky question: There is clearly a temptation to cash in on what may be a monopoly, but greed does not pay in the end, since it attracts others to enter the field and to compete for the market by undercutting the price. The correct solution is to reduce prices and to keep up profits by an increase in productivity; eventually this will return the new product to the average profit level of the company's other operations. Clearly, it is a sound policy to do this <u>before</u> any external pressures are applied, since the company can always then be confident that it can remain both technically and commercially ahead of its reputable competitors and keep the "cowboys" out.

(viii) No expert in material selection will ever fail to consider the possibility of optimising his choice by using a combination of materials. In this he resembles the virtuoso organist who artfully and cunningly selects the right combination of stops in order to achieve just the required overall effect. The building and packaging industries as well as the design of a number of household durables afford many examples and case histories in this respect which are most instructive.

(ix) It is strongly recommended that case histories of earlier attempts at the intended design as well as related designs be carefully studied, if any such exist. It is a salutary and often sobering experience to look at some harrowing stories of misapplications ostensibly due to bad luck, but, more likely, to incompetence on the part of the designer due to his lack of understanding of materials. Examples of these litter the garbage heaps of industrial enterprise. They warn us of the pitfalls which threaten the unwary and teach us humility since, however knowledgable one may be, there are always lessons to be learned.

BY R.S.LENK *

When considering what properties are required to make a material suitable for building applications the answer can only be given in the most general terms. Obviously, a home should provide the highest possible degree of comfort in return for the money paid by those who live in it. But this, in turn, is not easily quantifiable; moreover, the notion as to what is good value (or what is acceptable) is highly susceptible to changes in performance expectation and prevailing fashion. Before we can attempt an answer to the question what the building industry really wants one must recognise that a building is a complex conglomerate of often quite independent autonomous systems with close internal group affinities. The only feature that they all share is the fact that they each make a unique contribution to the whole. All systems must therefore be mutually compatible within the building in exactly the same way as all the branches of a tree integrate harmoniously in the overall structure of a tree.

Each system presents the designer with particular problems and therefore with the opportunity of coming up with specific and relevant answers. But it is first of all necessary to identify the various systems which comprise the essentials of the building industry. We propose to list these as follows:

1 Foundations;

2 Primary loadbearing structures above ground level;

3 Flooring;

4 Water management (supply, distribution, storage, waste water, surface water and sewage disposal);

5 Sanitary ware;

6 Other "services" (gas, electrical, lighting, heating, ventilation, etc.)

7 Curtain walling, infill panels and cladding (external and internal);

8 Partitions and doors;

9 Windows;

10 Thermal and acoustic insulation;

11 Roofing.

2.1 Foundations

It may be taken for granted that the primary requirement for satisfactory foundation is a structure such as rock or concrete which is eminently suited to support heavy static loads over long periods of time without cracking, distorting, shifting or corroding and which is relatively inexpensive. Plastics in bulk are obviously quite unsuitable to perform these functions. However, plastics do have an ancillary role in foundation work. Concrete needs to be protected from rising moisture and from any soil chemicals such as sulphates which this may carry in solution. It is therefore common practice to cover the hardcore base with a heavy duty barrier film of polyethylene, a function which was only moderately satisfactorily performed by bituminised paper in earlier days. Polyethylene film is also used to provide a curing membrane and to protect freshly laid concrete against rain; it is left in position until the foundation slab has hardened and can be allowed to dry out naturally. Heavy damp course membranes which prevent rising damp from creeping up the brickwork by capillary action also generally incorporate polyethylene film, usually combined by lamination with bituminised felt and metal foil. In the past bituminised felt has been used for this purpose by itself, although in superior type buildings more efficient but much more expensive alternatives such as slate and lead sheeting may be found. It might be stated in passing that polyethylene film is also used extensively to provide weather protection once the main elements of the primary framework have been set up, so that the workforce can continue operations under what might be described as factory conditions.

2.2 <u>Primary Loadbearing structures</u>

Since plastics are not, in general, suitable for sustaining heavy and continuous loads it follows that they cannot compete successfully with traditional materials such as stone, brick, reinforced concrete, metal or timber for the construction of beams or struts. The only exceptions here are certain lightweight one-storey (or, at most, two-storey) buildings such as temporary or demountable structures (site offices and shelters assembled from prefabricated glass-reinforced polyester units) and somewhat unusual "space structures" such as goedesic domes and folded-skin wall/roof designs; the latter are interesting, exciting and spectacular in appearance, but quite rare.

As in the case of foundations, however, plastics can be used to great advantage in combination with traditional materials in composite structures and as ancillary items in the production of concrete component units. Leaving laminated structures until later (see 2.6) we should mention the following:

The surface treatment of metals and concrete to minimise or eliminate weathering and corrosion in concrete and metals as well as weathering, rotting and bio-attack by moulds, fungi and woodboring insects in timber.

The construction of suitable moulds in the production of concrete shapes. This may take the form of small thermoformed moulds for patterned concrete slabs (UPVC), shuttering or the lining of timber shuttering (UPVC), or large assemblages of tote-box-like units for the construction of floor/ceiling structures from concrete reinforced with tensioned steel bars or wires. This technique is used for multistorey buildings and the units are recovered for re-use after the huge slab has been hoisted into its correct position.

The use of moderately plasticised PVC as "water stop" expansion/contraction joints between adjoining concrete slabs in order to prevent the penetration of water in vertical concrete wall slabs and in horizontal slabs such as are being cast in roadbuilding, replacing bitumen. In this application there are alternatives of weather and ozone resistant synthetic rubbers, but they are considerably more expensive and are only used when the highest performance requirements must be met;

Epoxidised bitumen surfacing of roads when wear and hence frequent repair work (with the consequent disruption of traffic and noise and dust pollution) must be minimised and when the considerable extra cost is justified.

2.3 Flooring

The traditional materials of decorative flooring such as woodblock and ceramic tiling continue to have a great deal to recommend them for mainly aesthetic reasons, but they are expensive. Apart from carpeting, which is not, strictly, a building component any more than furniture, the only alternative of the pre-plastics age was linoleum, usually laid on floorboards with or without some intermediate layer of felt, board, or the like.

The requirements of an acceptable flooring material are: good abrasion resistance, resistance to water, oils and household chemicals, non-slip surface properties and scope for artistic design at reasonable cost. These requirements are fulfilled to an admirable degree by a number of plastics of which the most important is PVC. In its slightly plasticised form it is available in tile form in a vast variety of colours and patterns, with plain or embossed surface and with or without a backing which may be jute or some cushioning material such as a closed cell rubber, PVC or polyethylene foam. The cost of such tiles varies greatly, depending upon quality. The cheapest of them contain large amounts of fibrous and/or powder fillers such as wood flour, chalk, slate dust and fibrous materials. The most expensive of them are almost devoid of filler and are semi-translucent, thus creating a marble-like effect in depth, as well as having excellent staining resistance. Sometimes abrasive fillers such as carborundum are included in the compound in order to improve non-slip properties, especially for stair tread and nosing. PVC flooring also comes in the form of continuous rolls which are slightly more plasticised and which are fitted like wall-to-wall carpeting. Continuous PVC flooring tends to be cheaper than tiles of fair quality and, as in the case of tiles, it is possible to create a wide range of artistic effects, including woodgrain and ceramic tile simulations. The cost can be kept down by making up a laminated structure with a transparent, thin (but hard wearing) non-slip top layer, followed by the decorative layer and the bulk thickness of PVC, the latter being often filled with an inexpensive mineral filler such as iron oxide. A cushioning layer of PVC microfoam may also be present.

Alternative flooring materials consist of carpet tiles made up of synthetic fibres (PP, nylon, polyester, acrylic, or a combination of these), natural fibres such as hogs' bristle, cotton or wool (usually mixed with synthetics) which are bonded together onto a suitable supporting layer of PVC or rubber and which are usually also provided with some cellular cushioning.

In the industrial field there may be extra requirements of resistance to heavy duty traffic, special chemical resistance. These are met by the use of synthetic rubber tiles of chlorosulphonated polyethylene ("Hypalon") or by trowelling of a special cold-curing polyurethane cement which sets to an extremely hard-wearing continuous layer. Such surfaces may be called for in aircraft hangars, forklift truck lanes or abattoirs, because they are also easily kept clean by hosing and flushing into a suitably sited drainage system.

2.4 Water and Effluent management

The efficient supply, storage and disposal of water and liquid waste is an essential requirement of modern living. The days when housewives had to laboriously carry water (of sometimes dubious purity) from the street pump in buckets and when the slops were thrown unceremoniously out of the window into an open sewer running along the middle of the street without so much as shout of "Gardy-loo" are happily gone. We must, however, pay tribute to the astonishingly advanced standards of the Romans who built impressive aqueducts, bathhouses, public lavatories and the sewerage system of the cloaca maxima, although the supply of piped water to Roman dwelling units was by no means universal. Unfortunately the Roman water supply and plumbing system fell into disrepair as the Roman legions withdrew from their crumbling empire and few attempts were made by the barbarians of the dark ages or the feudal rulers of the middle ages to set any standards of cleanliness and sanitation that would be acceptable to civilised man today, with the result that disease was rife, infant mortality high and the expectation of life short. This changed with the industrial revolution when large numbers of rural workers streamed into the cities and the situation threatened to get out of hand. Pipes and sewers were laid using glazed earthenware and metal pipes. An assured supply of pure water and the safe disposal of sewage to every house in densely populated areas as well as in small rural communities had to await the emergence of suitable materials which were also linked to an efficient mass production technology before the principal requirements in this field could be fulfilled. These are:

i Acceptable first cost;

ii simple and quick installation with a minimum of preparatory work, and

iii reliable and maintenance-free running over the entire expected functional life of the building in the confidence that the system will neither corrode nor be subject to mechanical failure during a freeze-up in a cold wintry spell.

Although traditional materials were able to fulfil those requirements to a satisfactory degree, the construction of water supply and water disposal systems presented considerable difficulties in many ways: Jointing, leakproofing and thermal insulation presented problems to which the answers were often untidy and inelegant, the installation work was labour intensive and therefore expensive and it was quite impossible to conceive of a "fit-and-forget" system which could be guaranteed to be free from any risk of corrosion. Also, it began to be realised that lead (which had been widely used in water supply pipes from Roman times onward) constituted a toxicity hazard, whilst iron and steel pipes tended to corrode rapidly and, though not injurious to health, caused the water to become tainted and stained with rust. It was only with the emergence of plastics that the complete solution of all these problems became available.

In order to ensure the absence of any leaks special attention must be paid to the joints. These are normally welded joints in the case of metal tubes and gasketed bituminous or mastic joints in the case of glazed earthenware or spun concrete pipe. These methods of jointing are also available and indeed appropriate to plastics pipes in some situations, but where temperature fluctuation occur this is not usually the correct solution. Plastics have a much higher coefficient of thermal expansion than metals or ceramics and this must be allowed for in the design, for example, of guttering and other rainwater goods as well as in above-ground waste pipes.

Let us first look at water supply pipes. Principal supply pipes may be several foot in diameter. They usually supply a water tower from which a branching mains distribution system goes to individual houses. Such distribution pipes are invariably laid underground. The supply line from the reservoir to the water tower is also usually buried in trenches and covered with earth. Traditional materials such as mild steel or cast iron are joined by welding and rest on concrete supports in order to ensure that they do not shift and crack. This is also true for glazed earthenware and spun concrete pipes which are traditionally used in sewerage systems, except that the joints here involve gasketing with bitumen, mastic and rubber. Moreover, the units come in short lengths and therefore require many joints for even quite short runs, and they are highly vulnerable to chipping and fracturing. The laying of such installations involves expensive trenching and preparation of concrete support structures and is very labour-intensive. UPVC pipe, in contrast comes in very long lengths, with well designed joints, is free from corrosion and may be simply lifted and dropped into a trench by a gang of workmen without heavy lifting tackle or specially constructed supports. Moreover, UPVC is sufficiently flexible to accommodate some curvature and change of direction. Sometimes welding is additionally resorted to, in which case electrically heated bands are preferred to the use of a hot air welding torch and welding rod. In underground pipes expansion joints are not necessary since they operate under constant temperature conditions. PVC compounded for the extrusion of water supply pipe contains no toxic ingredients while lead piping (which has been fairly extensively used until recently) has been recognised as a health hazard, especially in soft water areas. Containing no extractables of any kind, the use of UPVC pipe ensures that the quality of the water it supplies is exactly the same as that which entered into the system at the source. This is also true for ABS, an alternative material which is sometimes used but which is more expensive. PVC is especially suitable for large mains supplying offshore islands from the mainland. Unlike the traditional pipes, PVC pipe may be loosely anchored and even allowed to float intermittently over what might be the shifting sands or the pebbly subsoil of a tidal causeway. Indeed, no outside piped water supply to the island of Benbecula in the Outer Hebrides could be installed until UPVC mains water supply pipes became commercially available.

When considering hot water systems one must bear in mind that the coefficient of thermal expansion of plastics is much greater than that of metals and that longer runs of hot water piping must therefore have coiled or omega-shaped sub-sections designed to take up the strain and prevent failure due to the excessive stresses that would otherwise be generated. It must, however, be admitted that the metals, and especially thin walled copper pipe, have retained their hold in this application, mainly on the grounds of cost. Plastics alternatives such as chlorinated PVC do exist, but this material is expensive and offers no technical improvement over copper to justify its choice; on the other hand, the serviceability of PP hot water pipe and even of a hot water tank constructed from the same material has proved its technical suitability by standing up to long-term running under the most demanding field conditions, even with boiling water.

For rainwater goods, UPVC is now the natural choice, having superseded the traditional materials. It is cheaper than any other material on installed cost as well as on first cost, is free from corrosion and has more than adequate impact strength; defective portions may be readily sawn off in the unlikely event of damage in transit or during on-site handling; it requires no painting or corrosion protection. The surfaces are smooth, and gentle radiusing takes the place of sharp corners and welds. This enhances the efficiency of downpipe and guttering for coping with large flows during heavy downpours, because of reduced friction and vortex formation; it also reduces the tendency for dirt to accumulate, makes occasional cleaning out easier and discourages birds from building their nests in the gutter. None of the traditional materials (cast iron, asbestos/cement pipe, zinc pipe or lead gutters) exhibit anything even remotely approaching this impressive combination of properties. The tremendous success of UPVC in this application has impressed builders and architects as well as the general public to such an extent that the initial reluctance to try out these "new-fangled" materials in other applications has greatly diminished and the introduction of plastics for application in other "services" systems has been greatly facilitated. The confidence and goodwill thus gained imposes an obligation on the plastics industry to offer only well designed products perfectly suited to fulfil their intended functions and, above all, to refrain from making ill-founded claims on behalf of plastics when other materials are clearly better suited to a given application.

The need to take note of and accommodate the high coefficient of thermal expansion in plastics has already been mentioned in the context of hot water systems. This also applies to rainwater goods. It is essential that runs of guttering be provided with suitably gasketed expansion joints which are rendered leakproof , for example, by means of a weather resistant microporous rubber seating. This prevents distortion or fracture due to seasonal changes in the ambient temperature which may be as much as several tens of degrees. To a lesser extent this also applies to soil and stackpipes in the foulwater and greywater effluent systems.

Turning to the latter, fixed joints are the rule since thermal expansion, as with water supply lines, can be discounted when the pipes are buried in the soil. These joints are similar to those used for water supply, but the requirements of absolute leakproofness are very much more stringent for obvious sanitary and epidemiological reasons. Fortunately PVC and ABS pipes and their associated jointing methods as already described are at least the equal of (and probably superior to) those used for spun concrete or glazed earthenware, and certainly very much simpler and cheaper. In fairness and for historical reasons it should be stated that bitumen-impregnated and coated fibre pipe with carefully machined "hammer-home" male and female joints has been in use for at least a century and has proved to be exceedingly well suited for underground sewerage lines. Unfortunately it has never been possible to produce an integrated system complete with a full range of fittings and bends in this material, although bends in injection moulded black PP have been produced into which the pipes could be hammered home. A major disadvantage of pitch/fibre pipes is the slow and messy method of manufacture and the subsequent machining of the ends. It is for this reason that these pipes have largely disappeared from the market. Existing lines are retained because they are invariably found to be in excellent condition even though they may be many decades old and because they can be readily combined with fittings made from PP, PE, UPVC or ABS.

The importance of fittings cannot be overstated. No pipe system is functional without a set of the most diverse fittings that the various installations may require. Expansion joints have already been mentioned and they may simultaneously fulfil the function of fixing brackets. Injection moulded end pieces and corners for guttering are available in black PP. The same material is also widely used for small inspection covers, cleaning access covers and grilles, while strainers, collection manifolds, sedimentation boxes, sewage farm aeration fittings and the like are generally moulded from either PP, PE, PVC or ABS. These fittings are standardised parts which have been designed to extremely high standard of engineering sophistication, so that they clip onto or otherwise integrate smoothly with the pipes and gutters with which they connect. This contrasts with the crude bolting, screwing and nailing which is so characteristic for fixing and connecting the older type metal structures. However, even here plastics have occasionally been able to help out. Thus, the winding of PTFE tape round screw jointed metal pipe makes a perfect water proof connection which can be easily undone and reconnected; the oldfashioned plumbing method relied on sisal twine and red lead compound which, with luck, was leakproof, but which required a tradesman's services for its maintenance. Whilst this cited example may be considered somewhat trivial, it does illustrate particularly well how the use of plastics can solve many a tricky problem and do away with messy and often unsatisfactory alternatives; another instance of which is the use of putty and mastic for the leakproofing of rainwater guttering made in cast iron.

We finally consider storage tanks and cisterns. Galvanised and welded steel sheet has been the traditional material for cold water storage tanks in the loft. However, even with a generous protective coating of cheap bitumen the tanks cannot be relied upon to exceed a life-span of 10 years before serious corrosion sets in and causes leakage and possibly costly damage to plastered ceilings. Morover, the replacement of the old tank often presents difficulties owing to the restricted size of many loft trapdoors, to which an assortment of defunct rust water tanks in many an older type house bears silent yet eloquent witness. In such a situation a thickwalled replacement tank, injection moulded in black polyethylene, provides an excellent solution. These tanks are circular and have a slight downward taper as well as a thickened rim in order to provide improved rigidity. It can be squeezed through the access opening and will spring back to its original shape when it is released. Whilst galvanised steel tanks are certainly cheaper, the premium paid for the plastics tank is well worth the freedom from having to worry about possible future overhead flood disasters. All tanks of whatever construction are fitted with a ballvalve cutoff mechanism, with elbows and floats which provide scope for the use of nylon, PP and PVC respectively, while the lids are often made from a rigid plastics foam material. This, as well as other forms of frost protection in tanks water pipes will be discussed under the heading "foams". Apart from the logistics of installation there is really no a priori constraint upon the size or shape of a tank. Provided that it is lined with a plastics sheet material of suitable which can be put together in a reliably leakproof manner, the supporting loadbearing function may be performed by a retaining tank made from any material (notably plywood, boxboard or particle board, or metal sheeting).

Hot water tanks are invariably made from thinwalled copper sheet, but beads or granules of expanded polystyrene, synthetic fibre wool, polyurethane foam waste or kapok are made into tailored quilt-like lagging with a flexible PVC covering to provide thermal insulation.

Cisterns are really small storage tanks for flushing lavatory pans. At one time they were made from cast iron, a particularly ugly choice of crude design which soon became dirty and rusty. The earliest plastics cisterns were compression moulded in thermo-setting (mostly phenolic moulding materials), but these went out when injection moulded PP cisterns became available. Nowadays the up-market lavatory cisterns are made from glazed earthenware to a variety of elegent designs which match the rest of the bathroom/lavatory suite, while the PP cistern offers a cheaper alternative which is both technically adequate and aesthetically acceptable. All types of cisterns are fitted with a PP siphon and float and with a lever and valve control mechanism which incorporates moulded nylon parts.

2.5 Sanitary ware

This system constitutes the logical extension of what has been discussed in the preceding section and does indeed represent the raison d'être of of every hot and cold water supply and waste water disposal system. The principal items involved are baths and sinks, but there are a number of smaller ones such as taps and valves, drinking fountains, urinals and toilet seats, towel rings, toilet paper holders and soap dishes which are fitted to the wall.

The principal requirements for this type of application are:

i Mechanical stability, adequate rigidity, impact resistance and resistance to abrasion;

ii Resistance to hot (even boiling) water, hot fats and oils, to common household chemicals such as detergents, antiseptics, ammonia and hydrochloric acid, and to common solvents;

iii Good aesthetic appeal combined with an acceptable price structure;

iv Ease of installation;

v The expectation of a long service life with a minimum of maintenance and with no deterioration in either appearance or technical performance.

Although some of the traditional materials have performed tolerably well in some respects, they are far from ideal in others. Thus, the glazed earthenware deep kitchen sinks of pre-war days quickly lose their glossy smoothness due to the constant and unavoidable need to use abrasive scourers for cleaning; this also applies to enamelled cast iron or enamelled steel baths. Furthermore, these materials are irreparably damaged by chipping whereupon they become a definite safety hazard and a source of infection. Last, but not least, they offer little scope for attractive design and are awkward to handle and instal. The introduction of stainless steel sinks certainly represented an excellent solution in all these respects, although it causes noisy clatter when cutlery is tipped into it and this may be objectionable in institutional and administrative buildings if the kitchen adjoins areas where only very low noise levels may be tolerated. Since in such buildings (and increasingly also in private dwellings) dish-washers are almost invariably used nowadays, stainless steel sinks have become standard items of equipment, although integrally thermoformed acrylic sink/drainer units do represent a good alternative. Acrylic sinks do, however, come into their own in bathrooms and in vanity units which are frequently installed in bedrooms as well as in bathrooms. Here the superior aesthetics and design scope of acrylic sheet, sometimes combined with flat surfaces of decorative melamine laminate, come into their own. This is also true of thermoformed acrylic baths which have the further advantage over enamelled steel or tiled pits in that they do not feel cold on contact with the body and keep the bathwater hot for much longer owing to the low thermal conductivity of plastics. Acrylic surfaces do not stain readily and are conveniently and efficiently cleaned with a soft damp rag. Even when scratched the surface can be polished up and restored to its original glossy condition since the colour goes right through the thickness of the sheet. It is not however, recommended that cigarettes be stubbed out on an acrylic surface since this will leave a burn mark behind. This is one reason why floor-mounted multiple urinal units have not found favour in public lavatories, despite their intrinsic cleanliness and why individual urinal bowls are preferred which are fixed to the wall. Both floor-mounted and wall mounted urinals are generally made from ceramic materials which are well designed to serve their intended purpose. Wall mounted acrylic urinals are certainly feasible but they cannot easily compete with the former on cost. Much the same is true for drinking fountains, but the concept of multi-unit construction from acrylic sheet has been successfully applied to children's handbasins in school and day nursery washrooms, taking advantage of the simple installation and the absence of joints between individual units which make cleaning more difficult and which may harbour infective germs.

Toilet seats, traditionally made from wood, are almost entirely made from plastics nowadays. The cheapest and least attractive of these are moulded in black (or at best maroon, dark brown or dark green) phenolic, but generally the seats, as well as their lids, are made from U/F moulding material. They come in pastel shades as well as in strong colours and are designed to match the bowl and the cistern as well as the rest of the bathroom suite in such an attractive way as to give a touch of luxury, class, elegance and distinction to the most functional room in the house apart from the kitchen. Lavatory seats have also been made from flat acrylic sheet which is cut into a horseshoe shape. Such seats are mainly found in hospital toilets owing to their simplicity and cleanliness.

Associated with sinks of all kinds are traps and "greywater" effluent piping which eventually feeds into the main effluent system. Various metals such as steel and brass have been used for traps, but here we face the usual jointing problem. Nowadays clean traps which can be easily unscrewed by hand are injection moulded from PP, or occasionally from PE or ABS, and their traditional competitors have become virtually obsolete. The waste pipes that connect with it is also generally extruded from PP, ABS or UPVC.

Realising that acrylic sheet and acrylic moulding material fulfil all the requirements for application in the sanitary field (with the only exception of <u>universal</u> solvent resistance, which is, in any case, rather extreme), it was not surprising that acrylics should also be considered for moulding kitchen and bathroom tap handles. A long time ago these were sometimes made from porcelain, but they are now merely quaint though often attractive reminders of bygone days and may be valuable as antique curiosities. Simple brass or iron handles were once common, but eventually these were replaced by taps and handles made from steel which were subsequently chrome (or even gold plated)in order to add distinction to the product. The up-market product range also includes taps machined from marble, but simple elegance at moderate cost can be achieved with taps made from acrylic moulding material which comes either water white and crystal clear or in a variety of clear, translucent or opaque colours. The bodies of the taps themselves, and especially mixer taps for hot and cold water, are available in acetal moulding material which is moderately priced and suitable for many engineering applications which require that the part should have a reasonable degree of heat resistance.

As regards small bathroom and toilet accessory fittings such as towel rings, towel rails, toilet paper holders and soap dishes, here a wide range of materials including glass, ceramics, chrome- and gold plated metal compete with plastics. The actual choice may even be a combination of two or more of these, but if plastics are selected, then the most attractive of these is unquestionably acrylic, although PVC, PP or PS are occasionally bought because they are cheap.

We see that acrylics virtually dominate much of the sanitary ware field, as far as the application of plastics is concerned. This is entirely due to the unique combination of properties of this material which fulfil the principal requirements to an astonishing degree. It is perhaps surprising that it took quite a long time before the application of acrylics for this application really took off. This may to some extent have been due to some unfortunate earlier experience with pedestal wash-basins moulded from glass fibre reinforced polyester. Although the material is excellent in many ways and eminently suitable in other applications the product was prematurely marketed before the crucial importance of a generous gel coat was appreciated. In due course the glass fibre which remained exposed owing to an insufficient barrier layer of polyester resin began to "wick in" water, set up large internal stresses and eventually the basin disintegrated with a bang. This material has never again appeared in the sanitary ware market. Worse than that, the traumatic experience queered the pitch for plastics in building for a long time. When acrylic baths and sinks were eventually successfully introduced and found to be much more amenable to mass production techniques there was no chance of a comeback even for a well made glass fibre/polyester product whose "wet hand layup" method of shaping and long cure time made it labour-intensive and uncompetitive on price as well. Since then, however, glass reinforced polyester material has become an important material for other applications, as we shall see presently.

Before leaving the subject of sanitary ware it is worth mentioning some new ideas in bathroom construction in which the bath, the basin and all the fittings are conceived as parts of a single integrated floor/wall/ceiling structure made up from large thermoformed acrylic or UPVC sheet, although the earliest prototype was in glass fibre reinforced polyester. Units of this kind would have all their plumbing, electrical wiring and air conditioning components attached to the outside and they would be cocooned in a reinforcing layer of cured polyurethane or polyester resin.

They would be factory prefabricated and would merely need to be put on a support structure to enable each one to be transported and hoisted into the gap in the building designated to receive the bathroom. It would finally be hooked up to previously installed supply and waste points, the outside wall would be built to close the gap and a small trap door opening to the outside of the unit would afford access for periodic inspection and maintenance. Prototypes of such units have been made to demonstrate the feasibility of the project, but it never got commercially off the ground, mainly because certain constraints of present-day building regulations could not be overcome.

2.6 Gas and electricity supply, lighting, heating and ventilation

As regards gas supply pipes the situation is simple; Underground supply pipes carrying natural gas are suitably made from UPVC. Where coal gas is used PVC pipe can only be used if the aromatics content of the gas is low. Actual gas pipes within buildings must always be made if metal (mild steel, copper or brass) because of their non-flammability and mechanical strength and their consequent safety to mechanical damage or in a fire.

In the electrical field plastics serve as insulants for the conductor and as a protective covering for both lighting and power cables. Although PVC is a polar polymer and has a high loss peak, this only appears at a frequency range of suitably plasticised PVC which is far removed from that of the usual domestic A/C supply. Plugs and sockets are mainly made from UF moulding material with brass inserts of the conductors and fixing screws. Earlier on phenolics were used for this purpose, but they tended to "track" and leave a carbonised conducting path which constituted a severe fire hazard.

Rigid PVC is used in conduit and junction boxes, sometimes replacing steel tubing. The concept of combining conduit with skirting board is an ingenious development into which sockets have also been integrated. The skirting board is in fact extruded PVC of hollow box profile. It clips onto prepositioned moulded mounts. There are also moulded male and female corner pieces. The wires are threaded through and the neat installation also replaces traditional timber for the skirting which can therefore neither rot nor require painting. It usually comes in white or cream.

Lighting is concerned with optics rather than electrics. In most cases aesthetics play a major role, although price is certainly also relevant. Light transmission requires transparency, diffusion translucency and shading opacity. Here acrylics, flexible PVC sheet and polystyrene compete with glass in lighting fittings and false ceilings. Acrylic fittings come in a number of forms of which the box shaped channels of extruded, embossed and postformed covers for fluorescent tubes is perhaps the most familiar. A similar application of glass is practically out of the question because of its weight, cost and lack of design scope. A rather novel method of lighting relies on the unique ability of acrylic castings to transmit light even through bent rod and this unusal method of illumination has been used in prestige buildings, hotels and conference halls. Another excellent use of acrylic sheet involves the construction of a false ceiling supported on a suitable steel grid into which the material is fitted. The lighting elements are concealed behind it and the pattern of illumination is established by using a number of translucent sheet scattered among a majority of opaque ones. Illuminated ceilings can alternatively be designed using double-skin panels in which translucent flexible PVC sheet are stretched over a mild steel frame with the skins about 3 inches apart and then placed in the grid. The flexible PVC system is particularly suitable where a clean and dust-free atmosphere is required. In such installations (food factories, electronics assembly floors or aseptic ampoule filling shops) a slight flow of filtered air is maintained and a corresponding amount of air escapes through suitably positioned vents. Rigid acrylic sheet, on the other hand, is more suitable for car showrooms, fashionable restaurants, entrance foyers and reception lounges and this system is considerably more expensive than that based upon flexible PVC sheet.

Although lampshades have been made from all sorts of material from nonwoven and woven sheet material, glass, metal, coiled and adhesively bonded CAB extruded rod, skin, parchment and moulded plastics such as PS and PP, we need not consider these any further because they are furnishings rather than building components. The only final point that should be made is that they should allow for proper ventilation not only to prevent their own deterioration due to the heat generated by the light source, but also because they may affect the ceiling of the room.

Heating and ventilation are best considered together. Plastics are not suitable for the construction of heating appliances which are, in any case, irrelevant in the present context. However, the ducting of warm air and the removal of stale or polluted air is very well performed by plastics such as extruded UPVC, rigid PVC sheet which is made into box shaped length by bending and extruded UPVC profile which clips together in helical fashion and so yields a duct which is flexible and of adjustible diameter. The requirements of such structures is that they should be moderately heat resistant, light in weight and easily installed, cheap and unobtrusive. Materials other than PVC such as ABS and PP present alternatives, but among materials other than plastics only aluminium sheet comes into the reckoning and that has the disadvantage for hot air ducting that it conducts heat and thus causes losses en route, while in ventilation it tends to be noisy due to poor vibration damping. In both these respects plastics do, of course, perform much better. In industrial premises and large kitchens fume hoods and exhaust fans are installed where much the same choice of materials exists, the hoods being welded up from sheet; fan impellers on the other hand, are largely injection moulded from nylon or polycarbonate rather than from pressed and enamelled steel, but extractor and ventilation fans are, again, gadgets rather than genuine building constituents.

Plastic warm air ducting is likely to become very important in the future when we may look forward to the utilisation of waste heat from industrial processes for neighbourhood heating schemes and greenhouse heating purposes.

2.7 Wall construction

Since plastics are generally not suitable for primary loadbearing purposes it follows that their use must be restricted to systems in which the load they are expected to sustain is little more than that corresponding to holding up their own weight. This still leaves a major application potential in curtain walling, infill panels and cladding.

A curtain wall is a wall that is hung from a transome high up on a building and reaches much of the way down to ground level. An infill panel is an area element which is fixed to the loadbearing skeleton of a building on all sides of the panel in weatherproof fashion. Cladding involves the covering of an existing surface structure. If used in exterior wall construction the principal requirements are:

- Good weatherability (water, UVL and possible salt spray resistance);
- Resistance to spread of flame and fire penetration;
- Accommodation of thermal expansion and contraction while maintaining weatherproofing, especially round the margins;
- Good aesthetic appearance;
- Minimum maintenance, especially removing the need for frequent cleaning, painting and anticorrosive treatment;
- Reasonable installed cost;
- Adequate rigidity.

A number of plastics are suitable from the weathering point of view, including acrylic sheet, UPVC, glass-fibre reinforced polyesters and epoxies, melamine laminates and phenolic-impregnated board. Of these acrylic sheet is undoubtedly the most pleasing to look at, although stone set in epoxy resin and melamine laminates can also be made to be very attractive to the eye. UPVC and the older thermosets do not burn actively and there is no risk of spread of flame, but they are not immune to fire preparation, while acrylic sheet and polyesters (unless specially flameproofed) will fail to get a top level fire rating under the existing stringent building regulations. Costs vary and phenolic impregnated board is certainly cheap, though not particularly attractive, while acrylic sheet probably represents the other extreme. The most important requirement (resistance to fire penetration) is achieved by means of composite construction in which the plastic sheet provides the aesthetics, weatherability and freedom from maintenance, while rigidity and resistance to flame penetration are provided by combining the surface layer (which may be quite thin) with underlying layers of traditional materials such as metal sheet, a layer of concrete or plasterboard, possibly UF-bonded particle board, etc. Such complex laminated structures may be quite thick and should be symmetrical in order to maintain dimensional stability. A layer of rigid foam material may also be included in order to add to the thickness and thus to the overall rigidity without increasing the weight very much, whilst contributing the very acceptable property of good thermal insulation at moderate cost.

Cladding involves the covering of an existing wall structure of rough timber or breeze block with interlocking and/or overlapping sheet either in the form of a cunningly profiled extrudate or a suitably thermoformed (but essentially flat) shape. Weatherproofing is achieved by means of suitably designed fixings and expansion joints, using flexible foam, rubber gaskets or mastic compounds. External cladding is exemplified by the replacement of "ship lap" timber fascias with PVC extrusions which are shaped to look like timber but which require no painting and will never rot. Some injection moulded or vacuum formed sheet structures such as fake alpine window shutters permanently and immovably fixed next to the windows are also really a kind of cladding. Cladding has at times been extensively used <u>inside</u> buildings since this, combined with suitable backup fixing systems such as simple timber battening, can produce very attractive decorative effects and do away with plastering, painting and wallpapering while providing a surface which is also easily cleaned. Internal cladding can simulate runs of timber and timber panelling and this effect can be achieved with extruded and interlocking UPVC or with "reaction-moulded" rigid polyurethane tiles. Acrylic sheet can also provide highly pleasing effects - at a price.

Finally, it should not be overlooked that vinyl wallpapering also represents a significant advance in the quality of internal decoration, although, in the context of wall construction it is confined to a thin surface layer. The same is true for "cocooning systems" involving the integral multiple spray coating of walls and ceilings with a solvent-based PVC formulation. Following such treatment (for which professional contractors are available) the room may be hosed down, assuming, of course, that the wall-floor joint as, indeed, the flooring itself, is also water proof. This can be a considerable boon in hospitals, schools and institutional buildings, abattoirs, etc., in short, wherever a high standard of cleanliness is required, where disinfective treatment may have to be carried out and where sterile conditions should be maintained.

2.8 Partitions and doors

Partitions are really internal walls of a kind, but they differ from walls proper in that they are usually rather more flimsy and often light enough to be demountable. Demountable partitions are particularly useful for subdividing large floor areas into separate office units. The principal requirement is a combination of adequate rigidity and handling strength with lightness in weight, so as to enable one to alter the layout rapidly and easily. A number of fixing systems are available, usually involving metal brackets and bolts. Rigidity combined with light weight is achieved by means of laminated structures in which thin decorative and easy-to-clean plastic surface layers are laminated to hardboard, plywood, building board or aluminium sheet and form a sandwich structure containing a core of rigid foam or resinated paper honeycomb. Such a sandwich also provides good thermal insulation and may be fitted with windows, if required.

Doors are really hinged partitions and although they are commonly made from timber or hardboard fixed to a timber frame they can also be made partly (and even almost entirely) from plastics.

Swinging and sliding doors (the latter possibly including a suitable plastic extrusion acting as a guide channel) can be made in much the same way as the partitions just described, but folding doors are often popular because the are space saving; they are usually made from rigid metallic strip with a covering of attractively patterned flexible PVC. Some doors, room dividers, screens and portable partitions are made from specially textured acrylic sheet set into a suitable high-quality timber frame and they can look very elegent indeed, with the acrylic available in all colours, translucent as well as opaque.

Plastics have also been used for door furniture such as handles, knobs and finger plates, but these are generally low quality products which cannot compete with metals and ceramics except on price. However, nylon hinges are a successful alternative to metal hinges which neither rust nor creak and spring-loaded rotation door-closing fittings made from nylon are also an example of good design.

The most interesting development in door construction, however, is represented by an idea developed by an Italian company which extrudes rigid PVC to a remarkable degree of accuracy. A specially designed interlocking boxshaped profile slides laterally into the neighbouring length of extrudate and all the successive lengths which made up the width of the door are locked together by means of two or three metal bars which are running horizontally across and which are fixed by countersunk screw nuts at the ends. Since the extrusions can be of different colours, this gives the customer a choice of a single colour or multicoloured patterns. Such doors can also be fitted with window cutouts and extra rigidity could be achieved by the injection of low density polyurethane rigid foam into the hollows of the extrusions.

2.9 Windows

Windows consist essentially of two elements: A pane which admits daylight and a framework for mounting the pane. A further frame fixed to the opening in the wall receives the framed pane which may in turn be either fixed or openable by some form of hinge, pivot or sliding mechanism.

Dealing briefly with the pane first: Glass is the established material for this and plastics cannot compete with glass except in rather unusual circumstances. Glass is excellent in that it has a high light transmission coefficient, is rigid, weather resistent, relatively easily cleaned and not too expensive. The major drawback of glass is its susceptibility to brittle facture and fragmentation and the dangerous nature of the resulting sharp fragments. Another disadvantage lies in its high coefficient of thermal conduction which causes condensation on the inside. A clear plastic such as acrylic or polycarbonate sheet is a potential alternative; it has all the advantages of glass, plus easier handling due to lower density, is less prone to cracking under moderate loads or to fragmentation and broken pieces, if any, do not have dangerously sharp edges. There is also less condensation and better heat insulation. But acrylic sheet, like all plastics has a high coefficient of thermal expansion which cannot easily be accommodated in the design of a window pane with good see-through properties and it is certainly more expensive than glass. Acrylic sheet is therefore only used in locations where safety is the prime consideration, for example for the glazing of internal corridor windows which enable nursing staff to observe potentially violent mental patients in their padded cubicles, or of cell windows of potentially suicidal detainees. Polycarbonate sheet is used where the pane is intended to provide a maximum obstacle to vandals and intruders.

We now turn to the window frame and surround. The traditional materials here are wood and metal. Both are good materials with many desirable properties, but they also exhibit undesirable ones. The requirements for an ideal window frame structure are as follows:

- i Adequate mechanical strength and rigidity;
- ii Unaffected by rain, salt spray, UV radiation and heat levels such as might be reached after a number of hours' exposure to the sun on a hot day. (This might be 70° or higher, depending on the climate);
- iii Its design potential is such as to ensure a dimensionally stable product;
- iv A low enough water vapour permeability to preclude condensation of within the structure;
- v Sufficiently low thermal conductivity to prevent condensation along the frame within the building and to minimise the loss of heat to the outside;
- vi It should not require painting or any other protective or decorative surface treatment but should nevertheless look attractive and remain so with a minimum of cleaning;
- vii It should be easily installed and competitive in price;

viii The pane should be capable of being neatly, easily and replaceably fitted in, giving a perfect and durable weather seal.

We can immediately pick out the shortcomings of wood: It relies on a paint coat for its protective weather barrier. This barrier is neither permanent nor does it stop water vapour from penetrating and condensing in cold weather, thus encouraging rotting. It is true that certain hardwoods do not require painting and weather well, but these are very expensive. Steel windows frames have been on the market for quite a long time, but they too need painting and are liable to corrosion even with the best anticorrosive treatment such as galvanisation and special undercoats. Aluminium window frames have, indeed, largely overcome the problem of painting and corrosion and they do look attractive. They share the desirable property of good strength and stiffness in narrow sections with steel window, but like all metals, they have a high thermal conductivity and thus cause condensation inside the room. In the case of aluminium (which is extruded) the channels can be filled with polyurethane foam and this helps the condensation problem and equally importantly, contributes to minimising heat losses to the outside.

When considering alternatives which eliminate the shortcomings of traditional materials it is seen that UPVC in the shape of a suitably designed integrated system of multiple and complex box-profiled extrusions which are easily assembled together can provide a near-ideal answer. Such extrusions can be made strong and stiff enough (if necessary with metal bar reinforcement) to withstand the modest stresses that are likely to arise in service; accumulation of moisture within the structure may be ruled out since one no longer relies on a thin and vulnerable as well as rather impermanent paint coat to provide a water as well as a water vapour barrier. The thermal conductivity (already low, as in all plastics, but possibly raised when metal bar reinforcement is present) is easily boosted by filling the channels with polyurethane foam. UPVC weathers well, needs no decoration or maintenance and has adequate thermal stability; dimensional stability (ie. allowing for thermal expansion and contraction) is achieved by skilful design.

A number of highly sophisticated UPVC window frame systems are now on the market; they include top and bottom hung windows, sliding windows and windows which can be made to open on vertical and horizontal pivots which makes it easy to clean the outside from inside the building.

The one marginal disadvantage (literally) of UPVC window frames is that they need to be fairly wide in order to achieve the necessary strength and stiffness. This means that the frame may constitute a disproportionately large surface area of the opening and so limit the amount of light that can enter through the window. This makes UPVC-framed windows unattractive for small openings and aluminium frames are then preferred.

Lastly, we consider the method of fixing the pane to the frame. Both wood and metal generally rely on putties for the weather joint. This is both messy to apply, it needs to be painted and it has a very limited service life since it soon cracks or contracts away from the pane or wood, thus allowing moisture to penetrate and cause rotting or corrosion. Both UPVC and aluminium window systems use elastomeric glazing bars made from butyl rubber which also has excellent ozone resistance.

2.10 Thermal and acoustic insulation

2.10.1 Thermal insulation

In modern housing it is common practice to reduce heat losses by means of cavity wall construction, double glazing, loft insulation and (sometimes) underfloor insulation. The reduction of heat losses through cavity walls can be made substantially more effective by eliminating convection of the air in the cavity, provided always that this does not cause dampness. Rising damp can be prevented by a reliable and permanently efficient damp-proof course. Given such a damp-proof course it is sensible to fill the wall cavity with a material which is not prone to water sorption and of the traditional materials it is only mineral wool which is suitable for this purpose. However, it is not easily injected into brickwall cavities. There are two alternatives offered by plastics: (i) small beads of expanded polystyrene and urea-formaldehyde (UF) foam. Polystyrene beads tend to settle with time leaving empty spaces at the top and also contribute to the fire loading of the building owing to their flammability, but UF foam is easily injected under pressure and fills all the voids reliably even in remote corners. UF foam is nonflammable and although, in itself, it is weak and friable, it is never subjected to mechanical stresses which might cause it to collapse into a powder. The one disadvantage of UF foam is the fact that it takes some time to cure and dry out and during that time the unpleasant and slightly irritant odour of formaldehyde is very noticeable inside the building. Some authorities suspect that formaldehyde is a health hazard, but if so, then most of the medical and zoology students would be at risk since they have to work for hours over biological material which has been pickled in and reeks of formaldehyde; there is not the slightest evidence that this is the case. It is, of course, best to inject the cavities during the actual construction of the building and before it is handed over, so that ventilation and the passage of time eliminate this particular draw back before the occupier moves in.

Some prefabricated buildings use sandwich panels in their wall construction and these usually contain a core material of expanded plastics. Polyurethane rigid foam is a possible choice although its use is not encouraged under the building regulations for various reasons which centre on its behaviour in a fire. However, an excellent alternative is phenolic (PF) foam, a very rigid core material, eminently suitable to act as a fire-resistant core material for glass reinforced polyester or epoxy laminates. Such structures are not cheap, but they are light and easily erected, demounted and transported to alternative sites. Buildings of this kind have been developed by British Railways as temporary shelters for electrical switchgear equipment along the permanent way and similar structures are also useful for travelling site offices, estate sales offices, circus box offices and the like.

For loft insulation glass wool of adequate thickness is still the preferred material because of its safety in a fire, even though it is unpleasant to lay between the rafters, must not be trodden on and gathers dirt which cannot be removed. However, the lagging of pipes and tanks in the loft is nowadays largely done with moulded rigid polyurethane foam and this is a much neater and efficient method than using felt.

The use of polyurethane foam as a minor but useful component which greatly reduces heat losses through window frames (especially those up from extruded aluminium sections, but also those made from UPVC) has already been mentioned in the preceding section.

Thermal insulation at floor level is good practice in solid concrete floor constructions which incorporate a piped hot water underfloor heating system. This may well become exceedingly important in the future when one may expect neighbourhood heating systems to become widespread and in which waste heat from industrial processes will be largely recovered for space heating purposes. Since the actual heat involved is not high and since there is no particular fire hazard it is possible to use virtually any type of closed-cell foam material of good mechanical properties and polystyrene foam would seem to be a good choice because it is not too expensive and provides an additional bonus as a further barrier to rising dampness. Its good electrical properties, furthermore, would make it possible to consider its use in underfloor heating systems based on an electric power circuit.

Householders can sometimes significantly reduce their heating bills by simple do-it-yourself methods. The laying of cork tiles is an excellent example of this and this can obviously be extended to wall tiling which is also very attractive. Alternatively, rolls of thin expanded polystyrene sheet material attached to walls before applying the final decorative finish such as wallpaper or a sprayed finish will also be highly effective in conserving heat.

Finally, it is clear that thermal insulation works both ways: Not only does it minimise heat losses from the inside, it also keeps the inside comfortably cool when the outside temperature is uncomfortably high. Thermal insulation is thus of the greatest importance in climates which are extreme in either direction.

2.10.2 Acoustic insulation

Whilst it is undoubtedly highly desirable to protect residents from "noise pollution" - an increasingly objectionable feature of the jet age - it must be stated that plastics have little to contribute that is of any major assistance here. Acoustic insulation requires mass and plastics generally (and expanded plastics in particular) have very little of that. However, although plastics foam materials constitute quite a negligible acoustic barrier, they can be used to bring about a modification and redistribution of transmitted sound rather than any significant reduction thereof. Thus sheets of polystyrene foam laid between a ceiling and the floor above will spread localised impact-induced noises from the top, such as the movement of furniture or heavy footfall, so that it is less acutely perceived in any one place below. With the added advantage of the thermal insulation thus provided it is certainly good practice to include this feature in multi-storey flat construction at very small cost.

Other examples of sound modification are the prevention of echoes in concert halls and the attenuation of vibrations and reverberation especially in sparsely furnished corridors. This may for example, be achieved by means of drapes and carpets, but the actual choice of materials is not of any particular importance, although these materials are usually of a fibrous nature.

2.11 Roofing

The principal requirements of a satisfactory roof structure are that it must keep rain and snow out and that it must withstand the wind forces which tend to dislodge it. How these functions may be fulfilled depends entirely on the actual roof design. Traditionally roofs of dwellings and of public buildings are planar structures, usually inclined but occasionally horizontal, but curved roofs such as turrets, domes and cupolas are also not infrequently encountered, especially in architectural showpieces such as houses of worship, museums or castles. Pitched roofs are by far the most common. Their construction is based on a timber frame which is subsequently covered with interlocking and overlapping tiles, although metal sheeting has also been used. The tiles are usually made from concrete or baked clay. Although slate is an excellent material it is expensive nowadays since it is not extensively quarried any more owing to the severe health hazard which its manufacture entails for the workers. Primitive rural communities can be found where houses are thatched with straw or similar materials, or with timber tiles, all of which are difficult to maintain. A heavy roof is desirable since it is well able to withstand being lifted by suction in a gale and it is clear that plastics are not favourably placed to compete in this field.

Flat roofs are easy to construct in principle, but care must be taken to ensure the effective removal of surface water and the prevention of seepage and dampness. Such roofs are usually of a complex layered structure where slabs of explanded polystyrene contribute thermal insulation, zinc or copper sheet may be included and where the major weatherproofing is generally achieved by the use of heavy bitumen-impregnated roofing felt topped by molten asphalt and a layer of mineral chips, with a slight incline for leakproof drainage into a gutter. The supporting framework is usually timber joints which are in turn boarded over with timber and perhaps a layer of building board or plasterboard.

An integral multiple coating of solvent based PVC is a possible alternative to bitumen waterproofing, but it is expensive and comes into its own mainly when dealing with curved surfaces which are difficult (and therefore even more expensive) to construct or to repair.

It is clear that a massive use of plastics in roofing can neither be expected or recommended either at present or in the foreseeable future and that the role of plastics in this application must of necessity remain an ancillary one. The use of polystyrene foam slab in flat roof construction has already been mentioned, as has the spray coating with a solvent solution of PVC. Another use which is as widespread as it is sensible is the replacement of bituminised paper roofing felt below the roof tiles with flexible PVC sheet. This is simpler to fix since it is less easily damaged and it is also quite inexpensive.

However, when it comes to roofing of an altogether different kind such as space structures, folded plate structures, barrel vaults, geodesic domes or the roofing in of large spaces such as swimming pools, stadia, neighbourhood shopping precincts or terraced plazas, traditional methods are obviously incapable of helping in finding an acceptable solution. There is soope here for plastic sheet materials such as transparent, translucent or opaque acrylic or PVC as well as for sheet made from glass fibre reinforced polyester, provided that the fire prevention specifications of the building regulations can be met. The thermoforming of acrylic sheet also opens up scope for daylighting inserts into roofs such as domelight, lantern lights or arched corrugated sheet; the latter is also available in GRP, while corrugated PVC sheet is often used for simple and inexpensive porch canopies. GRP has also been used for the prefabrication of decorative turrets and steeples for churches or mosques.

Another idea which is well worth pursuing is the possibility of conceiving a roof as a water storage area in tropical climates. Using butyl rubber it is quite reasonable to consider water economy, under-roof space cooling, and the exploitation of abundant solar energy for generating hot water for domestic use together with the usual functions of a traditional roof. This opens up quite exciting possibilities.

3 PLASTICS IN PACKAGING

Introduction

Packaging as an industry was nonexistent until mass retail trading became the norm of contemporary living. It is the product of a consumer oriented society. Earlier on the modest needs of a relatively unsophisticated population were mainly met by home production and supplemented by the casual visits of pedlars and tradespeople. Shops - in the sense of retail depots with a modest range of lines may have sprung up in major population centres at times but were always at risk in violent times, especially during periods of famine which were only all too common. However, when townspeople could no longer grow their own food in the surrounding countryside as a result of the greatly increased rate in the growth of the population, and when law and order could be enforced effectively, a pattern of trading became gradually established in which the customer went out to buy rather than wait for the seller to offer his wares at the doorstep.

However, small stores - whether in town or in a village - faced the problem of stock conservation with a minimum of quality sacrifice, especially in highly perishable goods such as milk, fish and meat.

The emergence of supermarkets has largely solved these problems. Modern packaging has developed in step with the mass production of standardised consumer items, principally food, drinks, cosmetics, toiletries, detergents and certain hardware items; it made its impact through the medium of the supermarket, but has also penetrated into the residual small-scale retail trade which still has a significant role to play in smaller and more isolated communities.

If we were to designate any packaging materials as "traditional" we would have to name pottery vessels, wooden casks and baskets, as well as sacks from woven materials and some glass containers. These served to keep wine, oil, vinegar, grain, flour, salted fish, salted meat and salted vegetables, unguents and potions. Except for crude lids to jars and pots and simple stoppers and bungs for flasks and casks there were hardly any effective closures.

When regular shops became established the evident need for an acceptable wrapping material was met by paper which had become a cheap mass produced commodity and which was soon converted into bags and sacks into which the retailer dispensed from bulk stock which was kept in free standing open woven sacks, in drawers or in tins and jars. Apart from the questionable hygiene of such storage, there was the additional hazard of contamination by scoops, hands and scale pans. When sheet metal became widely available it became possible to combine standard portion pre-packaging, the maintainance of product quality and some expectation of freedom from contamination. This was supplemented by the mass production and thus the substantial reduction in the cost of glass bottles. However, the decisive break-through came with the emergence of plastics which competed with, sometimes combined with and often superseded metal, glass, paper, board, sacking and ceramics.

What, then are the revolutionary changes that new marketing methods (i.e. the emergence of supermarkets backed up by a virtually new branch of industry concerned with packaging) have brought about? These may be itemised as follows:

i The effective protection of merchandise from mechanical damage;

ii a far reaching reduction in the risk of contamination;

iii the optimisation of medium or long term quality retention as a result of "barrier packaging", i.e, the prevention of the passage of gases, vapours and liquids out of or into the merchandise, and as a result of "open refrigeration" of retail packs;

iv easier quality control, e.g, by date stamping;

v uniform appearance, attractive presentation by self-advertisement on self-serve shelves by means of the full exploitation of the graphic arts and design of shape;

vi a saving of labour in the actual dispensing operation by pre-packaging - partly on the premises and partly in the factory.

The nett effect of these changes is a massive reduction in diseases caused by contaminated food, the efficient and therefore cheaper distribution despite the extra cost involved in pre-packaging, the convenience (and especially the time saving) of supermarket shopping and the substantial reduction of waste. Nor should it be overlooked that fast transport on a global scale has made exotic and/or out-of-season lines available at a cost that is generally far from exorbitant.

In most (though not all) cases cost is a decisive factor in package design, with the result that one tends to "underpackage" rather than "overpackage" on the grounds that anything that is better than just good enough is bad since it makes the customer pay for something which he does not want.

It is a general guideline that the contents of a package must have no deleterious effect on the packaging material and that, conversely, the merchandise must in no way be tainted by the latter. The criteria of toxicity are naturally most rigorously enforced when foodstuffs, cosmetics and pharmaceuticals come into contact with the packaging material.

A rigorous classification of packaging would include the following headings:-

Flexible packaging

Wrappers and bags
Coated papers, coated film and coated aluminium foil
Laminates
Sacks
Netting and string
Overwrapping

Semi-rigid packaging

Cartons (including liquid proof cartons) and trays
Corrugated board and functionally related structures
Collapsible tubes

Rigid containers

Bottles, tubs, jars
Metal boxes and cans
Other boxes and crates
Drums, kegs and barrels

Closures

← Palletisation and "containerisation"

However, we need to simplify this classification in order to keep it within the manageable bounds of an essay rather than to allow it to expand into an exhaustive monograph.

Accordingly, the subject will be treated under the following eight headings:

1 Unsupported, supported (ie, laminated) and coated film or sheet for flexible packaging (wrapping, bagging, sacking) including heat sealable film for retail pre-packaging;

2 small moulded containers (tubs, jars, beakers, trays, boxes, capped tubes and vials, etc.) for factory and "in-house" pre-packaging.

3 Bottles and cans for drinks, sauces, detergents and chemicals;

4 drums and kegs; bulk containers.

5 Component devices for mechanical and/or thermal protection in transit (e.g. foam liners, foam packs and blister packs);

6 larger scale structures for easy handling in transit and for convenient display manipulation (crates, pallets, tote boxes);

7 closures;

8 Gathering and bundling devices such as overwrap shrink film, tape, netting and string.

Each of these categories demand the fulfilment of the criteria peculiar to it. We therefore proceed to review the spectrum of available materials in the light of the packaging function which they are expected to fulfil.

3.1 Flexible packaging

Before the advent of polyethylene the market was virtually dominated by wrapping paper, paper bags and paper sacks. Some speciality papers such as "greaseproof" are still fairly widely used because they are convenient for selling freshly sliced meats and similar products at a delicatessen counter; greaseproof paper bags have also superseded newsprint as a wrapping material for chips. But it is abundantly clear that the flexible packing market is dominated by polyethylene film, although polyethylene is also combined with paper by extrusion-lamination and although papers may also be coated with (or laminated to) other materials. While polyethylene is the single most important plastics material in flexible packaging it is not, however, the only one. Polypropylene film has also secured an appreciable share of the market and so have speciality film and coatings based upon poly (vinylidene chloride - $PVCl_2$) as well as the cling film obtained by copolymerisation of ethylene and vinyl acetate (EVA).

Materials other than plastics and paper in flexible packing include aluminium foil, an excellent barrier material, but one whose obvious mechanical weakness and puncture-proneness is often boosted by combination with paper or polyethylene. When aluminium foil is combined with paper the adhesive layer may be a polymer latex type adhesive, or a hot melt adhesive such as microcrystalline wax which latter further contributes greatly to the excellence of the resulting barrier material, but it is also obvious that such a structure is expensive and must therefore be justified by the absolute precedence of quality considerations over those of cost.

When paper dominated the packaging field it did so because it was, if not the only, then certainly the cheapest material. This is no longer the case. Moreover, although its fibrous nature undoubtedly makes it remarkably strong in tension (if not in tear), the same characteristic makes it generally freely permeable to gases and liquids. It is not, therefore suitable where barrier properties are required, unless its porous structure is modified by a coating process. One such coating process uses paraffin wax (old fashioned bread wrap) which had modest heatseal properties or a better heatsealing wax as in milk carton stock. Much better heatseal properties are, however, available if a polyethylene coating is given by means of extrusion lamination, or if polyethylene of a low molecular weight ("polyethylene wax") is used either on its own or in admixture to other waxes and resins. The use of paper as a component of a laminated structure also contributes opacity to the package, as well as easy printability and if the print is coated over subsequently it can neither be rubbed off nor contaminate the contents of the package. In addition to barrier and heat-seal properties a coating may also contribute gloss, scuff resistance, or release characteristics.

One of the most successful methods of semi-bulk packaging, especially of granular or powdery products - is the use of multi-ply sacks of kraft paper which are glued, stitched and/or taped at one end and which may have self-sealing easy-fill siftproof sleeves. The strength of this package is excellent and they may be stacked to considerable heights, but it is often desirable to protect the contents from moisture; this is achieved by coating the innermost ply internally with polyethylene; advantage can then also be taken of the heatsealability of the polymer layer at the bottom and at the top of the sack before and after filling respectively.

However, multi-ply kraft sacks are no longer as common as they used to be since heavy gauge polyethylene film has become competitive in price and strength and does, of course, provide its own intrinsic barrier properties.

Jute sacks and sacks from other coarse natural fibres such as sisal used to be common in pre-war days when a variety of "colonial" products such as dried spices and pulses and a variety of other items were shipped in them and displayed in grocers' shops. These sacking materials are smelly and unhygienic, they tend to rot and they are easily torn and not very suitable for stacking since their strength leaves much to be desired. Woven sacks of very great strength, excellent stackability, non-slip characteristics, reasonable siftproofness and acceptable cost (because they are returnable) can be produced from polyethylene film which is slit into ribbons of moderate width and then cold-drawn and reeled up like yarn. Such sacks do not rot and they can, of course, have the contents protected from the ingress of moisture by the provision of an internal or external lining sack made up from layflat polyethylene film.

When packaging foods, pharmaceuticals and cosmetics it is necessary to ensure that the packaging material contains not even a trace of a toxic component. The materials mentioned above are all perfectly acceptable in this respect.

It is now necessary to consider how specific barrier properties can be achieved.

i Water resistance. All the plastic packaging films (PE, PP, $PVCl_2$, EVA, Al foil) are excellent from this point of view, and this is also true for papers suitably coated with or laminated to them. Solution and/or dispersion coating may be carried out on paper or cellophane using various vinylidene chloride based materials, copolymers involving vinyl chloride, acrylics, styrene and butadiene, and solution coating with cellulose nitrate is still widely practised for chocolate papers and boxboard.

ii Water vapour resistance. The ultimate in water vapour resistance is obtained by the use of $PVCl_2$ film (e.g. "Saran" of DuPont) and solution or latex type materials based upon vinylidene chloride copolymers. In the case of coatings it is essential to ensure that these are free from pinholes and this is achieved by the successive application of multiple microlayers. The polyolefines also have very good water vapour resistance, as has, of course, aluminium foil which is often used as a diaphragm under the lid of instant coffee jars.

iii Oil and grease resistance. This is of very great importance in the packaging of cheese, meat, fish, potato crisps and similar fried products. The outstanding material in this respect is, again, $PVCl_2$ as a film or a coating on a suitable substrate, with the polyolefines some considerable way behind, especially when longer term storage at possibly slightly elevated temperatures is a possible hazard. It is interesting to note that many materials which have poor water and water vapour resistance often have very good oil and grease resistance; examples here are PVacetate, PValcohol (a clear but expensive and rarely used film material), and even starch, casein, alginate and natural gums.

It is most important, however, to realise that in most cases the barrier properties required involve water, water vapour and grease resistance simultaneously and if heat sealability is an added requirement, as well as a high degree of odour and gas impermeability, then the choice is virtually restricted to $PVCl_2$ and various combinations involving aluminium foil, with the polyolefines a poor seconds.

iv Odour and gas impermeability. This has just been referred to. The importance of odour impermeability is obvious when food is to be stored in refrigerators without the risk of tainting (or being tainted by) other items. Gas impermeability is particularly important in the long-term refrigerated storage of vacuum packed red meats which should retain their fresh look and of vacuum packed cheeses which would otherwise deteriorate.

Although release coated papers are widely used as backings for adhesive tapes and labels (a not insignificant aspect of the packaging process) they are also employed in flexible packaging, in a sense, when they serve as easily removable base wraps for cakes and other bakery products and for sticky foods such as dates, figs or crystallised fruit. The best material for this purpose is a greaseproof paper spraycoated with an exceedingly thin film of silcone which is completely non-toxic and very effective.

3.2 Small moulded containers

Small moulded containers are a highly characteristic feature of the modern packaging scene. Glass beakers and pottery dishes with suitable covers are still seen as containers for, say, mustard or meat and fish pastes and although tins (with a suitable internal corrosion resistant polymer coating) retain an impressive share of canned fish and cooked meat packaging the packaging of refrigerated dairy produce such as ice cream, margarine, butter, cooking fats, soft cheeses, yoghurt and the like almost invariably involves containers and lids which were made in circular or rectangular shape from polyethylene by injection moulding. Nesting egg trays which have long been and are still quite commonly made from cellulose pulp slurries by a wet moulding process, as well as trays for "in-house" pre-packaged and overwrapped meats, fish, fruit, vegetables and miscellaneous sundries, and moulded layer dividers for crated fruit are now frequently replaced by similarly shaped structures moulded from polystyrene or foamed polystyrene sheet which provides enhanced protection, notably against the bruising of fruit in transit.

Plastics materials are finding increased application in toothpaste tubes and tubes and pillow packs for small condiment portions and for shampoos; cosmetic creams and shoe creams are frequently packed in plastics compacts rather than small metal tins with lids; the use of small bottles and vials for pills and liquid pharmaceuticals is no longer monopolised by glass but involves polyolefines, polystyrene, polycarbonate and thermoplastics, e.g. as blow mouldings, blister packs and vacuum packs.

3.3 Bottles, cans and other containers for liquids, granules and powders

The glass bottle and jar has long been the principal type of container for liquids and granular products of many kinds. Glass has the advantages of chemical inertness, non-toxicity and transparency, although it can, of course, also be obtained translucent or opaque if required; glass is stiff and strong and maintains its shape for long storage periods even when its contents are kept under pressure as is the case in sparkling and carbonated drinks. Glass affords fair scope for design and bottles are easily labelled using suitable adhesives; glass bottles and jars are easily handled on fast operating automatic filling machines.

Glass is very widely used for alcoholic and non-alcoholic (including carbonated) beverages, for milk, and flavoured milk products, cream, cooking oils, liquid detergents, household chemicals, jams and marmalade, honey, pickles, mayonnaise, salad dressings, ketchup, sauces, instant coffee, dried milk and powdered milk substitutes, lotions, cosmetics, medicines, mineral oils, liquid fertilisers, pesticides, solvents, chemicals for laboratory use and for the packaging of a host of other merchandise. However, glass suffers from three major disadvantages:-

i It is extremely vulnerable to mechanical damage and when it breaks the fragments are sharp, often jagged, pointed and highly dangerous.

ii It is no longer as cheap as it used to be, even allowing for inflation, because its manufacture - though by no means labour-intensive - involves an extremely high energy input.

iii It is heavy, particularly in the thickness required to ensure that the strength is sufficient to reduce the probability of accidental breakage to an acceptable level.

Metal cans or tins represent yet another traditional packaging material. They are much less prone to mechanical damage than glass, although they may become dented and misshapen as a consequence of a knock. They are well able to withstand thermal shock and are therefore widely used for filling with hot liquids and semiliquids straight from the cooking process. They are then hermetically sealed so that the contents are safely protected from contamination and tampering. In this latter respect they have the advantage over glass in that they do not require a separate closure system such as a screw cap, screw lid, bung or crown cap. However, tinplate is prone to corrode; internal protection by a coating process using a polymer based lacquer is therefore mandatory in order to ensure that corrosion neither causes the contents to become tainted nor allows loss through leakage or access of air and airborne contaminants. Polymer coatings, including cellulose-based lacquers are effective in preventing corrosion even when the cans contain such acid products as fruit juices, vinegar and processed fruit, but metal containers should not be exposed to alkaline lyes and concentrated salt solutions; there is, however, an exception in this respect which also applies to other containers which are sufficiently rigid but which may be affected by their contents: they may simply be provided with a loose liner bag, say of polyethylene which contains the merchandise safely sealed in, so that the latter never comes into actual contact with the container proper. The use of metal cans and tins extends quite as widely as the use of glass and extends further into the medium and large container field such as fuel cans, drums bins, storage tanks and mobile tankers.

The advent of plastics and the price competitiveness of many plastics has resulted in a considerable displacement of both glass and metal from the packaging scene. Many of the items mentioned earlier on can and have been successfully packaged in plastics bottles and jars. Before plastics could do so, however, it was necessary to ensure that the actual materials selected were reliably non-toxic, chemically and environmental-stress-wise unaffected by the contents and of sufficient intrinsic rigidity to permit a bottle or jar to be designed which could be shaped into a container of adequate stiffness and dimensional stability at economically acceptable wall thickness.

Polyethylene, followed by its high density variety and polypropylene, opened the way and are still by far the most important plastics for making bottles and jars from plastics. However, PVC has been used for motor oils, anti-freezes and detergents, and some engineering plastics, notably polycarbonate and PET polyester have latterly been introduced into markets which have an enormous potential for plastics in competition with glass. The obvious advantages of plastics bottles and jars in general are their lightness in weight and hence their convenient inclusion in the shopping basket, their much greater intrinsic safety and their ready disposability. For non-returnable ("single trip") containers they are much cheaper than glass. It is interesting to consider the practical example of the milk bottle.

When milk is marketed by doorstep delivery the bottle in which it comes is invariably made from glass. The package is cheap because it is recovered when empty, washed, sterilised and reused many times before it eventually breaks or needs to be discarded because it has become unfit for further service. Doorstep delivery of milk is common and traditional in the UK and represents a considerable boon to housebound people such as the elderly, the disabled or the housewife with a number of small children to look after. However, competition from the supermarkets has had the effect of many people contracting out of doorstep delivery for a number of reasons which reflect the weakness of the system: (i) If the milk is delivered while the occupant is out on business it remains outside and is exposed to the sun, to fouling by animals and birds and to pilferage; (ii) it advertises the householder's absence from the premises; (iii) empties have to be washed and they often clutter up the doorstep for much of the day and night; (iv) it is inconvenient to check on the bill and to wait for the appearance of the milkman in order to clear the account.

The small or casual milk consumer therefore tends to buy his supplies from the supermarket where milk is invariably sold in wax or plastic coated cartons or heatsealed polyethylene bottles and where it is date-stamped and kept on refrigerated shelves. The loss of doorstep customers has tended to impair the efficiency of the milkman service and many milk rounds have been abandoned; others are trying to compensate by retailing not only milk and milk products but also soft drinks, groceries, bread and vegetables from their trolleys. But when a milkman begins to transform himself into what amounts to a travelling supermarket, then there is also a tendency for supermarket packaging techniques to be adopted and the glass milk bottle is likely to disappear in the long term from this particular field in which it has enjoyed an undisputed monopoly position for so many decades.

The story of the milk bottle has been dwelled upon at such length because this particular battle of materials subsequently caused a critical reassessment of glass for bottle and jar manufacture in comparison with the extrusion - and injection-blow-moulded containers which had become available in plastics.

The replacement of glass bottles for vegetable oils, vinegar, sauces, or liquid detergents presented no major problems, with a choice of the well-known polyolefine grades. But when considering wines, spirits and carbonated drinks a number of issues had to be dealt with before the market could be considered ripe for competition with glass or (as in the case of beers and certain types of soft drinks) metal cans. What was needed was a material which, unlike the polyolefines, could withstand the considerable internal pressures - especially of carbonated soft drinks and sparkling wines - without the shape of the bottle being seriously affected. Polycarbonate, polyacetal and latterly (and most importantly) mouldable thermoplastic polyesters (PET) are now available. There is no a priori reason why beers, soft drinks, wines and spirits should not be put into plastics bottles, provided, of course, that the materials from which the bottles have been moulded are toxicologically unobjectionable. PET injection-blow-moulded bottles are now frequently used for carbonated soft drinks. Sparkling wines pose no different problem and when it comes to ordinary and inexpensive table wines from the various wine lakes of Europe, Australia, South Africa or California there is the added incentive of cheaper transportation in the light plastics bottles, so that one may expect to see the total replacement of glass bottles in the down-market wine trade in the not too distant future. There is, of course, no long-term experience of PET bottles or their contents when it comes to the potentially long-term cellaring of treasured vintages, so that both producers and distributors, as well as the ultimate customers are understandably reluctant to depart from the traditional conservative practice of bottling such precious and noble liquids in glass.

There is no technical reason why whatever is the correct plastics material should not be used for <u>any</u> product which is to be filled into a bottle, jar, tin or can. The actual choice is almost invariably made on a cost basis, except in the extremely rare cases where absolute and total reliability takes precedence over cost consideration, i.e, in certain applications involving medical, surgical, military, or aerospace appliances and supplies. Polyethylene bottles, squeeze bottles and vials with diaphragm closures have been used for storing sterile injection and transfusion supplies such as vaccines, sera, anaesthetics, blood, plasma, saline solutions and the like in reliably aseptic refrigerated storage for extended periods of time and for immediate availability on call. Screw top bottles, including those of the child-proof variety are more and more frequently made from PET rather than glass, while polycarbonate bottles are often used as small aerosol dispensers.

Finally, it is of interest to mention two more unusual methods for blowing bottles which are uniquely applicable to plastics starting materials.

The first is the blowing of bottles from UPVC sheet which is folded over where the base will eventually be, introduced into a multiple split mould in which the sides and shoulders are joined by a heat seal of matching metal surfaces leaving a slit at the top through which air is introduced under pressure which forces the thermosoftened walls of the as yet flat sheet out against the cooled internal walls of the mould. In order to attain the required rigidity the bottle is designed with both hoops and vertical ribs. Scrap beyond the fin-like flash all round is cut off and eventually reprocessed into sheet. This bottle making process is integrated into the filling and labelling process and the top is finally heat sealed. The bottle is opened by snipping the top with scissors at an angle to form a pouring spout and a slit-like cap injection moulded from PP is slipped over to provide a friction-fit closure between use. Such sheet bottles were first developed in France where they were used for olive oil, fruit juice and small portions of cheap wine. In the UK the process was operated for a limited number of vinegar bottles for export, but it suffers from the need to use pre-formed sheet material which made it uneconomical. The basic concept, however is interesting in that it has affinities with vacuum (or rather pressure) forming and fuses together what are essentially two "half-bottles".

The second method of bottle blowing has considerably greater potential and is of much more recent origin. It is still an extrusion-blow-moulding process involving the formation of a parison, but the parison itself is a sandwich structure of three layers of coextruded polymer melts in which the core is of an entirely different material from the outer and inner layers and which is included in order to enhance the strength and/or rigidity. The supply of the core material can be stopped during the initial and final stages of parison formation, so that the top and bottom flash material is of one kind only and can be readily recovered and reprocessed. By skilful material selection this method enables one to use a core material which may well be more expensive but which nevertheless produces an overall cost saving if the bottle shows improved or equal performance with correspondingly less polymer materials used for moulding it. The method of coextrusion is as yet in its infancy, but is certain to be applied widely in the future, and will not be confined to bottle blowing alone.

3.4 Drums and kegs. Bulk containers.

Drums come in any size up to several hundred gallons capacity. We prefer to reserve the term "drum" for a cylindrical metal container with a metal pressure-fit lid or a lid held in place by a shaped toggle-tightened rim band, while we define a "keg" either as a laminated plywood or as a cylindrically or spirally wound laminated fibreboard structure with a lid which is usually shaped to slip fairly tightly over a suitably recessed top section of the container itself; some people refer to the latter structure as a "fibre drum". As an alternative to the method of closure just described, small kegs often have plastic snap-fit lids, usually injection moulded from polypropylene or UPVC. Typical small kegs with plastic lids are containers for ground pepper, spices, dried herbs and powders of all sorts from dried garlic to bicarbonate of soda, and from goldfish food to baby powder, rooting compound, bone meal or pyrethrum. Both drums and kegs are often provided with a fitting internal liner which may be attached or left loose. Commonly made from polyethylene film or occasionally from rotationally moulded polyethylene powder, the contents, whether of a corrosive solid or even of the liquid kind, are safely kept away from contamination by the container proper and are, conversely, unable to corrode, soften or otherwise damage the latter. Kegs and drums are thus very suitable containers for transporting and storing industrial heavy chemicals such as maleic and phthalic anhydrides, flake caustic soda, sodium carbonate, salts, mineral oils and latices in semi-bulk quantities. Wooden barrels are now archaic. Plastics cannot compete with metals, plywood and laminated paper board in the main structure, but it is possible to include plastic film layers in cylindrically wound fibre kegs in order to improve the barrier properties of the board laminate. Internal plastic liners have already been mentioned and this principle is also extended to the lining of the inner surface of steel lids of metal drums.

It is, however, possible to extend the concept of the large drum to even larger dimensions, i.e. to containers for static bulk storage or to mobile tankers. These are often (but not necessarily) cylindrical in structure and are usually made from sheet metal. Depending on the contents (fuel oils, petrol, solvents, water, milk, liquid fertilisers, molten phenol, salt solutions and other (often highly aggressive) liquids) they are lined with glass, heavy gauge plastic sheet, or a plastic or rubber coating, but they are also themselves occasionally made from spirally wound monofilament-reinforced polyester or epoxy resins, especially when they are expected to withstand some pressurisation.

3.5 Devices for the mechanical and thermal protection of goods in transit

These are essentially cushioning devices for which waste staple fibre, rag, crumpled paper, cotton wool and other primitive stuffing materials were used. Certain paper and board products such as corrugated paper and board and paper honeycomb constituted a tremendous step forward when they came onto the market, but when it was realised that cellular plastics and quilted polyethylene film laminate containing air bubbles of uniform size could be used here to great advantage the safe transportation of goods of a delicate nature was tremendously facilitated. Small items such as watches, photographic, optical, scientific and surgical equipment, as well as precision tools could be packed into a contour-moulded split brick of rigid polystyrene foam; a carton sleeve is then slipped over and the package is finally made into a postal or rail parcel by overwrapping with kraft paper and possibly finally securing with tape or string. Such a parcel can be thrown about with impunity and will be dropped into the customer's letter box without much risk of damage to the contents. Blister film from polyethylene can be equally effective. Polystyrene foam can also be used for "squaring off' corners and edges when larger components are crated in heavy shipping containers made from timber, but cellular polyethylene is a far less vulnerable cushioning material in this context, although it is also considerably more expensive. Polystyrene foam chips are extensively used for space filling purposes, but it should be noted that with large items the mechanical protection other than internal cushioning is provided by the crating. There is no doubt, however, that the use of modern packaging materials has made the packing and unpacking of large consignments both tidier and more convenient.

Foam materials such as cellular polystyrene in thick slabs, or polyurethane sprayed onto and foamed in situ either on the surface of metal containers or injected into the space between an outer and inner rigid container have been most useful in affording protection against frost damage or the effect of standing under the tropical sun for long periods. The thermal insulation can prevent the coagulation of latices in drums and it can maintain phenol in the molten state in road or rail tanker transit. The thermal insulation of static tanks marginally comes into this category, but is best considered in a context of building and construction. What can be said, however, is that these foam materials are vastly superior on the grounds of cleanliness, weight, convenience, cost and performance to felt or blankets. A thermal protection layer does, however, almost always require a master structure which provides the necessary mechanical strength and rigidity in transit. One notable exception here is the transport of fresh fish packed in ice on board ship or in the port where it is landed: The traditional wooden boxes leak, become dirty and smelly and refrigeration is not nearly as efficient as it ought to be. Boxes with integral lids, often hexagonal in shape, are moulded from polystyrene foam of sufficient density to be reasonably strong for a single-trip journey, are fully leakproof, clean and the ice keeps for a very long period, so that the fish is fresh when it reaches the store where it may be neatly displayed from the same box, if the fishmonger chooses to do so.

3.6 Crates, pallets, tote boxes.

Crates have become big business when bottles began to be mass produced and milk, beer and soft drinks began to be distributed on a vast scale. The earliest crates were made up from wood. They are heavy, awkward to handle, liable to chip and break, and expensive. Metal crates from stout steel wire were common for milk delivery, but they are noisy. What was needed was a relatively lightweight crate, strong enough, with clean surfaces and preferably a positive bottle grip which could be stacked without danger of collapse through creep over a reasonable period of storage; which should nest, if possible in order to facilitate the collection of empty crates and which should not allow glass bottles in it to clatter noisily. Naturally such a crate should also be reasonably cheap to produce.

The first plastics crates were injection moulded from Polyethylene of high density, later from PP because of its enhanced rigidity, later still from propylene copolymerised so as to improve its impact resistance especially during cold spells, and subsequently also from UPVC and even nylon and polycarbonate. The material, design and strength properties vary accordingly, but they are tailored to the specific performance requirements. Plastic crates have now completely displaced metal and wooden crates and the only alternative for bottles is the corrugated board box which is certainly cheaper, but which is designed as a disposable container for one trip only. The latter, however, also serves as a container for cans and tins, a use for which crates were never intended.

Palletisation is a modern method of bulk handling in transit and storage. Pallets were (and still are) mostly made from stout softwood and are used as a base for stacking sacks which may, in turn be held on the pallet by means of a PE layflat film overwrap. Pallets have, however, also been made from nylon by injection moulding and from GRP by a wet layup technique, although this has not becomme common practice.

Crates have also been used for transporting live poultry. Such crates have been designed such that they flatten out when not in use and are quickly assembled by raising the hinged side flaps which then make a snap fit and are covered with a suitable matching latticed lid. The sides and base are also of a lattice construction to save weight and the whole structure is injection moulded in polypropylene, taking advantage of the famous flexible integral hinge which the use of this material makes possible.

Tote boxes are really only large and usually rather shallow boxes which are used to transport merchandise from the store to the supermarket display shelves by means of a trolley which can stack a number of them at a time. Tote boxes are also used in the harvesting of certain crops, especially those which are immediately transported to processing plants or distribution centres for further packaging.

3.7 Closures

Closures are components which ensure the leakproof or siftproof packaging of liquids, granulates and powders in bottles or jars, irrespective of whether they are in the normal upright position or not. Traditional materials are wooden bungs in casks (now rarely, if ever encountered) and cork, the common closure for wine and spirits bottles. When glass bottles and jars were moulded to provide a screw thread top metal lids and caps were widely used to provide a closure which was in turn protected from corrosion by an often polymer-coated paperboard insert or liner. It was soon realised that there is no reason why screw top caps and lids should not be moulded from plastics and a variety of plastics found application in this field, beginning with thermosets such as phenolics and aminoplastics. These are still used, but they are brittle and their production rate is limited, so that thermoplastics, principally the polyolefines and UPVC have taken a large share of the market.

Metal tins still use matching press-fit metal lids, especially for paints, varnishes, putty and mastic compounds, but also for the packaging of instant coffee and similar granulated or powder products, i.e., for containers of the "drum" type. In the case of small "kegs" (see section 3.4) it is by no means uncommon to find that the cylindrical body made from paper board has a rolled top into which a plastics lid rather than one made from metal is pressed to afford a firm closure which can, however, be readily removed and replaced, as required. Any rigid plastic is suitable for this purpose, but PP, HDPE, UPVC and high impact polystyrene are common materials. Some bottles with outward rolled tops have cork-gasketed metal crowns which are clipped on as part of the bottling process, but polyolefines have penetrated into this market as a result of the development of a special design featuring a rip-off parting strip. The capping of cork-stoppered wine bottles with metal foil or a plastic shrink cap (often of cellulose acetate) is mainly intended to serve the interests of aesthetics and hygiene, but plastics stoppers with friction-grip ridges which may be additionally secured by wire are now commonly seen, especially in the bottling of sparkling wines.

Caps for small bottles and vials containing tablets can be cunningly designed to be childproof closures when moulded from plastics; other designs include knurled caps with an integral internal spring-like attachment which serves as a spacer and cushion and so replaces the traditional piece of cotton wool. It is obvious that the closure is an essential component of packaging and that its design must be part of the overall structural concept rather than an afterthought in the design of a bottle or jar.

3.8 Gathering and bundling devices

These include a miscellany of essentially uniaxial structures, such as string, monofilament, netting, tape and strips of film. String has traditionally been made from sisal and other naturally occurring fibres of considerable strength, but fast extrusion of polystyrene and other thermoplastics through tape dies with stretching and lateral twisting has resulted in synthetic string of excellent quality which is now widely used for tying and bundling purposes. Narrow tapes are similarly used for bundling and additional protection of wooden crates, cardboard boxes and the like and they can be made from axially drawn extrudates of polypropylene as well as from steel strip. Special gadgets are available to dispense, tighten and lock the tape in position. As has been indicated earlier on (see Section 3.6) relatively narrow widths of polyethylene or polypropylene layflat film can be used to wrap a stack of sacks filled with merchandise to its pallet base and this can be even more firmly unitised by subsequently heat-shrinking the film.

Finally, netting has assumed considerably importance in packaging and has superseded the use of paper and woven sacks and cartons in many packaging applications. Typical examples are "stocking" packs of oranges and other citrus fruit, nets for sprouts, cabbages, onions, carrots and other root vegetables, potatoes and nuts. Although these nets can be made from cotton fibre, it was only after the invention of a fast and highly efficient extrusion process involving the slitting, stretching and special manner of extrusion of polypropylene that this packaging material assumed substantial importance. It is true that the netting provided no mechanical protection, but this is not of primary concern in connection with the types of merchandise just listed, where effective display and convenient handling are the first considerations.

SUMMARY

The packaging industry has arisen as a result of modern production and marketing methods in a sophisticated industrial consumer society which is geared to mass production. Many of the traditional materials have ceased to be used, others have been modified or combined with new ones. Of the new materials without which the whole development would never have come off the ground plastics are the most important. Within that group in turn polyethylene is by far the most important in the film market, followed by polypropylene. Injection and blow moulded containers made from polypropylene, PVC, PE, ABS

PET and other thermoplastics have competed successfully with glass and metal in many applications, especially in the food products and refrigerated storage fields. The packaging industry extends from small items to huge structures such as those represented by tankers, with intermediates of the bulk, semi-bulk and retail type as categorised in the aforegone. Ancillary items such as closures, cushioning, thermally protective and bundling and gathering devices also involve plastics which have often replaced traditional materials (if any) with considerable advantages in performance, aesthetics and cost savings, or have been combined with traditional materials in order to exploit and optimise the advantages of each type.

4. Plastics in Agriculture.

For the purpose of this essay the term "Agriculture" is understood to include "Horticulture" (ie forced growing).

Agriculture has been the single most important activity of man ever since he abandoned the life of a hunter and gatherer and succeeded in domesticating both plants and animals in order to ensure a continuous supply of food without being excessively dependent upon the vagaries of good fortune.

Modern agriculture has benefited from the industrial revolution and the subsequent technological developments. These have led to a far reaching mechanisation, the virtual elimination of back breaking drudgery, an astonishing reduction in the labour content and a simultaneous enormous improvement in the quality of its produce.

With the advent of plastics it became possible to exercise a high degree of control over the growing environment so that favourable climatic conditions could be prolonged beyond the normal seasons and even created independent of the latter, whilst modern transport and storage facilities have made it possible to greatly extend the range of readily available foods that can be marketed at an acceptable cost.

Buttrey has recognised nine aspects of vital interest to agriculture to which we may add a tenth. These may overlap in some cases but they do nevertheless provide a convenient basis for breaking the field down into conveniently manageable categories as follows:

i growing aids
ii Disease and pest control
iii Water management
iv Fertiliser management
v Crop conservation
vi Livestock rearing
vii Produce collection and transportation
viii Tools, machinery and equipment
ix Buildings and structures
x Soil stabilisation

This subdivision is in itself indicative of the status of modern agriculture when compared with that which characterised the industry even as recently as 100 years ago. The horse was still a major energy source; artificial fertilisers were only just beginning to be available at a reasonable price; machines (such as they were) were unsophisticated; the industry was labour intensive; foods out of season were out of reach of all but the most wealthy, and large tracts of land were totally unproductive due to either being waterlogged or parched. The fact that similar conditions still pertain in many underdeveloped countries is of major concern to the international community since this causes hunger, disease and conflict.

It is true to say that the gratifying efficiency of modern agriculture would not have been reached, had not polymer materials become available to make their unique contributions under each of the ten headings enumerated above.

D N Buttrey, Plastics & Polymers 37 (127) 65, Feb 1969

4.1 Growing aids

Before the advent of polyethylene film the only way to grow cash crops under controlled conditions was to grow them under glass. The erection and maintenance of glasshouses is expensive.

With the advent of polyethylene film it became possible to use this material not only for glazing but to extend its use from a strictly horticultural to a truly agricultural use in the widest sense. The limited service life of the film is no disadvantage since it is cheaper to replace it than to keep glass in a clean condition. Indeed, film used for tunnels supported by wire hoops in fields is often so formulated as to ensure that it is UV degraded when its function has been fulfilled, so that it disappears into the soil without polluting the scene or hampering the operations necessary to prepare the field for the next crop.

For more permanent structures such as gardeners' greenhouses, glass may be replaced by acrylic sheet which has excellent UV resistance and light permeability, is much less vulnerable and much more economical from the point of view of heat conservation than glass.

Polyethylene can also be used for doubleglazing in order to restrict heat losses and also as a black film to reduce daylighting and to thus retard ripening and flowering in order to get produce just right for marketing or exhibiting at specified target dates.

Black polyethylene sheet is also used for mulching. This can have a number of desirable effects such as; (i) preventing excessive moisture loss, (ii) discouraging the growth of weeds between the seedlings which come up through holes in the sheet and (iii) keeping crops such as strawberries clean by preventing soil contact of the fruit without the use of laborious, messy and only moderately efficient procedures such as pillowing with straw.

In greenhouses heating, the supply of water and CO_2 gas to the plants is ducted through plastics piping. PVC, PP and PE are commonly used, but PE layflat film is also frequently employed as a flexible and cheap supply line. Plastics are, of course, widely used for plant pots, seed trays, growing boxes, watering troughs and irrigation equipment.

4.2 Disease and pest control

This is a most important aspect, especially where single crops are repeatedly grown on a wide acreage and where the soil must be rigorously sterilised to prevent infection by viruses, moulds, mildews, worms and insects. Few locations are as susceptible to potentially catastrophic outbreaks as the Channel Islands where much of the land is covered by tomato houses and where disease can spread like wildfire once it is allowed to become established in one place. Sterilisation is effected by chemicals and/or by steam, but plastics film and thermally insulating foams are used to blanket the soil and so prevent the premature escape of fumigants and excessive condensation of steam.

Spray equipment including pressure containers, handles, nozzles and connections is commonly made using PP and PVC while pump-housings are moulded in various engineering plastics such as nylon 66, polycarbonate, polysulphones, polyester or polyimide.

Netting of PP also plays a useful part by protecting orchards and soft fruit against the vandalisation of fruit buds and blossoms as well as against the depredations on the part of certain species of birds who feed on seeds and young plants or who damage fruit crops in the garden.

4.3 Water management

This includes a number of problems, such as:

- i Reservoir construction and storage tanks
- ii Distribution piping to irrigation points and cattle drinking troughs
- iii Drainage
- iv Evaporation control

4.3.1 Reservoir construction and storage tanks

The simplest way to ensure that no water is lost from a reservoir by seepage is to line the dug out and/or banked up area with a suitable membrane. Polyethylene, PVC and butyl rubber sheeting have all been used for this purpose, polyethylene is cheapest, but it must be protected against mechanical damage and degradation by UV radiation and it needs to be simply and reliably jointed. Mechanical protection is achieved by laying the film over a layer of soft sand and covering it with soft sand and round pebbles of medium to large size; protection against UV is effected by ensuring that the film is never exposed to sunlight where it comes up at the banks; jointing is effected by sandwiching mastic between overlaps and folding the joints over, using more mastic between layers. PVC film has better UV resistance provided it is properly formulated, while black butyl rubber sheet is best in all respects and can be welded - but it is dearer than the other two materials.

Water storage tanks of 10-20,000 l capacity are used in appreciable numbers on UK farms and smallholdings and they are presently mainly constructed from galvanised steel. It would appear, however, that here is a potential outlet for rotationally moulded polyethylene containers.

4.3.2 Distribution piping

This is, in principle, no different from domestic water supply, except that the pressures are usually lower and that the consequences of leaks appearing are less likely to be serious when they occur on agricultural land. PE piping is popular because it is sufficiently flexible to be coiled and paid out by a "mole plough", a machine which digs, lays the pipe, covers it (leaving a neat scar) and does this in one fairly rapid pass over the terrain.

4.3.3 Drainage

Here rigid PVC piping is laid underground with a slight incline. The pipe has lateral slots through which the drainage water enters. The pipes lead to a collecting ditch.

4.3.4. Evaporation control

Reservoirs and tanks which might rapidly dry up in tropical climates can be largely prevented from doing so by covering them with layers of hollow spheres moulded from a plastic that can withstand UV light and which are prevented from being blown away by netting of some kind.

The use of soil covers has already been mentioned when considering mulches.

4.4 Fertiliser management

This involves both transport and storage of solids as well as of liquids in individual units and bulk containers.

4.4.1 Transport and storage of solids

Solid fertilisers are generally supplied as free flowing granules rather than powders and are conveniently prepackaged in plain or gusseted flexible sacks in 25 or 50 kg lots. These sacks are usually made of heavy gauge LD polyethylene, occasionally from PVC and, less commonly, from butyl rubber. The choice partly depends on whether these sacks are to be stacked under cover or whether they are to be capable of withstanding weathering, particularly degradation upon extended exposure to UVL in the open. Even polyethylene which is very susceptible to UVL degradation can, however, be satisfactorily protected by the inclusion of suitable amounts of carbon black. PVC sacks are liable to embrittlement due to loss of plasticiser and the stabiliser system may contain toxic compounds. Care should therefore be taken lest empties be reused for the storage of animal feed, unless the formulation of the PVC is such as to justify an explicit statement on the package which declares it free from all toxic components. Butyl rubber sacks usually contain carbon black. They are the dearest, but they do not contain any toxic ingredients and have excellent stability and flexibility.

Large users of fertilisers may wish to save the cost of unit prepackaging by receiving supplies by the tanker load which is then transferred to large storage containers on site. These may be constructed of suitable traditional materials provided that these are not subject to corrosion by the fertiliser or protected by a suitable liner, as well as provided by a waterproof cover. Specially made containers can be made by the rotational casting of bins similar to the large water storage tanks mentioned in section 4.3.1., except that they must, of course, be moisture proof.

4.4.2. Transport and storage of liquids

Liquid fertilisers have both advantages and disadvantages. Their advantages are:

i They are ready for application by spray equipment after suitable dilution with water, as necessary.

ii They are cheaper than the dried product for obvious reasons.

iii They almost invariably come by the tanker load and thus enjoy the advantages of bulk handling.

Their disadvantages, on the other hand, are that

i They require a designated tank which is not available for any other storage purposes.

ii They entail the cost of transporting water which partially cancels out the savings of not having to evaporate solutions in order to obtain the granular equivalent.

iii Care must be taken to check and adjust the concentration before use.

iv Special dispensing equipment is required for applying the liquid fertiliser to the land.

As far as storage is concerned, one is again confronted with problems which are, in essence, no different from those involved in the bulk storage of dry chemical fertilisers, except that it is obviously even more important that the storage tank is both leak and rainproof.

4.4.3. Compost and manure

It is worth while, in this context, to mention natural fertilisers, such as compost and animal manure.

Composting is mainly practised by market gardeners. The availability of suitable polymer sheet material (principally PVC) as well as specially designed and easily erected PVC composting bins with fitting covers are helping to convert organic vegetable waste material to a valuable fertiliser which, in addition to enriching the soil, also improves its tilth.

Manure obtained from cattle pens and horse stables have for centuries been known to be valuable means for enriching and restoring arable land. Indeed, it was the only means of combating soil exhaustion and erosion until the recent advent of readily available chemical fertilisers in bulk. In as much as manure is already at hand as a waste product it is cheap, but it is neither plentiful nor chemically or physically consistent; moreover, it is smelly and awkward to collect, transport and distribute. Farmers in both developed and underdeveloped countries can now benefit from improved manure management methods requiring suitable containers and machinery which in many cases involve the use of plastics tanks, liners, pipes and moulded parts. Central to these methods is the concept that raw animal dung is a valuable starting material which must not be allowed to go to waste and which, after applying simple biofermentation techniques, can yield appreciable quantities of energy in the form of fuel gas as well as a manure of the most convenient consistency which is also more conveniently handled.

European farmers have always constructed stables such as to recover liquid manure using gutters, drains and underground collection pits, whilst the semi-solid material was laboriously swept up and composted in the open. The use of water hoses has tended to save a great deal of manpower for this disagreeable task and has made it possible to maintain far better sanitary conditions which greatly improved the health of stock and reduced the risk of infection. However, it also entailed the loss of a valuable resource and generated a serious effluent disposal problem. This has led to entirely novel concepts of animal husbandry, especially in the field of pig breeding and egg and poultry production. Special circular piggeries divided into sectors with feeding and watering troughs are provided with a grille type floor through which all the droppings fall into an underground pit. Heating and ventilation ensure that usual smells are virtually absent and the droppings are continuously processed into organic fertiliser.

Egg production by battery hens also requires a means of maintaining clean conditions. The construction of suitable collection and storage devices for poultry manure is, as in the case of pig rearing, part of quite revolutionary livestock rearing methods which would have been impossible to develop without the availability of plastics and which will be more fully described in section 4.6.

4.4.4. Fertiliser application

Fertiliser handling and application equipment, like spray and other dispensing equipment for pest control nowadays often features moulded working parts, particularly nozzles, over corrodable metals. Technical advantages of such engineering plastics as nylon, acetal, thermoplastic polyester moulding material, polysulphones (and occasionally PTFE) are considerable.

4.5 Crop conservation

Crop conservation is an essential aspect of agricultural planning since crops, once laboriously and successfully raised and harvested must obviously be protected against spoilage. Spoilage is the inevitable consequence of insufficient protection against the elements and/or pollution and infestation.

The correct measures of conservation obviously depend on the type of crop. In the case of fresh fruit and vegetable produce the traditional methods of chemical conservation by pickling and salting are nowadays supplemented and virtually swamped in importance by canning and deep freeze methods.

Canning (and preservation in bottles, drums, barrels, etc.) is discussed in the essay dealing with packaging generally, but it is well to recall that plastics play a most important role here, both on their own and in combination with metals and other materials.

The success of deep freezing depends upon the availability of both suitable containers (again dealt with under "packaging") and chests and chambers with appropriate hygienic linings and thermal insulation.

In both respects plastics have made a vital contribution in the form of sheet and expanded materials respectively.

More importantly, however (and much more germane to agriculture), conservation needs to be considered as a storage problem of cash crops on the farm or at a depot. The principal crops involved here are grain, pulses, coffee, cocoa, tobacco, root vegetables and animal feedstuffs such as sileage and hay.

Grain stores must be constructed so as to provide appropriate ventilation, temperature and humidity control, including the prevention of condensation which would encourage germination or the growth of moulds. They must also provide a barrier to rodent and insect infestation; this may be achieved either by mechanical or by chemical means such as fumigation, or a combination of both. The UK Ministry of Overseas Development has a Tropical Stored Product Centre which is specifically concerned with the problem involved. One of the solutions developed involves a pneumatic grain silo from butyl rubber sheeting(about 12 in high and capable of storing 1000 tons of grain)which rolls up to quite a small size when deflated. Much more elaborate rigid structures based on huge concrete constructions are, of course, available, but they are very expensive to construct and require careful internal control and logging in order to keep the grain in a good condition.

Hard-shelled produce such as nuts, coconuts, coffee and cocoa beans present similar problems, except that depots tend to be of more modest capacity. Tobacco enjoys some chemical protection once it is cured, but it needs rigorous protection against moulds in the early processing stages, including careful humidity control.

Root crops and tubers (potatoes, carrots, onions, sugar beet, turnips, etc.) are normally stored for limited periods not exceeding a season and they need protection from frost damage and/or dehydration, as well as from mould and rodents.

One of the more successful methods of "clamping" crops of this type is blanket roll layering which involves the use of clean dry straw and polypropylene netting, as well as location in cool and covered barns. It is essential here to maintain an effective separation so as to prevent extensive spread of rot if individual pieces become affected. Similar principles - though achieved by layered box crating as well as within - layer individual separation - are used for the storage of apples, pears and citrus fruit and the separators are either made from cardboard or from PS foil.

In storage houses for tropical fruit, especially bananas, it is often necessary to retard or accelerate ripening in order to regulate the market supply position. This can sometimes be achieved by means of ethylene oxide gas and if this is used then it is clearly essential to control the gaseous atmosphere by enclosure in a suitable barrier material such as plastics film or sheet.

Silage and rick construction for animal feeding relies almost exclusively on the use of polyethylene film, with such accessories as extruded closure zips and fastening devices, such as netting. The use of plastics film and zips in silage making has been described by R P Walley (Technical Sales Director, Stephens Agricultural plastics Ltd) at the Eastbourne Conference of Plastics in Agriculture in April 1968, while the use of plastics in netting for agricultural uses was described by K W Carley of Bridport-Gundry Ltd at the same conference.

In the case of silage success depends on the prevention of aerobic fermentation. This can achieved by enclosure of the ensiled charge in a zippable pillow constructed from polyethylene sheet which can be evacuated by a simple pump through a valved sleeve and which can be topped up with freshly cut grass at suitable intervals. The resulting silage is highly nutritive, palatable to cattle and ensures a much higher yield of feed per unit area of cropped grass land than traditional haymaking or tractor - rolled compression methods.

As for the protection of traditional haystacks, a cover of polyethylene film is an obvious and simple device to prevent nutrients from being washed out by rain and the safe positioning of the film is ensured by wide-mesh polypropylene netting thrown over and weighed down with stones at the margins.

Finally, the importance of fibrillated film (mostly PS) for baler twine should not be overlooking since it accounts for an appreciable volume of trade.

4.6. Livestock rearing

Here we distinguish between egg production, poultry rearing (including hatcheries), animal houses such as piggeries and stabling, and temporary cattle shelters in the field.

4.6.1. Egg production

The battery system has led to the design of cage units in rows and tiers which are largely made of moulded plastics and which incorporate devices for supplying food and water to the birds, collecting and washing the eggs, for removing the droppings (and then collection and conversion to manure) and for maintaining hygiene with a maximum of automation and hence with a minimum of labour. These are almost entirely based on plastics materials, especially polypropylene. The moving belting for egg and manure collection is made from polyester film.

Pig rearing is also largely carried out under semiautomated and computer controlled conditions and reference to this has already been made in section 4.4.3. However, young pigs are particularly susceptible to pneumonia and they need to be kept warm and have to be carefully protected from draughts.

The construction of suitable pigbreeding and - rearing houses requires substantial capital investment and uses a lot of structural GRP in combination with polyurethane foam reinforcement and insulation: the resulting efficiency and ease of management is impressive.

All stabling can, of course, take advantage of certain aspects of plastics in building (see essay 2) especially internal "cocooning" with plastics (which facilitates cleaning by hosing down), the use of expanded plastics for thermal insulation, plastics for daylight control, draught control, heating and ventilation ducting and water supply structures.

Animal shelters in the field are often simple tent-like structures and consist of little more than a layer of polyethylene film sandwiched between polypropylene netting and layed over a suitable framework of poles with or without side walls of some sort; they give considerable protection to cattle and sheep under severe weather conditions, especially in exposed hilly and mountainous terrain where the animals may not be easily shepherded.

The transportation of live poultry is often done in collapsible (ie flattenable) moulded cages which are readily moulded in PP and which are provided with integral hinges for the side walls and top.

4.7. Produce collection and transportation

Produce collection is largely but not exclusively bound up with packaging.

The collection of field crops may involve on-site packaging direct for the market (eg in crates and tote boxes) or an intermediate stage of transport and handling in a factory. The factory operation may be confined to cleaning and/or further packaging for wholesale or retail distribution; alternatively it may be a conversion process such as canning, freezing, extraction, refining.

The type of operation of the latter kind will determine the method of gathering. Where large scale conversions are carried out the method of field-to-factory handling and transportation will require that packaging and handling costs be at a minimum. This means that containers (if any) must be returnable rather than disposable and in that case large plastics containers will be a sensible long term investment preferable to wooden crates which are heavy and quickly become dirty, and cheaper - after a period - than single-trip cardboard boxes. The returnable plastics containers are often hinged and collapsible for easy return of empties.

If a crop such as sugar beet is loaded by the waggon it is desirable to stack produce as high as possible and prevent spillage through bouncing off by a cover of PP netting.

The long distance shipping of fresh produce by air or by express train is only feasible if it arrives at its destination in prime condition. This can be ensured by the use of air conditioned compartments, but the use of perforated polyethylene-film-lined corrugated board boxes or boxes made up from PS foam sandwiched between two layers of kraft paper by special extrusion lamination are rational alternatives which have been proposed for packaging a number of other luxury items such as out-of-season lettuce and good quality cut flowers for the fastest possible long distance shipping.

4.8 Tools and machinery

This is an area where the value of plastics is indisputable and yet comparative little use of them has been made in relation to the volume of equipment produced. Engineering plastics such as the ones mentioned earlier or have indeed been used in many working parts where their corrosion resistance has mainly been exploited. Otherwise the use of plastics has been mainly confined to handles for small tools, guards, nets, sheet material for linings or weather protection and small mouldings, pressure containers for relatively small spray containers and the like. However, there are now numerous gardening accessories available which contain a large proportion of plastics. These include hover mowers, pumps and rocker-type irrigation equipment. Mechanical gathering devices for nuts and olives have recently come onto the market.

The need for fuel economy through weight saving is likely to tilt the materials choice balance more in favour of plastics when it comes to farm machinery, a development which is likely to proceed in parallel with the increased use of plastics in the automotive industry.

With the need of special corrosion resistant pumps and containers in the relatively new practice of hydroponics there also seems to be a future outlet for components moulded in plastics.

4.9. Buildings and Construction

This has already been referred to in sections 4.5 and 4.6 which dealt with storage and animal husbandry respectively.

As for the farm house itself, the same considerations apply as those which were dealt with in detail in essay two (Plastics in Building).

As for greenhouses, however, discussed in section 4.1, it should be added that it is also possible to construct air-supported structures from flexible transparent film material by maintaining a small nominal air pressure by means of a pump and so erect a tent-like hangar-type greenhouse with scarcely any external support other than anchoring to the ground.

One of the most exciting prospects is what may be termed the urbanisation of food production. Ruthner has proposed the construction of high-rise acrylic-glazed towers within which the climate is controlled so as to optimise conditions for specific crops. Seedlings in individual pots are introduced and advance up and down at a rate which allows one to harvest the fully grown cabbage on cauliflower (or whatever) at the far end of the moving belt in due course. This may well involve hydroponics (ie growing in soil-less culture media) and would, for the first time in the history of mankind, make "arable" farming independent of the weather. Furthermore, such an arrangement is ideally suited to make use of waste heat from power stations and industrial processes, an idea which has already been exploited in greenhouses for the raising of tomatoes near power stations in the UK.

4.10. Soil stabilisation

It is true that all manner of additives, especially of the organic and nutrient kind also improve and stabilise the soil structure.

However, there are two situations where the problem is of an altogether different order of magnitude.

i Coastlines where the pounding of heavy waves erode a low lying coastline.

ii Semidesert areas where storms tend to blow away what little soil may be available for the growing of any kind of plant.

The best defence in both cases is the establishment of hardy plants whose roots can bind the soil together and give it mechanical cohesion such as to enable it to confront the elements with a better chance of preservation.

There are two examples of how this can be achieved:

i The "planting" of PP tufts along the sandy shores of the Ayrshire coast which stabilised the soil sufficiently to enable simultaneously planted seeds of hardy grasses to root and become established.

ii The grid-like dripping of an aqueous UF resin on the shifty wind-blown sands of the Negev desert. It was observed that wind makes sand grains jump and propagate another jump by the grain which it hits ("saltation"). This propagation is stopped when the grain hits a spot which had been "seeded" with UF resin. The heat of the sun evaporates the resin which then partially cures and bonds sand grains together into a kind of pebble. Not only does this prevent the formation of sand dunes, it also provides nitrogenous fertiliser for any seeds of hardy scrub which can thus establish itself and become the beginning of a developing flora (and, ultimately, a fauna) in what was a desert area. All that is additionally needed is careful irrigation and soil management to achieve what has been the dream of many: the reclamation of the desert for productive agricultural use.

4.11 Conclusion

This review has revealed many facets which have transformed traditional agriculture and which are still in the early stages of exploiting the full potential of food production which has been created as a consequence of the development and application of plastics in this oldest of all of man's industries.

5. PLASTICS IN ROAD TRANSPORT.

INTRODUCTION.

The major components of internal combustion engines and the transmission (with the important exception of the tyres) of road vehicles are invariably designed using metals as the structural materials. Plastics cannot serve in a major load or thrust bearing capacity for the motor industry any more than they can replace steel, timber, brick and reinforced concrete in building and construction. Plastics can, however play an important ancillary role in the design of minor components both under the bonnet and elsewhere, components which may be associated with the engine and with the transmission system as well as with other systems, a role which cannot be fulfilled by metals for a number of reasons. Indeed, it is no exaggeration to say that the motor industry as we know it today would not have got off the ground at all had it not been for the timely discovery of fibre reinforced phenolic resins by Baekeland in the first decade of this century.

As regards plastics the motor industry makes even more stringent demands because of additional requirements of thermal and dimensional stability over considerably wider temperature ranges; moreover, the stressing rates and the stress acceleration which occur under dynamic conditions impose even greater material limitations in engine, transmission and bodywork design than the largely static loads impose upon material selection problems under the conditions which dominate structural engineering design in building.

Plastics have nevertheless found occasional use for structural purposes in buildings of a special type such as stressed skin and folded plate structures, barrel vaults, geodesic domes and related space structures. A previous essay also mentioned that more modest structural applications of reinforced plastics for temporary and transportable buildings of modest size are entirely feasible and cost-effective. An analogy for this exists in the automotive industry in the construction of car and cab bodies which is often based on reinforced plastics when tooling up with presses and production lines which require a huge capital investment: The outlay is only justified for mass production of tens or hundreds of thousands of units per annum. Reinforced plastics are functionally very suitable for making body panels and the production method and simple machinery involved and,- most important - the relative cheapness of the latter, favours these materials for the production of models with modest annual sales. Such models - unlike their building equivalents - are not just unusual, architecturally experimental or of strictly limited functional utility, but they constitute an important and well definable range of products including the following: Prototypes, sports and racing cars, recreational vehicles, invalid carriages, lorry cabs, and occasionally public vehicles such as single decker buses and ambulances; the list can even be extended to cars manufactured or assembled in some overseas countries where there is, as yet, only a limited demand for private vehicles and where import costs and currency problems justify setting up production facilities locally.

If one extends what so far mainly referred to the conveyance of people (be they passengers or drivers) to the transport of goods it is clear that the construction of containers for general or particular classes of merchandise needs to be considered together with the overall design of lorries. In a sense, this is an intrusion of the concept of packaging into the bulk transport field and is not even restricted to road transport, but extends to "shipping" generally, a term which is commonly used nowadays to include transportation by any means, but especially by rail, cargo boat and air in addition to transport by lorry.

When looking at private and public road vehicles, however, one identifies further classes of material usage which are associated with important functions other than the basic (chassis) structure, power generation and transmission. The systems that immediately spring to mind are: fuel supply and storage, lighting and electrical systems, mechanical devices such as handles, door furniture, winding gear and catches, air conditioning (including heating, ventilation and cooling), general comfort (including vibration and noise damping), safety devices and the aesthetics of interior trim, external finish, weather proofing and corrosion protection.

The application of plastics in road transport will therefore be considered under the following sectional headings:

- Plastics for bodywork
  - Prototypes, sports and recreational vehicles
  - Buses, ambulances, invalid carriages and lorry cabs
  - Integral and demountable containers for bulk delivery by lorry
- Plastics associated with the engine and transmission systems.
- Plastics for secondary mechanical functions (electrical gear wheels, pumps, handles, catches, etc.)
- Plastics in electrical systems
  - Ignition and sparking plug protection and suppressors.
  - Lighting and conduit
- Sound and vibration damping
- Plastics for fuel systems
- Plastics in air conditioning (heating, cooling, ventilation)
- Safety devices
- Exterior finish, weatherproofing and corrosion protection
- Interior trim.

The use of rubber and reinforcing fibres for tyre moulding as well as the design and use of rubber hose has been excluded from this review since these important structures are best treated in their own right.

5.1. PLASTICS IN BODYWORK

The major incentive for the replacement of metals by plastics in car bodies is weight saving and a coresponding improvement in fuel economy, but there are other considerations which further improve the case in favour of plastics:

- low capital expenditure on moulding equipment and power expenditure during the moulding operation;
- Easy modification of moulds for custom specification on design improvement and the use of semiskilled labour;
- Simple finishing;
- No need for rustproofing;
- Good mechanical properties and ease of repair;
- A high degree of design freedom;

These advantages are the more pronounced the smaller the numbers in a production run. For prototypes one could not possibly consider setting up a metal sheet press, neither is this economically sensible for racing cars, sports models and bodies for private cars made locally for a restricted market. Even lorry cabs, ambulances and single decker buses have had their bodies made from glass reinforced polyester (GRP) because the economy of the wet-lay-up moulding favours this method over that involved in making and assembling pressed steel panels for short production runs. The break-even point has been a matter of much dispute, but may be taken to be somewhere between 10,000 and 50,000 units per annum.

When a large volume of production is envisaged and the high cost of press tools and energy can be spread over, say 100,000 + units per annum the wet-lay-up method and not even low-pressure accelerated curing methods can any longer be considered. The process is too slow, too messy and too wasteful as regards factory floor space to compete with the highly efficient and computerised pressing and assembling methods which characterise modern volume car production.

5.1.1. PROTOTYPES, SPORTS AND RECREATIONAL VEHICLES

There is **absolutely no** alternative to reinforced polyesters for the construction of models for car engineering design purposes. The mould and the process of moulding are cheap, simple and quick, and modifications needed in the light of, say, wind tunnel experiments or indicated by minor changes in the stylist's judgment are readily accommodated. This extends further into the field of racing car design, do-it-yourself kits for car enthusiasts, custom-building to special requirements and small production runs (generally of less than a few 1000 units per annum).

This idea further extends to recreational on custom-modified vehicles such as motor caravans and trailers some of which are designed with integral sleeping, living, kitchen, washing and sanitary facilities. Here additional thought should be given to particular hazards such as flammability in the selection of the material of construction and some grades of polyesters are specially designed for such applications.

It is worth noting, in this context, that very similar thinking governs the approach to the design of boats and small cabin cruisers, since these fulfil an analogous recreational function on water as caravans and trailers do on the road.

Conventional private cars such as the BL Mini, certain Ford and Vauxhall models, and others, have been made using GRP body panels. These were moulded and assembled on site and under licence in Turkey, Brazil and elsewhere in order to avoid the need of imports from hard currency areas, as well as in order to reduce transport costs and create local employment. This may involve quite a substantial production volume and could be the precursor of a modern pressed steel car production facility in a developing country with a growing internal and potentially regional export market.

Finally it should be said that the reinforced plastics range is not confined to glass fibre reinforced polyesters and that even thermoplastics have been used in the production of body panels for certain models.

Thus, epoxy resin is an alternative to polyesters which has superior mechanical and intrinsically flameresistant properties, although it is considerably more expensive. Furthermore, glass fibre is not the only reinforcement material available and carbon fibre, boron fibre and polyaramides such as "Kevlar" (Du Pont) fibre have been put forward as alternatives which provide a remarkable improvement in mechanical strength over glass fibre reinforcement, although, again, unfortunately at great additional cost.

A number of companies have experimented with thermoformed ABS skins injected with polyurethane which latter sets into a rigid self adhesive core. The resulting sandwich panel has considerable strength. Single-ply body panels of the cladding type have been used in airport runabout vehicles of which a version of the Citroen Dyane and the "Mini Moke" are examples.

5.1.2. BUSES, AMBULANCES AND LORRY CABS

Buses have been known to be built from GRP by the wet-lay-up method on a steel chassis where even the floor structure comprised an aircraft-type floor sandwich made up from GRP skins with a rigid PVC/polyurethane foam core.

The GLC has been producing its own ambulances in the same way. The main reason for prefering GRP here was the frequently recurring need for repairs to scratched and dented panels due to damage sustained in emergency rush conditions and the ease and cheapness with which this could be carried out in the local authority's own coach building shop.

Lorry cabs are largely made from GRP panels nowadays. They are not usually made in the numbers charactistic for large volume production private cars, so that the economic considerations discussed above apply. Moreover, the greater design freedom makes it possible to include features which greatly enhance the driver's and mate's comfort, a most important consideration in view of the long trips and the consequent fatigue to which international routiers are exposed nowadays.

5.1.3. CONTAINERS FOR BULK DELIVERY

Containers for bulk delivery may be an integral part of a specially designed platform on wheels which is articulated to the "mechanical horse" or power unit consisting of the engine and driver's cabin. One example of such a unit would be the familiar one for the delivery of ready-mixed concrete. In this case plastics do not feature to any significant extent. Another example is provided by the (usually slightly inclined) liquid tankers carrying petrol, fuel oils, liquid fertilisers, solvents and other liquid chemical solutions, water or milk. Such tankers are normally constructed from steel and are internally lined with glass, rubber or suitable plastics. They are always designed to carry just one (or one of several closely related) products such as, say, toluene and xylene, because the lining material is selected to enable it (i) to protect the container proper against corrosion and chemical attack from within and (ii) to ensure that the liquid carrier does not leach out any significant amounts of extractables which might either contaminate the contents or damage the lining. In this context the role of plastics is confined to that of a protective internal coating. Additionally, however, some liquid tankers (eg those carrying molten phenol or aqueous dispersions) are provided with an external insulating layer of rigid polyurethane foam in order to provide thermal insulation and prevent the contents from freezing solid or coagulating in frosty weather. In such cases it is customary to provide a facility for electric heating so that the plastic must possess some modest heat resistance. It is customary to protect the insulating layer from mechanical damage by giving it a further coating of sprayed-on GRP. Occasionally cylindical tanks are made in GRP by filament winding.

The principal disadvantage of tankers of this kind is that they fulfil no useful function on the return trip other than the obvious one of being available for the next one-way journey. This may be tolerated for very large bulk loads wuch as petrol tankers, but if the liquid volume is more modest it is worth considering the use of demountable containers which may be hoisted onto a flat truck, secured in place by bolting or lashing and which will then quite probably be of a non-cylindrical shape. Such containers may be of suitably lined steel or of GRP. Special spherical containers with a flat platform are made from steel or filament-wound GRP for extremely corrosive chemicals, for pressurised liquids and for liquid gases (liquid NH_3, liquid CO_2, liquid air, etc.) and the latter will then require the excellent thermal insulation of an additional foamed polyurethane jacket provided with an external protective layer against mechanical damage to the foam layer. Since the emptying of such containers is hazardous the full bottle is exchanged for an empty one at the point of destination.

If milk is transported in bulk the container must be sterilised by steam under pressure and the lining must be able to withstand an infinite number of cycles, so that glass rather than plastics or rubbers are preferred lining materials.

Experiments have been carried out with flexible containers in the shape of valved pillows made up of nylon and polyester-based woven fabrics of great strength which are impregnated and/or coated, laminated and made reasonably secure against accidental puncture. Such pillows are then lashed to the flat truck. Although a flat load cannot be stacked up for reasons of stability and the danger of surging when the vehicle corners, the flexible pillow has the advantage of being capable of rolling up after emptying, so that the truck is free to take another payload on the return journey and is not restricted to transporting just one type of commodity.

Open and semi-open tank cars for use on railways as well as road trucks have been integrally designed for granular products such as cereals, for crushed ores, hops, stable manure, raw hides, refuse, etc., but the scope for the use of plastics here is almost negligible.

Some of the most modern so-called bulk containers for container ships (especially the refrigerated variety such as those buying frozen meat from Australia, New Zealand and South America) have been made from a number of materials and often feature a sandwich combination of steel liners with rigid polyurethane or polystyrene foam cores, GRP sheet, chipboard, blockboard, particle board, hardboard, plywood, liners of rigid PVC or ABS, all with the objective of optimising thermal insulation (where necessary) and mechanical performance, as well as fuel economy in transport by weight saving, especially when the individual bulk containers have to be transported by road trucks during any significant length of its journey.

5.2. Plastics in private cars (volume production models).

Before considering the use of plastics in private cars one must first enquire why plastics should be used there at all. The answer is the same as that which applies to any other material considered for application in the automotive industry: A case in favour exists if there are reasonable prospects for improvements and/or economies such as may figure under one or more of the following headings:

- Better technical performance
- Improved styling, appearance and overall aesthetics, leading to enhanced sales appeal
- Improvements in the fuel economy (notably through weight saving)
- Reduction of showroom prices and subsequent maintenance costs
- Enhanced driver and passenger comfort
- Improvements in the safety of the vehicle.

The material properties which the designer looks for are one or more of the following:

- Reasonable impact strength, especially in thin sections
- Wear resistance and low-friction properties
- Flexibility or stiffness, as appropriate
- Flame resistance and/or thermal stability up to some stated (e.g. stoving) temperature
- Colour and gloss retention on prolonged exterior exposure
- Petrol and oil resistance, resistance to crazing and environmental stress cracking
- Easy paintability without the need for laborious priming methods
- Easy bonding with readily available adhesives
- Good light transmission; transparency or translucency.

The usefulness of plastics in the automotive industry based upon these criteria is reflected in the following figures which illustrate the growth, in terms of weight of plastics per car, from pre-war days:

		lbs
Average U.K. family saloon	(1939)	5
ditto	(1963)	16
Average U.S. car	(1963)	15
Citroen ID	(1963)	56
Fiats	(1963)	26
Chevrolet	(1963)	30

The early 'sixties saw a tremendous increase in the use of plastics in cars. According to Chem. Eng. News the amount of plastics materials used for cars in the U.S.A. rose from 135 million lbs in 1961 to over 172 million lbs in 1962. In 1965 the chairman of ICI Plastics Division claimed that "every car could contain 250 lbs of plastics". These were the days of heady optimism when the first GRP lorry cabs and sports cars had come onto the market, when the vacuum forming of body panels (including foam sandwich structures) was under investigation and when the injection moulding of entire body shells was dreamed of.

From time to time one encounters statistics and projections. These tend to be coloured by the prevailing climate of the economy and must therefore be treated with caution, but two sets of figures based upon hard fact are worth quoting. They come from the VDI (Association of German Engineers) and date from 1979. The first lists the use of plastics in the 1979 model of the VW Golf and the second compares the price movement of various materials which are of relevance to the automotive industry, taking 1958 prices as the base:

<u>The use of plastics in the VW Golf (1979):</u> (Total: about 4? kg, breaking down as follows:)

Polymer	kg (interior)	kg (exterior)
PVC	14	–
ABS	4	1
PP	4	–
EPDM/PP	–	3
PE	1.5	0.5
Polyacetal	–	2
POM	–	0.5
PMMA	–	0.3
PS	0.1	–
PU	8	–
Various thermosets	5	–
	36.6	6.3

Price comparison of various materials of relevance in car design (1979)

(1958 = 100)

Timber	107	PVC	63
Paper	114	PS	48
Cast Iron	129	ABS	58
Aluminium	109	Polycarbonate	62
Zinc	157	HDPE	30
		Polyamides	53

Unfortunately the days when plastics became ever cheaper in money terms even before adjusting for inflation while other materials exhibited a reverse trend have gone forever. Not only has the scope for price reductions due to improvements in the efficiency of processes and unit cost reductions due to increasing production volumes been largely exhausted, but the unprecedented rise in the cost of petroleum based feedstocks has made plastics as susceptible to the effects of inflation to which they had seemed to be immune for so long as other materials have become due to the rising costs of energy and labour. Having thus lost their edge in the relative trends of material cost plastics will henceforth have to rely on their many other assets in order to compete with other materials as successfully - and even more successfully - than they have done up to now.

It is not intended to go as far as to deal with each of the many categories of applications within the private car sector of the automotive industry which had been detailed in the introduction in order to outline thebreadth and depth of plastics involvement in this field, since this would expand the present review to proportions which vastly exceed the modest scope of an essay. We therefore confine ourselves to consider the use of plastics under two encyclopaedic headings, namely:

(i) Plastics associated with the engine, transmission, braking, steering and other mechanical systems, and

(ii) Plastics for trim, finish, accessories, comfort and safety.

5.2.1. Plastics associated with the engine, etc.

Carbon fibre reinforced plastics have been suggested [illegible] propeller shafts which reduce bearing loads on the gearbox, centre bearing and rear axle, improve shaft performance and give better stability throughout the lifetime of the vehicle (1980).

Some truly remarkable developments were featured at Interplas 1981. These included various highly exciting major structural applications such as carburetter bodies moulded in GRP which represent an enormous simplification of the manufacturing technique of metal working, bolting, drilling, welding, assembly and waste management, not to mention the saving of labour costs associated therewith. Another important development is the production of inlet manifolds from GRP with a "hot" metal insert which promotes fuel vaporisation. However, the most significant advance of all promises to be the renewed and apparently successful attempt to design a major and truly loadbearing chassis from sophisticated fibre-reinforced polyester and epoxy materials in the light of which one may well have to revise one's earlier pessimism as to the feasibility of plastics for major loadbearing purposes. Whilst one might not be inclined to expect volume production models to be equipped with plastics chassis for yet a while, it is as well to reflect how established notions and predictions may need to be revised in the face of unexpected developments, especially in the field of plastics and composites.

Radiator header tanks and overflow tanks, engine timing covers and gear box consoles are now made by blow moulding rather than by injection moulding because the former method is more economical and requires less capital investment on machinery.

The first plastics air filter in the U.K. was moulded in PP in 19[illegible] for the Ford Cortina and the Hillman Hunter, but the replacement of pressed steel has not become universal, possibly because the weight saving is relatively small, because there is little difference in first cost and because the technical performance is no better than that of the pressed steel air filter.

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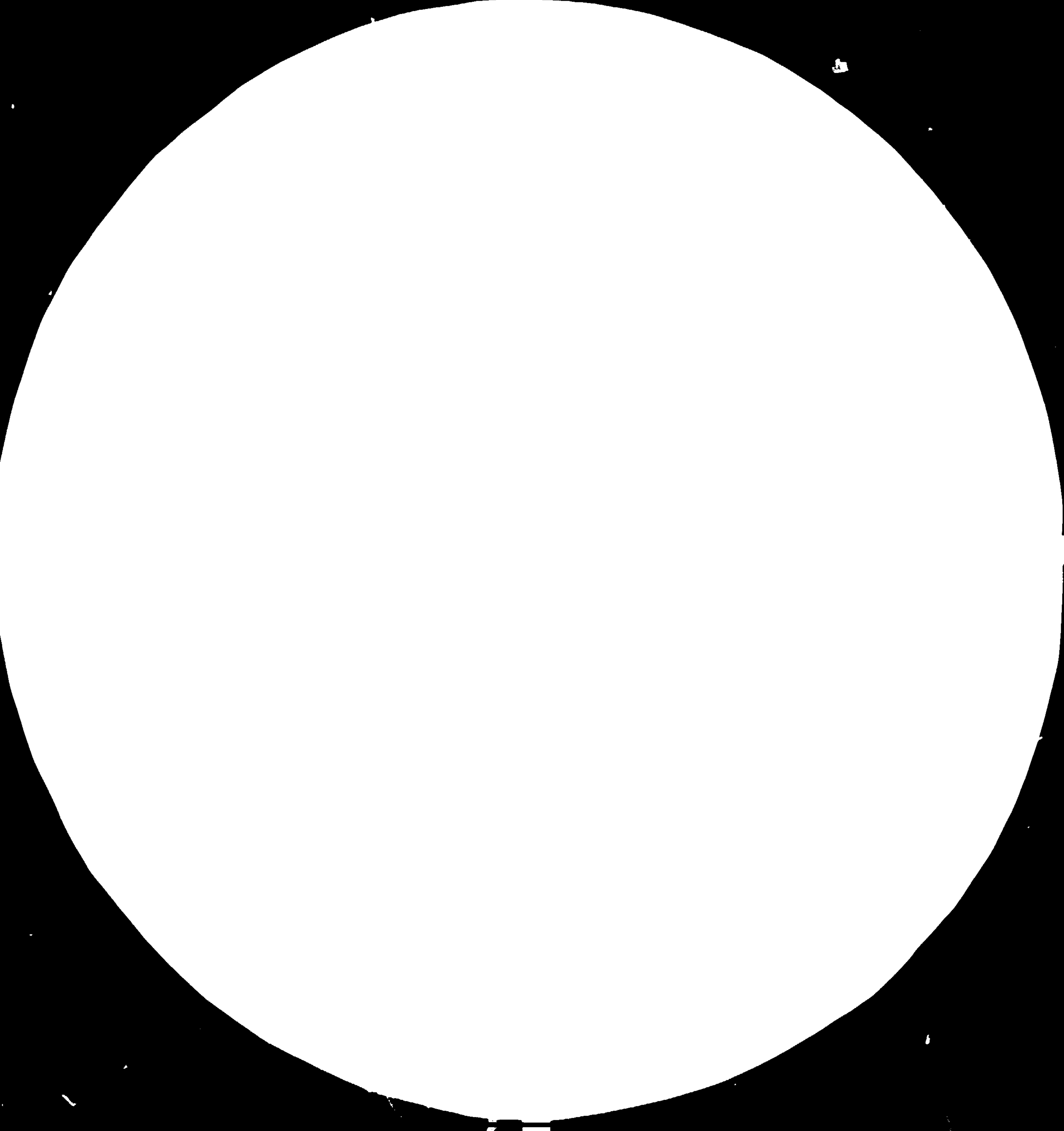

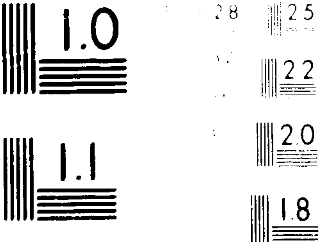
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Another very interesting though little noted development is the first reported use of nylon moulding material for car wheels: It appertains to the rear wheel of the "Montala", a go-cart for track racing. It consists of two halves joined by four bolts with eight pins each and with thirty-six grips moulded on the rim to prevent the tyre from creeping. In this connection one might also mention a plastics wheel moulded from glass- and carbon fibre reinforced polyester which is claimed to be stronger than a wheel with steel spokes; it is part of the "Itera" cycle the body of which is made from the same materials. It has been designed in Sweden and is about to go into production in Essex.

Major advances in materials technology has enabled Monsanto to offer a mineral filled nylon moulding compound which is suitable for moulding the rocker arm of AMC's 1981 six-cylinder vehicles; this is stated to save about 50% of weight compared with the stamped steel equivalent which weighs nearly 4 lbs. The new material was found to be the best of a number of alternative reinforced plastics investigated, including polycarbonate, polysulphone, ABS, PPO, polyacetal and SAN.

A number of minor components, including some for use under the bonnet, include the following:

- Switch bodies, carburetter spacers, distribution and sparking plug covers and moulded cooling fans from phenolic material;
- Bushes, brackets, speedo gears, water pump bearings, carburetter components, fan pulleys, cooling fans, handbrake cover sleeves and door striker mechanisms from nylon;
- Window crank and door handles, windshield washer pump housings, windscreen wiper gears, carburetter components, steerage linking ball seats and handbrake cable pulleys from polyacetal;
- Steering columns from PPO (AUDI 80, 1973);
- Steering column covers from a special heat resisting PS (MINI 1969) and steering wheel covers from CAB;
- Accelerator pedals, brake cylinder plugs and gear wheels for small electrical motors from PP;

- No-loss cooling systems involving the use of an overflow bottle moulded from HDPE;
- Steering column saddle brackets, windscreen and brake fluid containers, brake cylinder plugs and defroster nozzles from HDPE or PP;
- Accelerator pedals with integral hinge from PP;
- Thrust washers, gear (change) linkage bushes, pivot bearings and camshaft pivots from PTFE, exploiting to the full the unique low-friction properties of the material;
- Nylon tubing as a replacement for copper and brass tubes in fuel lines.

A most important development of very recent origin (1981) relates to filament-wound rear suspension leaf springs: This spring for the 1981 Chevrolet weighs only 3.6 kg, as compared with a weight of 18.6 kg for its steel predecessor!

Blow-moulded radiator header tanks represented a notable advance on the earlier overflow bottle.

Auxiliary fuel tanks had been made from rotomoulded PE or nylon, as well as by direct casting of monomeric materials as early as 1968 and this had been considered for the Ford Bronco. The subsequent availability of ultra-high-molecular weight PE ("Lupolen 46261 A", BASF) and the development of appropriate moulding techniques have led to an important development a decade later: The production of a fully fledged fuel tank with sufficient flexibility to minimise the risk of rupture in an accident. Vent and breather nipples (injection moulded from the same material) are spin-welded in. The polymer is unaffected by environmental stress cracking and ageing in the presence of hydrocarbons and its high impact strength remains unimpaired by thermal shock. At the same time it is strong enough to cope with theusual and more or less continuous stresses which arise from mounting the tank in its conventional location. Its weight is 1.5 kg, 3.2 kg less than that of the conventional steel tank. The tank remained undamaged when a test car was subjected to a rear-end crash test. Filler caps of PP have been on the market for some time, but they have not found universal acceptance.

5.2.2. Plastics for trim, finish, accessories, comfort and safety.

The major proportion of all the plastics in the popular volume production models has for many years been in the form of PVC interior trim, notably seat, head rest, back rest and arm rest covers, door handle pads and internal door cladding. The PVC is heavily plasticised to simulate a flexible and easily cleaned leather-like furnishing material which is usually laminated onto a fabric base and which may additionally have a PU or PVC foam layer. Nothing needs to be said to further describe the innumerable plain or embossed and variously patterned designs, but it is worth noting in passing that PP fibre fabrics are also known to make a minor contribution in this field and that additional protective and comfort-enhancing seats covers from synthetic fibre fabrics and fur-like piles are available and popular. PU foam is not only a common upholstery constituent but also serves to aid in sound and vibration damping, as well as fulfilling an important safety function in shock absorbing crash pads.

Polyurethane lacquers are now commonly replacing the traditional cellulosics for the exterior stoving enamel because of its superior adhesion, chip impact resistance, general mechanical properties (especially its hardness and scratch resistance), weathering, oil and petrol resistance and its corrosion protection which these properties guarantee to a high degree.

Returning to interior comfort and accommodation: Seat stocks represent a substantial deadweight in a car. Various engineering plastics have been proposed for making a moulded seat to replace the tubular steel based stocks, including polycarbonate, PPO, PET, glass filled nylon or polyacetal and glass filled polypropylene.

Heater cases have been made from talc filled PP by injection moulding and from dough-moulded GRP (1970), while the air intake grilles of the 1976 AUDI were made from nylon and its instrument cowls, ducts and grilles for air conditioning, as well as the glove compartment, have been commonly made from HDPE or PP.

Fascia panels have been moulded in a variety of materials including PP, ABS, SAN, polyacetal and polycarbonate. ABS is also found as an armrest component, for seat side shields and as channelling for sliding windows.

Battery boxes (originally moulded in phenolocs or bitumen moulding material) were structurally moulded in HDPE foam in 1969, but these were subsequently replaced by injection moulded PP. Compar4d to the old type battery cases the mechanical properties, the weight saving, the structure improvement as well as the overall design and tidiness are impressive.

The bumpers of the 1978 VW are injection moulded from EPDM and provide an enormous weight saving while at the same time being far less prone to damage than chrome plated steel bumpers with no loss of efficiency. Some models feature reaction moulded PU formulations for bumpers and other semi-structural components.Earlier attempts at using GRP for this purpose had not been successful.

As for major headlamp components - housings have been moulded in PP and headlamp cowls have also been made by dough-moulding of GRP.

Acrylics are used for knobs, badges and decorative emblems, but their most important use in the car industry is for light lenses, sidelight, rearlight, brake light, and foglight covers and here they have competition from other plastics such as SAN and polycarbonate which have similar optical and weather resistant as well as oil- and petrol resistant properties, but which differ slightly in cost and mechanical properties.

The 1976 VW AUDI features nylon, ABS and polycarbonate in a variety of other applications such as air extractor louvres and grilles; rear lighting housings (with PVC gaskets) ; door handles; covers, bases and internal contact plates for the central electrical system.

Centre consoles in ABS have been in use since 1959. In that year metallised plastic exterior trim became a familiar sight and wheel trim components from ABS and polycarbonate.

As regards safety, one of the most remarkably spectacular, yet basically simple device was invented by Theodore Patacell in 1974: Two semi-circular elements (injection moulded from HDPE) are clamped round the well of the wheel rim, a roller is slipped inside and the two halves are bolted together. This device can prevent catastrophe after a tyre blowout at 60 m.p.h. since the roller slides onto the wheel and synchronises with the ruptured and deflated tyre which is thus prevented from collapsing. The car can then be driven for miles to the next garage or service station.

Little need be said about the importance of seat belts in car safety, but it should not be overlooked that nylon fibre is used for the webbed belting and that buckles and release mechanisms of moulded polyacetal is replacing the heavy and inelegant metal buckle.

Blow moulding as an economical method of manufacture has already been mentioned in connection with a number of components. The list can be further enlarged by inclusion of a variety of others such as: Windscreen washer reservoirs, glove boxes and lids, air extractor ducting, children's safety seats, spoilers, demister ducts, sill finishers and rear lamp covers.

Much thought has been given to the design of door cladding which can suitably replace the current steel configuration. General Electric have suggested their "Lexan" as an outer skin with an inner reinforcement of aluminium. The glass is made to adhere rigidly to the skin by means of, say, a silicone sealant in order to enhance the overall stiffness. Such a door would be much lighter in weight than the current steel door, but it has a slightly greater degree of torsional and flexural movement.

Mudguards for trucks in glass reinforced PU by reaction moulding are claimed to afford substantial economies compared to GRP, especially as regards material waste, finishing costs, and labour (1977). Other developments with PU include wheel arch extensions which are reaction-moulded with an integral skin, as seen, for example, in the VW Golf GTI of 1981.

Summary:

The automotive industry is the creation of the 20th century. It has had to rely largely on a modern steel and alloys industry for its basic structural components and is likely to continue to do so, although there are notable developments taking place which may lead to the replacement of steel in major load bearing structures, following the by now well established use of GRP and sandwich structures for certain types of car bodies, lorry cabs and recreational vehicles.

The industry is always on the lookout for materials which enable the designer to effect weight savings and the fuel economies which with this. This approach not only affects styling, but also certain components of the engine, transmission, fuel supply, lubrication and electrical systems, as well as the more obvious components associated with furnishing, interior trim, general passenger comfort and safety. A variety of engineering plastics other plastics are involved as well as the plethora of processes characteristic for the shaping of plastics materials, some of which have had to be specially adapted to meet the specific and often very demanding requirements of the car maker.

As in other fields, it is clear that the combination of new material and new technologies mutually catalyse each other's progress. When the resulting advances are applied to old problems and to new concepts they can open up an entirely new vision of material life for modern man

Introduction

Man has been "messing around in boats" since the dawn of prehistory. Why? There are many answers to this question - some simple, some more complex.

It is an innate characteristic of man to rebel against the limitations imposed by his environment. He feels irked and challenged by the physical barriers by which nature would restrict his dominion to the dry land. Lacking fins he will nevertheless want to swim faster than a fish; lacking wings he will nevertheless want to fly higher than a bird; and if no living creature has ever been known to go to the moon and to explore space and time he will nevertheless attempt to do just these things. It can thus be argued that the first reason why man should wish to make himself master over the waters is his psychological need to prove to himself that ingenuity and perseverance can succeed against the odds of apparent physical disadvantage. The simple answer to "why?" therefore is engrained in the Lucifer in man, his quest for knowledge, his thirst for adventure and his shear cussedness. This is epitomised in the answer given by Hunt and Hillary when asked "why climb Everest?": "Because it is there!"

Having discovered that the navigation of rivers, lakes and oceans <u>could</u> be accomplished - albeit initially at considerable risk - other human traits asserted themselves to command that this activity <u>should and must</u> be pursued with the utmost vigour:

i greed - the desire to acquire new territories, if necessary by conquest;

ii the urge for security - the need to escape from demographic, social, political or economic pressures in the old homeland;

iii the exercise of power - the desire to dominate the main water ways and sea lanes in order to control the flow of wealth and resources and to deny a share of these to a potential rival.

iv the attainment of affluence by trade and the establishment of regular communications;

v altruisim laced with self-interest - the desire that the free interchange of material and spiritual resources should lead to the elimination of proverty and the promotion of universal felicity.

Let us now consider what made it possible that man should succeed in taking to the water. As usual, success in reaching new and ambitous goals involves the catalytic association of the creation of new materials on the one hand and the development of the appropriate technology to exploit their potential to the full.

River craft, rowing boats and small sailing craft were initially largely confined to the close proximity of the land for obvious reasons of safety. Such craft included hollowed-out tree trunks, coracles, kayaks and craft made from balsa wood, papyrus and planks of timber. The pitch-caulked sailing ships and long boats of the Vikings and other redoubtable mariners and raiders did, however, venture far out to sea. The naval achitecture of the Phoenicians and the Graeco - Roman world and its successors (the Turks, Venetians, Geuoese, Florentines, Spaniards, Portuguese, French, Dutch and English) was impressive in its power and majesty. Their merchant vessels were providing effective transportation of spices, silks and other highly prized Eastern commodities. But, being powered by gallery slaves as an alternative to sails, they were poorly manoeuvrable and rather clumsily inefficient. The advanced design of sailing ships, reaching its pinacle in the fast clippers of the early 19th century and the subsequent invention of steam and nuclear powered engines, however, demanded a complete rethinking in the methods of naval architecture and the materials this required. Steel became a structural material and the 20th century saw the rise of plastics. The latter had a large bearing on the design of all manner of craft.

The principal advantage of plastics for use in marine construction are:-

i Weight saving;

ii A high strength-to-weight ratio;

iii Low waste in component manufacture;

iv A high degree of design freedom and scope for creating integral situations;

v Freedom from corrosion

vi Reduction in service and maintenance costs;

vii A high potential for fuel economy;

viii Water resistance;

ix The elimination of painting and primitive methods of caulking.

The choice of plastics materials for ship construction is largely confined to reinforced plastics such as glass reinforced polyesters (GRP). The same material is also the most important for smaller vessels such as boats, cabin cruisers, sporting and recreational craft, but there do exist alternatives which will be mentioned in the following.

There are, however, many other ways in which plastics have enabled man to master the navigation of rivers, lakes and oceans and to make them the backdrop of his activities - his traffic lanes, his hunting grounds, his scene of struggle, his working place and his playground.

In order to analyse this further the following categorisation of the marine use of plastics is proposed:

6.1 Rowing boats and their accessories; dinghies, small powered craft and cabin cruisers; sailing dinghies and sailing yachts; sailing accessories; surfing, windsurfing and waterskiing equipment.

6.2 Shipbuilding

6.3 Hovercraft

6.4 Typically marine equipment and fittings for ships

6.5 "Hotel uses" and fittings for passenger liners

6.6 Fishing and angling equipment, lobster pots, fishermen's apparel, wet suits and diving gear

6.7 Buoyancy and lifesaving equipment

6.1 Rowing boats and their accessories, dinghies, small powered craft and cabin cruisers; sailing dinghies and sailing yachts; sailing accessories; surfing, windsurfing and water skiing equipment

To make a glass fibre boat of 30 ft length or more one needs a female mould with a parting layer (eg, of polyvinyl alcohol) on which a gel coat is sprayed, followed by a layer of glass scrim and resin and successive layers of 2 ounce glass mat impregnated with resin until the structure is thick enough. Each layer of resin and glass weighs about 4 lbs/sq. yard and is about 1/16 inch thick. The required total thickness depends on the length of the boat. To make a boat which conforms to Lloyd's requirements one layer is required for every 10 ft of length plus one for the residual fractional footage. The layup is cured without heat or pressure being applied. The hull is stiffed with bulkheads made of marine plywood or GRP. These are secured while the hull is still in the mould.

The advantages of such a construction over the conventional timber structure are:-

i It is not attacked by dry rot, wet rot or marine borers such as shipworm and needs no painting or sheathing;

ii The hull is homogeneous, there are no potentially leaky seams and the material does not sweat;

iii Underwater fastenings are unnecessary. The engine can be mounted by building the fuel tanks in such a way that they can serve as engine bearers and this also minimises vibration; alternatively, it can be mounted on 1-inch ply girders which are secured like the bulkheads. Such a mounting can take a thrust of 6 tons per ft run.

iv The hull is more durable - it does not deteriorate over the years;

v Repairs are easier: A 2 ft hole can be restored in 24 hours by semi-skilled labour - about one-tenth the time required by a craftsman for repairing a similarly damaged wooden boat;

vi Although barnacles and algae will adhere to the surface, these are cleaned off much more easily;

vii The hull does not absorb water on launching and hulls of 30 ft or more weigh less than a corresponding wooden boat. A 56 ft round bilge hull built to Lloyd's requirements weighs 5,000 lbs nett, including frames while the timber equivalent would weigh twice as much;

viii Design features such as double curvatures can be uncorporated which are impossible in timber boats

ix Cost advantages: To cover mould amortisation six 30 ft boats must be made to break even on wooden hull construction. With larger boats the number is even less: two for boats 50-60 ft long, and even longer ones make it economical (compared to wooden hull construction) to make a mould even for just <u>one</u> moulding. The cost of raw materials for a GRP hull 56 ft long is less than that of the timber costs of a wooden hull, to which latter one would also have to add the cost of paint and fastenings.

In order to maintain consistent and optimum quality it is essential to carry out the wet layup in carefully temperature and humidity controlled conditions and to make regular and rigorous control checks on the materials.

The success of boat building in GRP is illustrated by the following evidence:

The 11th International Boat Show at Earls Court, London in 1964 showed that 30.5% of craft on show were built from this material, while in 1965 the figure rose to 39.1% using improved lamination techniques and resins. This included motor cruisers and a few smaller runabouts, a prototype mini-hovercraft and sectional boats which could be stacked on a car roof. By 1972 plastics had virtually obtained a monopoly position over wood, especially for power boat racers. The use of isophthalic polyester resin reinforced with polyaramid fibre has made it possible to build a flat-water amateur racing canoe for the marine market which halved the weight of the boat to 33 lbs (Sawyer Canoe Company - Champion IV, 1979)

Araldite epoxy resins have been used both for mould construction and for hulls and this included catamarans and trimarans. A 34 ft working catamaran was built by Prout Marine of Canvey Island to Lloyd's specification from GRP in 1971, while an 85 ft GRP hull of a motor yacht was completed by Halmatic of Havant in only 12 weeks (1972). It had wood decks, an aluminium superstructure and twin Rolls-Royce diesel engines going at a speed of 12-15 knots.

A sea truck - a light working craft with a hull of heavy duty GRP - has been developed by Rotork Marine of Bath (1971). It rides on a cushion of foam and is intended for use as a fast fire boat. It is made in a single moulding and is protected in vulnerable areas to form a "starframe backbone". This backbone (or chassis) incorporates a 12 inch deep wedge section of GRP around a polyurethane foam core which fills the frame cavities and provides the main loadbearing hull/deck platform, giving diagonal and torsional rigity as well as longitudinal and lateral strength. The bottom is of double thickness extra heavy duty GRP with five reinforced rubber strips to withstand constant beaching on rough ground. The deck is composed of point load resistant GRP, integrating the hull chassis and forming the sealed platform. Fine chippings are incorporated in the final GRP layings giving a hard non-slip surface. Tests on the Thames showed that the craft is capable of speeds 3 to 4 times as fast as present London Fire Brigade fireboats due to the "air lubricated" hull principle. Air is rammed under the square prow and trapped by the side skegs as the craft moves forward. The air mixes with the water and at speeds exceeding 10 mph creates a cushion of foam on which the main load-bearing section of the craft rides. It will ride comfortably at full speed over waves 3 ft high. In rougher waters the speed has to be reduced but the ride remains fairly smooth. The polyurethane foam filling of the hull makes it unsinkakable. It can carry 4,000 lbs of load, and up to 7,000 lbs in an emergency so that it has no difficulty in carrying two Coventry-Climax-powered pumps capable of pumping 2,000 gallons per minute of river water to riverside fires. Cabin structures include a small wheelhouse and a fully enclosed craft. These sea trucks are operating in many European and overseas countries.

Important though GRP structures are, they are by no means the only ones. Thermoplastics have also entered the market. Crude flat bottomed chine craft consisting essentially of four pieces of rigid PVC sheet welded together have been used in shallow pools of amusement parks and fairgrounds. Thick walled rowing boats sinter-moulded by the Engel process from black polyethylene have been used as getabouts in the fjords of Norway.

Polypropylene has been used for the moulding of hulls for sailing dinghies. Two large injection mouldings (made in 7 minutes) are welded together and fitted out to completion in another 3 hours. Apart from the mast and boom and some smaller fittings each of these "Toppers" (made by Rolinx assembled by Liskeard Engineering and marketed by Dunhill Boats of

Basingstoke) is built entirely from plastics materials. The cordage is made from nylon, polypropylene and/or polyester fibre and the sail is made from polyester fibre. The polypropylene marine structure is claimed to have the following advantages of a GRP for this small dinghy: It is more robust in that it can fall from a car roof without suffering serious damage and is said to be better able to withstand the inevitable knocks sustained during sailing; being self-coloured it requires no painting or finishing; it is lighter and more consistent in weight from boat to boat; safety is improved since polypropylene floats, so that it cannot become waterlogged. The centre board and rudder blade are injection moulded in a coupled-glass-reinforced grade of polypropylene structural foam and are more efficient than the structures which they supersede; moreover they need no finishing. The mast, boom and tiller extension are made from aluminium, but virtually everything else is made from plastics, including the mast step cup, boom gooseneck, eyes and cleats which are made from nylon.

Power boats have also been made from thermoformed CAB sheet in the USA.

For the enthusiast who can't afford a whole rowboat (or for a pair of incompatible shipwreck survivors in a single lifeboat), half a boat is better than none (or one) - provided that each half has a pair of oars and is made by sandwich construction of two skins of vacuum formed ABS and a filling of closed-cell polyurethane foam. More seriously however, the largest of these boats is just over 12 ft long, will take an outboard motor of up to 35 hp and seat four. Smaller boats (down to about 7½ ft length) can be adapted as sailing dinghies.

Oars and canoe paddles have been made in plastics. An outstanding example of design excellence is a high performance canoe paddle (Otter Sports of Northampton, 1973) with an ABS blade and a PVC-coated aluminium shaft filled with expanded polystyrene for buoyancy. The blade is the first with a curved profile to be made by injection moulding in ABS.

The West German four-man sailing team which won a gold medal in the 1972 Olympics used a carbon and glass fibre reinforcement tape to strengthen their oars and those areas of the boat which are subjected to high loads. This produced a weight saving of 15% over the conventionally built craft.

Inflatables have become popular. Initially these were considered to be little more than toys, but they have since been developed into quite sophisticated craft, equipped with outboard motors and/or sails and made very safe as a result of improved puncture resistance and compartmentalisation. A high-speed inflatable has been developed by designer David Still which has proved its superb handling qualities in the rough waters of the Solent.

The $1\frac{1}{2}$ ton craft has an inflatable seat and flotation collar, a beam of $10\frac{1}{4}$ ft, a length of $29\frac{1}{2}$ ft and is the largest craft that had been built up to 1977. It is also the first craft to be diesel powered turbo-charged 4-cylinder Ford engine developing 150 bhp at 2500 rpm; power is transmitted by a Dowty hydrojet without endangering people to exposed propellers or being liable to damage in shallow waters, so that it is eminently well suited to a multi-purpose role of crash-rescue-personnel-cargo carrier. It can carry 30 seamen without loss of handling or stability.

Surfboarding and windsurfing have become sporting pastimes. The equipment is invariably based upon a rigid foam core sandwich structure. Its construction is so simple and obvious as to make a description the choice of skin and core materials superfluous. One might add, however, that windsurfing on skates, roller skates or wheel-based chassis is also possible, so that an essentially water-based fun activity can conceivably be transplanted to sandy shores and stretches of suitable windy flatland.

Water skis have been moulded in GRP. They are popular with both beginners and experts. They have a large planing area which helps novices and a high gloss finish and thin edges which give the expert increased speed and greater dimensional stability with fast turns. The skis are hollow and float and their construction is strong and durable.

6.2 Shipbuilding

This is largely an extension of the experience gained with GRP in smaller craft.

One of the earliest developments was the scaling up of boat building from the 80 ft limit (imposed by initial strength considerations) to 200 ft and displacements of up to 900 tons. This was achieved by a design of the Bristol Aeroplane Plastics Ltd reported in 1966 and exploited in cooperation with the Vosper Thorneycroft group based on a sandwich construction with GRP skins.

The mould is constructed of sheet steel and is in 3 parts: The mould and the side panels are fixed to the floor of the building shed; the hull mould slides on runners and forms the launching trolley for the finished vessel; the stern mould is also moveable and is taken out of the building before launch.

The hull mould is assembled, the interior surfaces are cleaned and a polyvinyl alcohol release film is laid on. Instead of the usual gel coat the hulls are skinned with a special resin reinforced with fine strand mat with a base layer of glass tissue. The hull is then built up using automatic dispensing and impregnating equipment mounted on a gantry which runs the length of the shop. The woven glass mat is run through a roller and trough unit where it is thoroughly impregnated with resin. It is laid on the surface of the outer skinning by hand rolling, the operatives standing on platforms slung under the gantry. As the cloth is laid on so the dispenser unit traverses the width of the hull. The cellular filling is next applied, followed by the inner skin (in the same way as the outer). Flat panels for bulkheads and decking are similarly built on flat moulds. The hull and ribs are hand-built on shaped moulds and are then fitted into the hull, as are the bulkheads and decking.

When the hull is completed the stern mould is run away and the side panels of the midship section (hinged at the keel level) are swung downwards. Launching is done stern first, using the hull mould as a launching trolley.

The moulds are then reassembled ready for construction of the next hull.

Early prototype work led to the construction of the 53 ft long HMS Wilton, a GRP - hulled minehunter which proved that GRP construction could offer upkeep savings of 2[illegible]% or more. The idea of sandwich construction, however, was later abandoned in favour of a single-skin GRP laminate made up of isophthalic polyester resin and 800 g/in^2 woven rovings.

The work eventually culminated in the commissioning in 1978 of HMS Brecon. Although of modest length (60 ft) it is the first of nine vessels of the Royal Navy's new Hunt class which incorporates many new features, not least of which is its economy in first and maintained cost and its mineproofness due to its non-magnetic properties, with corrosion resistance thrown in for good measure.

The fire performance of samples showed an initial flash-over as the outer resin skin burns off and becomes virtually self-extinguishing when the first layer of glass fabric is exposed.

In the meantime GRP had also begun to be used for the construction of fishing vessels. According to Hallett and Simpson (Plastics & Polymers 36 (121) of February 1968) initial costs are higher than for wood by about 12% and higher than for steel by about 3% up to 83ft lengths, but this is more than compensated for by savings in maintenance and payload capacity.

According to the authors GRP solid laminate compares favourably with sandwich construction economically as well as technically, especially with respect to impact strength, with no significant sacrifice in corrosion resistance and thermal insulation. Experience in South Africa has led from modest beginnings to a point where orthodox ship construction methods have been replaced by new techniques for integrating frames, decks and bulkheads as already shown before. The personnel of the shipyards consists of ⅔ trained laminators and ⅓ shipwrights, carpenters and engineers. Comprehensive quality control is necessary.

The work has resulted in the production of 83 ft single-screw pilchard catchers and in various designs of 146 ft ships (naval as well as fishing) as well as a 200 ft cargo ship. Much of the pilchard is reduced to fish meal. Steel holds are highly susceptible to corrosion by liquids and gases and require complete rebuilding within 18 months. Wood may last for 2-3 years. GRP holds have shown no sign of deterioration after 4 year's service.

About 30% of the total construction costs are for the GRP (taking steel as a base); other constructional materials compare as follows (1968 prices):

Steel	100
Oak	150
GRP	300
Aluminium	350
Teak	600

The ratio of direct labour to materials costs in GRP ships was stated to be about 1:3 and this was expected to reduce to something like 1;5 eventually.

As for shipyard investment, the ancillary services for GRP are cheaper, the handling of structures is easier and the proportion of highly skilled labour required is less. The moulds are expensive (£30,000 to 40,000 for a complete set of permanent moulds at 1968 prices), but these will, with care, produce up to about 100 ships.

6.3 Hovercraft

Small hovercraft have already been mentioned, but large size commercial hovercraft have become standard seaferry vehicles and their development owes a great deal to plastics. In this connection one must refer to rigid light weight PVC foams which have provided the core material not only for special aircraft sandwich structures for light weight and considerable strength but also for racing vessels. The initial impact which this type of sandwich structure made in wartime applications was in 1966 when Derek Kelsall used it on his boat "Toria", the 42 ft sloop-rigged trimaran which won the 2,000 mile Round-Britain race. This was followed by the 57 ft "Sir Thomas Lipton" which won the 1968 Transatlantic Single-Handed race by so wide a margin that its skipper Geoffrey Williams was ready to return home before any of his rivals had even reached Rhode Island.

It was next used in a 5-berth twin-hulled power boat, the Jaguar 27 skippered by Terence Compton which competed in the Round-Britain Power Boat Race during the following year.

The PVC foam core sandwich construction with GRP skins was then adopted for the "Hovermarine 2" 60-seater sidewall hovercraft which was described in detail by A. Marchant (Reinforced Plastics, December 1968). Unfortunately this pioneering company had to go out of business dispite the excellence of its design and engineering achievements because of undercapitalisation, but hovercraft have since become a familiar sight on the car ferry routes linking Britain with the continent, less than 20 years after Sir Christopher Cockerell first demonstrated the basic principles of the air cushion system(which was not even restricted to water but which could also perform equally effectively on flat land and potentially on sails).

The major reason for selecting GRP for the stressed-skin structure in preference to aluminium was based on a comparison of production costs, riveting of aluminium being twice to seven times as expensive as the manufacture of a GRP structure by wet lay up. On the other hand, GRP has lower stiffness in shear and compression, so that more material has to be used - but the savings are still considerable. GRP requires no anticorrosion measures, shows no serious environmental effects (a small loss in strength due to immersion may be discounted) and little, if any maintenance is required on the structure during the life of the craft.

The cabin floor is a sandwich panel of aluminium alloy honeycomb faced with GRP skins of epoxy resin and woven cloth reinforcement because of the need for high shear, compression and tensile strength as well as good stiffness. It is bonded to the vertical frames of GRP-faced PVC foam sandwich panels which also provide further compartmentalisation of the buoyancy area. The frames are bonded to the bottom skin which is further reinforced by a stiffener formed in GRP over a polyurethane foam core.

The use of GRP is thus justified for the primary and secondary structure and it is only left to the design engineer to adapt the materials to his needs. The structural design and manufacture are discussed in some detail (loc. cit.) but we need not go into such detail here. Suffice it to say that when the hull structure is ready it is fitted out and this involves further plastics applications:

Thus, plastics are used for the cooling water system. The main components are intake scoops (GRP) moulded into the side of the craft below water level. These carry the water through filters and 1½ - 2 inch ABS pipes to points where it is used for cooling the engine and for lubricating the propulsion shafting which runs in rubber bearings. The use of ABS piping has been so well documented in building and other applications as to require no further justification here, but the light weight and non-corrodability compared to metal alternatives assume special significance here as well as in the bilge pipe system of the craft.

As for the seats, upholstery and internal trim, these are "hotel applications" to which we will return in Section 6.5.

The window panes of all the windows except the wheelhouse forward windscreen (which is manufactured from toughened glass) are made from acrylic or polycarbonate sheet which is 2½ times lighter than glass and also more economic, particularly where a curved window is required.

Perhaps the most important area of any hovercraft is the flexible skirt. It is attached round the entire structure for peripheral type craft and at the fore and aft ends for side wall type craft. It contains the pressurised air for the cushion when inflated by the fan system. Any obstacle passes through the skirt by deflection, whereupon the air pressure immediately forces the skirt back so that the pressure is maintained. So far the best material for the skirt has proved to be neoprene rubber reinforced with woven fabrics from high-strength man made fibres - principally nylon. The material must withstand constant deflection and correction of the skirt as well as manoeuvring "off-cushion" against water pressures. Attachment is by polyester fibre ropes in conjunction with moulded nylon and metal components on the main structure. There is still much scope for improvement in performance through material and design advances*.

The fan runs at 2900 rpm and provides the cushion pressure. It is an all-GRP construction, comprising fan blades built from GRP-skinned expanded PVC which is bonded into the back and shroud plate. On the plate of polyester/woven roving laminate a layer of continuous glass filament " roving" is added to provide the strength necessary to withstand the centrifugal and hoop stresses. Some tendency to corrosion on the leading edges can be reduced by the addition of a capping strip of polyurethane rubber sheet.

As for the future:-

1 The search for better skirt materials and designs must continue since the main reasons for failing of seals on cross-channel ferries have been identified as tearing and break down of rubber-to-fabric adhesion by severe flexing under wet conditions.

2 The use of new reinforcing fibres such as polyamide, boron or carbon fibre would certainly produce even greater strength, especially in conjunction with epoxy resins, but it remains to be seen whether the considerable increase in cost can be justified (possibly by enabling a substantial sealing up of the craft).

6.4 Typically marine equipment and fittings for ships

These may include components found in other applications as well but which fulfil a specific function in ships which is not quite paralleled elsewhere. Some examples of these are as follows:-

* Reference: E.R. Gardner (Avon Processed Polymers Ltd): "Hovercraft and their skirts" (Foundation Lecture of the Plastics & Rubber Institute, Brighton 1977)

Ballast suction pipes

These are pipes of fairly large diameter and are used for flooding and emptying ballast tanks. They may be immersed in sea water for long periods and iron pipes corrode badly under such conditions. Polyethylane pipes are adequate except where a section may pass through tanks filled with oil, in which case a section of iron piping may be needed and this presents jointing problems. Polyacetal may be a more suitable all-round material, but glass reinforced epoxy resin pipes have been found most suitable, despite their substantially higher cost, since this material permits the pipes to operate at higher working pressures. Pipes of up to 20 inch diameter can sustain a pressure of 25 psi at a fast flow rate and show negligible wear when the water is heavily laden with sand, as may be the case in some estuarine waters. They are therefore used for the rapid flooding and emptying of ballast tanks in Admiralty vessels. A major problem is the avoidance of damage to the pipe by welding sparks. This has been solved by applying a metallic paint for protecting the pipe during ship construction and stripping the paint off thereafter. The smooth bore of plastic pipes makes pumping more efficient and gives one the option of using a pump of lower power than the one which would have been needed in conjunction with conventional piping materials.

Air vent pipes

These are small bore pipes running vertically from double bottomed tanks to the weather deck. They may be either polyethylene or UPVC.

Sounding pipes

These are made from UPVC or ABS and serve to check the water level in tanks.

Washdown pipes for warships for radioactive decontamination

These can be made from UPVC, but glass reinforced epoxy resin pipes have also been installed for this purpose by the US Navy.

Shock absorbing Butyl rubber fenders

These assist in berthing giant tankers without damage and come in a number of cylindical lengths, with spigots and tapered end pieces held in position by a chain fitment.

Various application of foamed plastics

Polyurethane and Polystyrene foam sandwich structures in combination with epoxy resin or neoprene skins give excellent thermal insulation and prevent condensation on the deckhead below where glass wool (previously widely used in ships) has proved ineffective. This applies particularly to locations with steamy atmospheres such as galleys and gangways.

Steel rudders are hollow structures in which corrosion may allow water to penetrate to the inside and cause more rapid damage than would appear visually from the outside, as well as causing a serious loss of manoeuvrability. This is prevented by the injection of polyurethane foam into the cavity.

Stabilisers are also appropriately filled with polyurethane foam, mainly in order to largely damp out vibration.

These applications are found in the "Canberra" and in the "British Mariner".

Polyurethane and polystyrene foams have been used extensively for the insulation of refrigerated holds. The advantages of in-situ foaming are obvious, but the cost is greater than that of the conventional glass wool. Nevertheless, shipbuilders favour the plastic foams because of their tidyness and reliability. More recently rigid PVC structural foam has been introduced for thermal insulation under extreme low temperature conditions where the material still retains excellent resilience and mechanical properties; thus, the tanker "Methane Progress" which was used to transport liquid methane from North Africa to the UK used a UPVC foam of $3\frac{3}{4}$ lb/cu ft density, for sheathing under deck and for insulating the tanks at a temperature of -170°C.

Other examples of the widespread use of foams (notably rigid polyurethane foam) are found in the motor ship "Ioric" which has about 24 tons of foam in it and the "Oriana" with over 50 tons of foam, a large proportion of which is used for composite light weight structures including bulkheads, partitions and doors, but this application belongs perhaps to the category "hotel applications". (see Section 6.5)

Rudder and stern tube bearings

Fabric laminates bonded with phenolic resin has been widely used for this purpose. It replaces the scarce and expensive conventional lignum vitae, an extremely dense but rare timber material now under preservation in the Amazon rain forests. The phenolic laminate has a high compression strength, long wear and good dimensional stability and its use has been established since about 1950.

Ventilators

Cowl and mushroom type ventilators in GRP with UPVC trunking have been approved by Lloyd's and the Ministry of Transport.

Navigational aids

Without going into detail on sophisticated instruments many of which (notably Radar and Sonar equipment) contain plastics components one should mention a variety of components which involve the use of acrylics and polycarbonate such as spray and wind deflectors and optical equipment especially of the kind used for lenses, navigation lights, telegraph covers and other signalling devices.

Lifeboats

These are, of course, just small craft which have been discussed in great detail earlier on. However, they are properly included again here because they are essential items which every ship must carry as part of its equipment. The first recorded instance of the replacement of traditional timber based lifeboats by GRP lifeboats was the installation of 20 lifeboats on the "Oriana" in 1958. Since then GRP has become standard, the principal advantage being the reduced cost of maintenance and freedom from decay.

Lifeboats for use on oil tankers are, however, designed altogether differently. They are made from steel and are covered by a PF resin bonded layer of asbestos, so that they can safely convey the crew through a sea of burning oil.

These boats must withstand a temperature of 1,000°C for 5 minutes and thereafter remain structurally intact. Protection against heat and fumes is afforded by a closely fitting steel canopy coated with the heat absorbing resinated asbestos layer which is further lined with drapes of asbestos cloth. Although the resin will burn off in the intense heat, this itself will absorb energy ("lifesaving ablation", similar to the concept used in space re-entry rocket nosecones). or else the resin will contribute to the overall thermal protection as a carbonised layer.

6.5 "Hotel uses" and fittings for passenger liners.

The term "hotel uses" implies that the application of plastics in this context is of a "building" nature and that the ship is seen essentially as a floating establishment catering for the accommodation of passengers under conditions of varying degrees of luxury.

The increasing tonnage of plastics used in ships is largely accounted for under this heading and it is therefore appropriate to analyse these uses further despite the apparent duplication of what has already been dealt with in the essay on plastics in building.

There are some striking differences when considering the attitudes of the building industry and shipbuilders. The former has long been characterised by an ultra-conservative stance to innovation in the choice of materials and methods of construction; although this ossified attitude has now largely given way to more enlightened thinking it has been a hard struggle to overcome the prejudice against "new-fangled" ideas which were enshrined in often unnecessarily restrictive building regulations and codes of practice. Naturally, safety (especially as regards structured soundness and fire hazards) must always be a first concern and this applies to shipbuilding no less than to building on land. But shipbuilders' attitudes have always tended to be sympathetic to innovation where this held out the propects of weight saving, with the consequent advantages of higher payloads, lower fuel costs, higher speeds and thus faster turnover rates, as well as technical advantages such as noncorrodability and scope for reduction in painting and other maintenance costs. Moreover, the shipbuilder tends to work on commission to the specifications of the eventual owner who is very conscious of maintenance cost, while the builder of houses (especially the estate developer who caters for the speculative market) is more concerned with cutting first costs than with maintenance costs which will not involve him once the house has been sold.

Some typical examples of this are given below:-

Decorative laminates

Two most impressive examples here are (i) the fitting out of the 8,000 ton cargo liner "Centaur" in which some 100,000 sq ft of decorative melamine laminate has been used for the bulkhead surfaces and cabin walls, ceilings and shower compartments, as well as for furniture and (ii) 130,000 sq ft of the same material in the Union Castle vessel "Reina del Mar".

Foam sandwich structures

These have already been discussed in section 6.4 where thermal insulation is involved, but here this is extended further to partitions and doors where the main aim is weight saving whilst maintaining high regidity.

Services

Water and waste-water piping and electrical conduit and insulation have been accepted in building, but even more widely so in ships, including, in some cases, for hot water pipes. The same is true for sanitary fittings such as baths, sinks, washbasins and toilet fittings, including lavatory seats and bowls, as well as for cisterns and tanks and a wide variety of devices for lighting and illumination.

The ICI publication "Plastics Today" No. 34 (February 1970) reviews the use of plastics in the Cunard liner "Queen Elizabeth 2", a ship designed to perform a 5-day Atlantic schedule and to be capable of passing through the Panama Canal whilst offering resort facilities of the highest class for cruises to most of the world's major ports. This made it essential to reduce weight and save space whenever possible. The most widely used plastics are PVC and GRP, but acrylics, nylon, polyolefines and fluoropolymers are encountered in many places and virtually every common plastic is found somewhere in the ship. Specially designed components include acrylic rooflights, decorative screens, stairway balustrades in GRP (capped with PVC) deckhead louvres, coverings (including carpeting), furniture and upholstery materials and PVC stern shaft seals.

To convey an idea of the scale of these applications the following figures may be pondered over:-

Vinyl flooring	5,000 sq yd
Chairs upholstered with vinyl cloth	10,000

Wiring clips (Nylon and PVC)	500,000
Restaurant chairs upholstered with vinyl cloth and gliding on pads which incorporate fluorine polymers	1,300
Acrylic baths	300
standard acrylic cabin lighting fittings	1,300
Injection moulded chairs (polypropylene)	900
PVC electrical conduit	61 miles
PVC skirting extrusions	30 miles
Acrylic lighting diffusers (extrusions)	1 mile

6.6 Fishing and angling equipment, lobster pots, fishermen's apparel, wet suits and diving gear.

With the advent of man-made fibres and monofilament it was obvious that rope, netting and cordage for fisheries purposes would be made from these materials in preference to the traditional natural fibres which are weaker and therefore much more easily damaged. Moreover the latter tend to rot and are much more difficult to maintain in serviceable condition.

Angling equipment encompasses a large variety of items. The most obvious are angling rods which are made from polyester or epoxy resins by filament winding of glass or carbon fibre reinforcement. Although this is not a large tonnage market it is a highly lucrative one, since angling is an enormously popular pastime on which the enthusiast is prepared to spend a great deal of money in search of the rod best suited to his particular individual requirements. The same is true of fishing reels where strength and corrosion resistance are the key properties required. Glass filled nylon is therefore chosen for moulding the spool, end plates and components of the centrifugally operated governors (K P Morritt, Ltd).

The reel only requires a minimum of lubrication. The exceptionally high strength/weight ratio gives a very strong reel with quick and low-inertia starting and fast free running. The hard durable gloss finish of the nylon is particularly important for the end plates because it ensures that there is no risk of their chipping or cracking. The line itself is almost invariably nylon monofilament.

Aucillary equipment for anglers include catch-storing nets for fish and all manner of artifical fly for which various plastics of diverse colours and moulded shapes are available.

Turning to <u>fish farming</u> rather than fish <u>hunting</u> an interesting development is worth mentioning which was first reported in VDI Nachrichten of March 9, 1979:

> On an area of 320 m^2 36 bath-shaped containers have been erected which hang on a steel framework in three tiers. The containers are of woven polyester (coated with plasticised PVC) which are welded together as flexible hanging tanks by high frequency welding. The total volume of water is 140-150 m^3 and accommodates more than half a million high grade fish, mostly trout. The operation obviously involves careful control of feeding, oxygenation and veterinary hygiene, as well as sophisticated breeding techniques. The top tier holds the young fish (4-8 cm), the centre one intermediate sizes (8-15 cm) and the bottom one the marketable product (up to 30,000 fish with a total of about 7,000 kg).
>
> The advantages of this method of fish farming are: cheapness and simplicity of the basic layout, the absence of sharp covers and edges which could damage the fish and the smooth surface which discourages the lodgment of dirt, bacteria and parasites. The fabric is 0.7 um thick and has a weight of 700 g/m^2. It is exposed to a maximum long term tensile stress of 3 kN/5 cm.

There is no reason why this technique should not be extended to other fish including salt water species.

Lobster traps

While basic economics may be the prime mover in a switch from conventional materials to plastics, the changeover often also lead to a complete redesign of the original product with the result that performance improvements are achieved while costs are lowered. The new high density polyethylene lobster trap introduced in Canada in 1964 is a striking case in point. It has an expected service life of 8-10 years compared to the 3 years for conventional traps and a number of important design advantages besides.

The trap is dome shaped, with a vertical entry for the lobster. This gives enhanced bottom stability and allows lobsters to enter from any direction. The entry is closest to the bait and is made of thin fingers of PE which are resilient and yield to the lobster attempting to enter, but spring back into place and close off the entry. The opening can spread to 9 inches and can therefore trap much larger lobsters than the conventional traps which have 4 inch diameter entry hoops. A small exit port on one side allows undersize lobsters to escape.

The new trap incorporates a quick-release bait container which can hold whole or mashed bait. This allows fishermen to use cheap fish trimmings and other low cost bait and represents a large saving. It also prevents ground feeding fish from poaching the bait.

The igloo-shaped traps come in four sections. The base (which has a mild steel ring which snaps into it), has a tow eye welded on and is coated with epoxy resin to prevent rusting ; the bait box which snaps into the centre of the base; the dome-shaped body which twists onto the base and is held by mating lugs; and a top section with the entry port which is hinged to the body and closes with two latches.

Each port nests separately when transported and the trap can be baited and assembled in seconds. This enables many more traps to be carried in a standard lobster boat than before and 300 to 350 "igloos" can be hauled and positioned in one trip.

The "igloo" weighs 25 lbs, compared to up to 100 lb for the conventional trap. The dome shape and ballast arrangement as well as the slight buoyancy of the polymer ensure that the traps settle on the sea bed in an upright position.

More than 40 million lbs of lobster are landed in an average season, so that this is a most important factor in the economy of the Eastern Seaboard of North America.

There are some 4 million lobster traps set there, 2.4 million of them in Canadian waters. The traps have been developed and are marketed by Markland Works Ltd of Amherst, Nova Scotia.

Fishermen's apparel

The traditional oil cloth gear has now been entirely superseded by capes, trousers and hats and gloves made from PVC which is heavily plasticised with suitable plasticisers so as to ensure long term low temperature flexibility under arctic conditions. The external weather protection is supplemented by electrically heated undergarments which may contain a proportion of man-made (eg, acrylic) fibre in a woollen mixture. Suitably designed rubber boots, Wellingtons or waders complete the outfit of outer garments.

Wet suits

Wet suits are generally made in one piece of skin-fitting rubber with waterproof zips. They are fairly thick and very effective in preventing undue losses in body heat. These are supplemented by integral gloves and paddling fins. Special helmets with acrylic visors also incorporate a number of plastics and rubber components, especially for scuba diving attachments.

Diving Gear

For just-below-the-surface underwater swimming nothing more is required than a rubber-gasketed well fitting and therefore reasonably waterproof acrylic sight piece, rubber fins and a snorkel. Snorkels are primitive breathing devices enabling the swimmer to draw air without surfacing. They are commonly made from polyolefines or PVC.

For scuba diving at moderate depths the diver needs a wet suit (see above) and a supply of air contained in cylinders carried on his back. The cylinders - usually two in number - are carried in a harness with cylinder straps made of acetal copolymer. The buckles on the woven nylon harness are also moulded from acetal copolymer. The cylinders are equipped with non-return valves and regulators, and hand wheels moulded from acetal copolymer (Submarine Products Ltd). The flexible hose and gaskets linking the air supply to the helmet is based on special high quality rubber reinforced by metal wire.

At greater depths special pressure-resistant suits and helmets are required. Deep sea diving equipment incorporates a number of plastics and rubber components, but the consideration of this lies beyond the ambit of this review.

6.7 Buoyancy and lifesaving equipment

Lifeboats have already been discussed under section 6.4. It is, however, appropriate to draw attention to a capsule specially designed for launching from a considerable height from an offshore oil rig in an emergency. This is the Brucker Survival capsule of lenticular shape which is named after its inventor, an American aeronautical engineer (1968).

The capsule is of 14 ft diameter, accommodates 28 people in comfort and 53 in an emergency. It is made in fire-resistant GRP impregnated with a radar-reflective material and has a central steel column for added strength. A sprinkler system wets the outside when oil slick fires are encountered, while the air inside is purified and recirculated. A patented stabiliser and a free-floating ballast system give it a self-righting ability which makes it unsinkable. The hull will withstand an explosive force of 10 tons at 35 ft. The capsule incorporates a self-heating system, radio telephone, toilet and food for 28 people for 5 days. It can be launched from 65 ft in less than 60 seconds with all the occupants on board, but it is designed to be launched from heights of up to 150 ft.

The capsule is entered through two large watertight doors which are closed by a lever control. Passengers fasten themselves by safety seat belts for the launch which can be controlled at a rate of from 1 to 10 ft/sec. The launching mechanism is controlled from inside and no external power or deck assistance is required.

Once in the water the craft's own inboard engine takes over. Less sophisticated (and therefore cheaper) versions are available for cargo and fishing boats and tankers.

At the other end of the scale there are, of course, lifebelts, inflatable jackets and similar devices which traditionally used cork (if not air) as the buoyancy material. Cork has now been replaced by polystyrene closed cell foam.

Other buoyancy uses of plastics include anchored marker buoys for the charting of shipping lanes, regatta routes and harbour and coastal waters. These range from simple coloured hollow rigid plastic spheres, anchored to the bottom, to more sophisticated floating structures emitting light or radio signals.

Finally, there is the "rocker stopper", a device consisting of three cymbal-shaped plastic plates on a rope with a suitable weight at the end which acts as a drogue and can stabilise boats up to 26 feet.

Summary

The marine use of plastics covers a spectrum the width of which is paralleled in no other field of application except building and household durables. It involves locomotion, transport, hunting and farming of fish (and other foods) in freshwater and salt water, it enhances the scope for sporting and recreational activities and makes possible the design of all the many-faceted devices and structures that serve these ends.

The writer is convinced that man's conquest of the seas, though still far from complete, would not have been accomplished to the extent that it has been in the absence of plastics and the associated technologies. If the reader is similarly persuaded this essay will have fulfilled its purpose.

7 Plastics in Household Durables

Introduction

Most of the greatly diverse collection of gadgets which are commonly included under this heading are the characteristic appurtenances of advanced western consumer communities. Few of them have any traditional functional parallels other than primitive tools inefficiently powered by human labour. Most of them fulfil purposes the desirability or the need of which had not occurred to people even a few decades ago and which in earlier ages would have been regarded with the utmost suspicion as the supernatural designs of witchcraft, inspired and abetted by the devil, that "Evil Promoter of Idlenesse which is the Cause of all Corruption of Man's Immortal Soul".* (In some cases people hold to this day - and with some justification - that certain items which we forbear to specify here should be so regarded!).

Household durables include appliances which take the drudgery out of housework and have replaced the batailions of domestic servants of bygone days which were once needed to provide for the ease, comfort, leisure and luxury of the fortunate few who could afford to employ them. The unprecedented spread of affluence in the 20th century greatly reduced the availability of cheap domestic labour. It was brought about by the combination and mutually catalytic effects of progress in materials science, sophisticated design engineering and associated processing technologies, with the result that investment on reliable gadgets was brought within the affordable range of millions who were quick to recognise the advantages of time-saving efficiency, modest running expenses and low maintenance even in the face of the escalating energy costs of recent years.

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* Adaption of a quotation from a 19th century inscription on the gateway arch of a school building in Hertfordshire.

The vast majority of household durables are electrically powered. Some of them are mechanical gadgets for cleaning, food preparation, gardening or craftsman's tools. Others serve for heating, ventilation or refrigeration purposes, while yet other types of products have visual and audial entertainment functions. A few, notably some simple kitchen accessories, fulfil a traditional function by traditional means, but with design improvements made possible by the advent of plastics. Whatever the category to which an individual item may be assigned, the suitability of the material of construction will depend on a favourable combination of mechanical, electrical, thermal and aesthetic properties for mass production, over a reasonably predictable and guaranteed service life, together with a suitability for maintaining close tolerances in mass production and a cost which is acceptable when set against performance expectations. The advent of plastics and the ready availability of aluminium, stainless steel and speciality glasses have led to the elimination of severe design limitations imposed by some traditional materials such as wood, the heat and mechanical susceptibility of old-fashioned types of glass and the obvious disadvantages (weight and corrosion problems, chipping, etc.) associated with cast iron and glazed enamel ware. It is true to say that without components (if not always entire gadgets) made in plastics particular items could not be made at all.

We propose to subdivide the field of household durables in the following manner:

7.1 Simple accessories

7.1.1 Pans and brushes

7.1.2 Buckets and washing up bowls

7.1.3 Basins, mixing bowls, colanders and containers

7.1.4 Small moulded articles (sink tidies, funnels, strainers, sieves, egg slicers, holders for air sweeteners, etc.)

7.1.5 Hand powered mincers, grinders and mixing devices

7.1.6 Scales

7.1.7 Hand powered carpet sweepers

7.1.8 Coated pans

7.2 Electrically operated cleaning equipment

7.2.1 Vacuum cleaners, carpet shampoo machines and floor polishers

7.2.2 Washing machines and spin driers

7.2.3 Dishwashers

7.2.4 Sewing Machines

7.2.5 Electric irons

7.3 Water softeners

7.4 Refrigerators and freezers

7.5 Fans and ventilators

7.6 Electrically operated food processing equipment

7.6.1 Electric mixers, mincers, homogenisers, grinders and juice makers

7.6.2 Tea and coffee makers

7.6.3 Slicers and carving knives

7.7 Gadgets for personal hygiene and comfort

7.7.1 Shavers (cutthroat, safety - and electric)

7.7.2 Hair care equipment (combs, curlers, hair driers)

7.7.3 Toothbrushes (hand or electrically operated)

7.7.4 Massage equipment

7.7.5 Electric blankets

7.8 Audio and visual equipment for entertainment purposes

7.8.1 Wireless

7.8.2 Television and television games

7.8.3 Sound production equipment

7.8.4 Cameras, slide and film projectors

7.9 Telephone equipment

7.10 Gardening equipment and tools

7.10.1 Lawn mowers, cultivators, hedge and edge trimmers

7.10.2 Rolling and spiking equipment

7.10.3 Sprinklers and chemical spray equipment

7.10.4 Compost makers and storage bins

7.10.5 Garden hose

7.10.6 Garden pool accessories (fountains, waterfall)

7.10.7 Moulded ornaments

7.10.8 Trellis and fencing

7.10.9 Wheelbarrows

7.10.10 Hand tools

7.10.11 Craftsman's tools such as power drills

7.11 Miscellaneous items

7.11.1 Typewriters

7.11.2 Watches and clocks

7.11.3 Instruments (thermometers and barometers, hygrometers and anemometers)

It will be noted that furniture is excluded from this list which is already much too long to make it possible to deal with each item in detail within the bounds of an essay. In order to do justice to wireless, TV sound reproduction and video equipment, for example, would arguably require a monograph in its own right.

We will therefore depart from the technique that has characterised the approach used in previous essays and desist from going through this formidable list on an item-by-item basis. This is also hoped to spare the reader the boredom that might arise as a result of repeatedly emerging features common to many applications. The proposed treatment will, instead, be brief and involve a general discussion of plastics in the field, followed by case histories which have been selected with a view to focus attention on particularly interesting design problems from which useful lessons may be learned.

Plastics Materials for Household Durables

A museum of household durables of the 20th Century (if such existed) would mirror the stage-by-stage progress of plastics developments over the same period. One would recognise:-

i the era of first-generation plastics such as PF, UF and cellulosics;

ii the discovery of condensation polymers, notably of the polyesters and the aliphatic polyamides as well as of melamine resins

iii the phenomenal emergence of the vinyl type polymers such as polystyrene, polyethylene, PVC, acrylics and their copolymers;

iv the preoccupation with the production of speciality grades including polyurethanes, expanded plastics, silicone resins, ABS stereospecific polyolefines, fluorocarbons and epoxy resins;

v the evolution of sophisticated engineering plastics such as glass-and carbon-fibre-reinforced plastics; polyimides and polyaramides; and moulding-grade aromatic polyesters.

Using this materials-timescale despite the absence of clear chronologically based dividing lines and the presence of obvious overlaps one would note, under each numerical heading respectively:

i the relatively few new gadgets that appeared early on, with plastics showing up mainly as phenolic mouldings for knobs, temperature resistant handles (saucepans, irons) and as mouldings of phenolic resin-impregnated paper fibre backs (and later the front housings) of radio receivers, cellulose laquer finishes and various largely novelty-type and trivial mouldings made from cellulose acetate;

ii the appearance of hard-wearing decorative surfaces;

iii the emergence of large moulded items such as refrigerator liners (usually thermoformed from sheet) from PS, ABS or PVC; acrylic stoved finishes, melamine worktops on front-loading washing machines and dishwashers, radio and TV housings reaction-moulded in PU or injection moulded in PP;

iv the appearance of food processors, tea and coffee making machines with clear liquid holders made from PS, polycarbonate or acrylics;

v the introduction of high-strength, high-modulus, high-temperature resistant, electrically suitable and highly reliable as well as reproducible moulded products to serve as components fulfilling particular special requirements in machines. Such parts might be:- housings, thermal and electrical insulation materials, impellers, gear wheels, supports for electronic circuitry, low friction non-stick and "self-lubricating" items.

Selected items of gadgets and case histories

Simple kitchen utensils such as buckets, washing-up bowls and sink tidies were first moulded from LDPE. Nowadays PP has completely superseded PE because of its better gloss retention, surface hardness and scratch resistance. A fully integrated range of cleaning, food preparation, tableware and other kitchen items is marketed by various stores under a variety of trademarks. These include virtually all the items listed under 7.1 except coated pans and baking trays which feature non-stick PTFE on an aluminium base.

Casings and housings

The most widely used material here is ABS because of its good impact resistance, high softening point and good surface finish. Thermosets are confined to really high temperature applications. Specifically electrical applications including motor covers.

Morphy Richards "Vanity" hairdryer has an ABS shell. Vacuum cleaners (both of the barrel and upright variety) make extensive use of ABS for the base casing and the part containing the dust-bag. ABS, incidentally, is also used for the brush attachments, while nylon is used for the cooling fans and the internal brush bodies.

The carrying case and base, with detachable extension table is injection moulded for Singer sewing machines in high impact PS. Most housings of hand-held or stand-mounted power operated mixers, food processors, tea and coffee brewing machines, power machine tool motors for hobby or garden use are also injection moulded in ABS, polycarbonate or acetal. One of the first of those was the Kenwood mini-mixer which contains 14 injection moulded components. The dust-pan of hand-operated carpet sweepers is also made from ABS while the body is of medium-impact PS. Hairdryers and electric shavers have ABS or polycarbonate housings but additionally feature other plastics components. The housing of the "Waymaster" kitchen scale, as well as the pan and pinion assembly is moulded in acetal copolymer while the domestic hand-operated "Spong" mincer has a hopper and barrel moulded in unchippable nylon.

The drier of the Hotpoint washing machine consists of a container of PP which is welded to the top cover of the same material.

Impellers

The Kenwood A1212 dishwasher has an impeller which must operate satisfactorily at 100°C and be unaffected by detergents. It is therefore moulded from acetal copolymer which satisfactorily meets the specified performance requirements.

A washing machine with an injection moulded structural-foam-coupled glass-reinforced PP drum had been shown in prototype by Philips at the IDEA exhibition in Birmingham in 1979. The tank weighs 6.3 kg and is thought to be the biggest single-shot moulding in this material. It replaces steel and has a number of advantages: It runs more quietly, has good thermal insulation, is leakproof, non-corrodable, resistant to boiling water and detergents, has the required strength characteristics and is cheaper than a vitreous-enamelled drum.

Hoods for professional hairdryers on stands have been made in a number of plastics and the various designs were discussed in Modern Plastics of December 1964:

i cellulose acetate/propionate hoods give a clear unobstructed view of the surroundings. The inner dome has drilled-in vent holes for heat dissipation;

ii ABS hoods can be given a textured surface for pleasing effects and has a telescopic air stack which fits into the hood when the unit is carried about. The motor-housing is in ABS;

iii Polystyrene hoods, stack and base are injection moulded, vent holes are drilled in. The stack snap-fits into the hood, telescopes and folds in for carrying;

iv PE hoods are blow moulded into a concertina configuration and can be compressed for packing. A pleated spiral serves to circulate the air.

The Hairdryer "Superb" made by Salon (Nelson) Ltd., features nine different plastics, according to "Plastics Today" (ICI Publication):

The rear and visor hoods are made from acrylic sheet. This was chosen for rigidity and strength, good aesthetics and resistance to chemicals used in hairdressing operations. The baffles which fit into the visor hood are injection moulded in acrylic.

Six components are made from PP:

The visor hinge arms
The swivel access panel

The hood fixing knob
The thermostat control box
The thermostat stem connector
The (internal) hood locating collar.

The reasons for this choice of material is the required shock and heat resistance. The thermosets used earlier on tended to break after a while. Moreover, the dimensional accuracy (especially for the hood-locating collar) are important in relation to the markings on the time and heat cycle control knobs and this is very readily achieved with PP.

Nylon 66 is used for four components:

The terminal block and the suppressor clip in the electrical circuit
The hinge mechanism in the visor hood
The clips to hold the baffles within that hood

PF is used for the fan impeller and the motor deck because of the required combination of strength, heat resistance and rigidity. Colour is not important because the components are not seen. In the external thermosetting components, however, colour obviously does matter and the heat control knob and boss handle are therefore moulded in UF which enables one to achieve whites and pastel shades as well as strong or dark colours. Both components contain metal inserts which grip tightly on shafts and these are in turn tightly gripped in the moulding so that a thermoset is preferable to a thermoplastic. The heat control knob should also be readily lacquerable to cover the coloured scale markings and this is possible with the thermosets.

PVC is used for the injection moulded cable sleeves which are standard in hairdryers. It is also used for covering the small caps for the fixing screws which therefore need not be plated.

PE is used for an oil filler cap with a captive closure and CAB (with metallic decoration) is used for trimming the rear hood.

The story of the "Superb" hairdryer is most instructive.

Gear wheels and couplings

These are made in PP (or occasionally in PE) when chemical resistance is needed, while nylon and acetal are used when the mechanical requirements are high (but still low enough not to demand the use of metals).

Watches Acetal resin has been used to produce the outer casing for a range of watches made in France. They are injection moulded. They are claimed to be not subject to stress cracking, are said to be scratch resistant and undeformable.

An even more interesting range of components moulded in acetal copolymer are the minute wheel, escape wheel and anchor, hairspring holders, bearing and movement rings of some Tissot watches. These parts are of pinhead-size order of magnitude and are injection moulded to close tolerances without requiring subsequent finishing operations. Although not many tons of polymer go into this application, it is an interesting one because it illustrates the high precision which can be achieved when moulding polyacetal and because production is simpler and cheaper than with metal parts. Moreover, the polymer components require neither lubrication nor are they subject to undue wear or corrosion. Furthermore, they are antimagnetic.

Telephones

Telephones nowadays come in a variety of shapes and sizes. Their casings, hand and earpieces had been compression mould in PF or UF for many years, but acrylic moulding material, ABS and acetal resins have superseded the thermosets. Acetal is also used in coin-operated kiosk telephones, including 73 items such as: fastening screws, handle, coin insertion plate, coin lead-in, coin checker, coin funnel, visible coin storage, coin switch, coin see-saw bridge, casting tube, refund tube, refund channels, reject channels, coin checker plates, snap lock, relay block and its snap lock, battery and its terminals, impulse unit, credit counter, call bell, insert block, distributor bar, hook switch-over contact, totaliser counter, cash box frame, push-button deblocking for the hook and spring clamps for micro-telephone cable.

The telephones have been installed by the Swiss Post Office in 1966.

Typewriters

For its Linea 88 Typewriter Olivetti chose ABS as the material from which the bodywork is moulded. It is tough, impact resistant and absorbs shocks and vibrations, has excellent dimensional stability and a hand glossy surface. It resists typewriter fluids, typists' cosmetics and scuffing. Marks disappear with light polishing and the colour possibilities are unlimited. The typing letter surfaces are likewise suitably moulded in ABS or polycarbonate and in "golfball" models the golfball is nowadays moulded in an engineering thermoplastic which may be a moulding grade polyester. Portable typewriters almost invariably have carrying cases and/or covers of PP, acetal or polycarbonate.

Summary

The enormous diversity of household durables makes it difficult to present a detailed cover of the wide range of products which come under this heading. A list of classified items is therefore given and the subsequent treatment is confined to a discussion of materials and examples illustrating why the rise of plastics and their associated technology have given us the means of enjoying comforts in the home which earlier generations could not have envisaged as being within the need of the most wealthy, let along the general public.

Introduction

Advances in medicine - which for the purposes of this essay is deemed to include surgery, dentistry, prosthetics and all general aspects of health care as well as extending into the veterinary field - depend on the mutually catalytic effects of the development of suitable materials and the emergence of a technology capable of exploiting those materials. In that respect advances in medicine do not differ from advances in any other field of application. There are, however, two other factors present here. One factor which contributed decisively to the efficiency of both diagnosis and treatment is the introduction of electronic devices, especially for monitoring purposes before, during and after surgery. Electronic devices are a distinctive feature of the present age and are as indispensible in modern medicine as they are in telecommunications and the instrumentation of automated manufacturing processes. The second factor is unique to medicine: it is the tremendous growth in the understanding of the mechanics of natural processes which has come about in what are globally referred to as the "life sciences" and which include such specialised subjects as pharmaceutics and biochemistry, biophysics, embryology and genetics, oncology and the study of growth and ageing processes, physiology, bacteriology, parasitology, virology and immunology, as well as the anatomy and etiology of morbid conditions. The study of these in term demands sophisticated equipment and techniques which involve the use of special materials.

Medicine presents a field of application where polymers are important materials and where good business opportunities for both material suppliers and converters exist despite the fact that tonnages are not large. Moreover, the market is virtually unaffected by the state of the economy at any one time.

The most spectacular developments in medicine include the emergence of the heart/lung machine which enabled surgeons to bypass the vital organs while open-chest surgery is undertaken, machines capable of detoxifying the blood of a patient with failing kidney function, laser beam techniques in eye surgery, fibre optical techniques, microsurgery, organ implantation and prostheses. In all these plastics and rubbers have played a literally vital part.

The history of polymer applications in medicine goes back to Roman times when straws were used for tracheostomy purposes. Later a rubberised teat was used for this purpose. The Aztecs were known to make bulbs and springs of rubber for the purpose of introducing fluids into the body. When cellulose nitrate was made by Schonbein the use of its ether/alcohol solution as a wound dressing ("collodich") soon followed, while James Syme used a solvent naphtha solution of natural rubber for coating cotton for improved surgical sutures. Guttapercha was used for splints, rubber for blood tubing, stomach tubes and catheters as well as for cushioning artificial limbs, while ebonite was used for dentures and tracheostomy tubes. It is hard to credit that these primitive beginnings which nevertheless represented a takeoff point for modern medicine took place a mere century ago, after antiseptic surgery was established by Lister and after aseptic conditions were demanded by Macewen in Glasgow and by Semmelweis in Vienna.

After natural rubber because commercially available, and especially after the discovery of the vulcanisation process by Goodyear, rubber tubing was beginning to be produced on a large scale and some of this tubing found applications for the draining of wounds, for administering anaesthetics and for the emptying of body cavities such as the stomach or the bladder.

However, it soon became obvious that natural rubber (NR) suffered from a number of serious limitations such as:-

i A high ratio of internal to external diameter is desirable for the sake of the efficiency of a tube that has to fit into a restricted passage. This ratio, in the case of NR rarely exceeds 0.5 because of the lack of stiffness and proneness to collapse of thinwalled rubber tubing during and after insertion. In addition, this ratio is further reduced due to the restrictions of attachment;

ii The limited storage life of NR which deteriorates rapidly especially in a warm environment. Its useful life is further diminished when it is subjected to repeated cycles of steam sterilisation when it becomes sticky and perishes. This can be highly dangerous (as in the case of endotracheal tubes for the administration of anaesthetics) or merely thoroughly unpleasant (as in the case of a stomach tube which has to be swallowed);

iii Vulcanised rubber is an irritant to tissue. It cannot therefore be left in place for any appreciable length of time. This implies intermittent use which may be clinically undersirable and which increases the chance of infection. Permanent implants of NR are obviously impossible.

The following are the principal requirements which must be met by any material before its use in surgery can be contemplated:-

i It must be sterilisable by one of the standard methods such as:

steam autoclaving at 115° to 134°C for 30 to 3 minutes;

Exposure to dry heat in an oven at 160° - 180°C for 60 to 20 minutes;

Exposure to gamma ray and electron beam radiation for a minimum dose of 2.5 Megarads;

Exposure to ethylene oxide gas;

Immersion in suitable antiseptic solutions;

ii The material must be non-toxic and must not contain any toxic extractables. Generally the foodstuffs packaging code applies but in some countries (USA, Germany) the compound must not contain any other than specifically approved and listed ingredients.

Neither must the material be pyrogenic. Pyrogenicity is the property of causing a significant increase in the blood temperature following implantation, despite the absence of any identifiable extractables. This is important especially in transfusion sets and standard tests consist of observing whether a maximum permitted increase in the rectal temperature is exceeded after a saline solution of the extraction-treated material is intravenously injected into rabbits;

iii When introduced into tissue the material must not cause any local irritation. Tests normally involve implantation of the material into the muscle tissue of a laboratory animal and observation of the effect over some months;

iv The material should be suitable for modern production techniques such as extrusion or injection moulding;

v The product should have a good surface finish and appropriate mechanical properties, especially a suitable balance of rigidity, flexibility and elasticity. It is also useful if the material is capable of being welded or cemented into complex assemblies.

In the light of these requirements it is convenient to deviate from the method of classification of uses employed in other fields and to examine the way in which specified polymer types have been used to perform particular tasks in the field of medicine.

The most valuable plastics materials for medical purposes are PVC, PE, nylon, acrylics, PP and fluoropolymers, but others such as high impact PS, GRP, epoxy resins, EVA, acetal, PU, thermoplastic polyester moulding materials and silicone elastomers have found specialised applications, especially for prosthetic purposes. The problem of the mechanical strength of implants has been highlighted by G W Hastings (Plastics & Rubber Weekly, 23.2.1979) who points out that by standing on one foot up to 7 x the weight is transferred to the hip joint and that jumping off a chair imposes a load of up to 25 x the body weight on the knee joint. Even top quality steel can fracture under these conditions.

8.1 PVC

PVC is the most useful material despite the fact that it is generally employed in a plasticised condition and that the number of permitted plasticisers and stabilisers is severely limited, for toxicological reasons, to, for example, acetyl tributyl citrate on the one hand, and zinc and calcium compounds on the other. This makes it difficult to obtain a good balance of hardness, resilience and tensile properties and medical grade plasticised PVC compound is not employed for any other moulding purposes.

Typical structures made in plasticised PVC are:

Anaesthetic airways and tracheostomy tubes for patients who require an artificial channel during an operation or as a result of a breathing defect.

An airway (which is linked to a face mask) can be boiled between uses and reused often without becoming sticky or perishing, although it will gradually lose plasticiser and become insufficiently flexible.

Tracheostomy tubes may stay in the windpipe for years, a necessary requirement for patients suffering from breathing paralysis. Originally these tubes were made from metal such as silver and they were both uncomfortable and expensive.

Double airways for mouth-to-mouth resuscitation are also made from PVC.

The endotracheal tubes for the administration of anaesthetics were originally made from NR, but are now exclusively made from PVC. These tubes are curved and often slightly tapering, with bevelled ends to facilitate insertion. The outer end is attached to the machine via an adaptor. Smaller suction pipes are associated with the endotracheal tubes; these remove any accumulating liquids.

<u>Other tubing</u>: The greatest use of PVC is in tubing for catheters, stomach pumps and cannulae. A tube is often stitched into a wound for drainage purposes and left in place until healing is well under way. It is interesting to note that PVC tubing of BS softness 60 or more can be sterilised at 130°C without deterioration, provided that mechanical stresses are avoided.

Many designs exist for urethral catheters for emptying the bladder. They differ in length, the shape of the tip and the position of the drainage holes. As distinct from rubber catheters they can be left in place for months which is invaluable especially for paralysed patients. The tube should be long enough to be coiled several times (5 ft) which ensures that bacteria do not enter; it is directly linked to a collecting bottle and causes hardly any inconvenience to an ambulatory patient other than having to carry the bottle around with him.

PVC tubing is used for joining onto hypodermic syringes, for suction machines and transfusion sets. Some of this special tubing is made by the casting of plastisols rather than by extrusion. Stomach tubes have one end closed and smoothly rounded, with 2 to 6 lateral holes for suction or aspiration. The end carries a metal marker so that the tip can be located under x-ray. The other end carries a mount for fixing to the suction machine. The tube is smooth, has no objectionable taste or odour, is non-irritant and is easily swallowed. It is flexible enough to pass through the nose and oesophagus without causing injury yet rigid enough to resist kinking and collapse under suction at much smaller wall thicknesses than used to be customary in rubber tubing.

Special-purpose feeding tubes include indwelling tubes for infants which may stay in place for weeks and months, as well as multiple tubes for use, eg, after partial gastrectomy; an ordinary stomach tube keeps the gastric remnant empty while a longer one reaches into the intestine so that food can be passed through without coming into contact with the operation area.

Cannulae. These are tubes carrying blood - eg, to and from hear/lung and kidney machines. They have to be tough, kink resistant and have a smooth internal finish to prevent damage to the blood corpuscles. They should also be transparent (or at least translucent) and are fitted with filters of woven nylon fabric to remove any clots that might form during storage.

PVC film has been used for sterile preparation of skin prior to a minor operation. The film is attached by means of a sterilising adhesive dispensed from an aerosol container. The surgeon makes the incision through the film. The adjacent skin is completely and permanently isolated from the area of operation, tatty fringes of skin are avoided at the periphery and the wound is finally stitched up through the film which is not removed until the stitches are due to come out.

A controlled environment bag from flexible PVC sheet for postoperative wound treatment has been developed. It involves enclosing the traumatised part in a transparent bag in which aseptic conditions are maintained and the humidity, temperature and pressure are adjusted to optimum healing. It is claimed that swelling is thereby controlled, circulation assisted and pain reduced while no special skill is needed to apply the dressing.

PVC mounts and adaptors are widely employed as moulded attachments.

PVC in artifical restoration of the face. PVC is an excellent material for matching the texture, appearance and junction of natural tissue. Artifical noses and eyes date back to the ancient Egyptians while the Chinese used wax for restorations. Noses have also been made from wood, clay and leather. Leaving aside eyes (which will be dealt with under "acrylics") we will concentrate here on noses and ears. Between the wars the first were made from silver and painted, the second from vulcanite. Noses were made in acrylic, but both nose and ear prostheses are nowadays almost always made from soft PVC. The types of defects that need to be remedied may be congenital and require preparative cosmetic s... before the prosthesis can be fitted. A mastisol or double sided adhesive tape is used for retention. Occasionally an ear or a nose prothesis is attached to spectacles. Acquired defects may be the result of disease or accident and may vary a great deal in size and complexity, from a nose to half a face; and may incorporate dentures, eyes, eyelids and eyelashes.

8.2 Polyethylene (PE)

This material is less versatile than PVC but is particularly useful where chemical inertness is required without high temperature resistance being necessary.

PE can be used for permanent implants. Typical examples of this includes the replacement of the ear ossicles in certain types of deafness and artifical tear ducts. Since they cannot be autoclaved chemical or radiation methods must be used for sterilisation purposes.

Special purpose tubing. A double tube for the X-ray examination of the duodenum consists of a longer tube which slides freely inside a shorter one. The ends of each tube is provided with a metal marker for location under X-ray. The double tube enters the stomach and the longer inner one passes through the pylorus into the duodenum.

Special thin walled tubing is also used for artificial linings for the oesophagus in cases of inoperable cancer.

Very small bore PE tubing is fairly widely used for introvenous work. The outer end is flamed and a metal adaptor is screwed in, but small bore nylon tubing with nylon - cemented mounts have been superseding PE here.

High density PE is not often used. Its higher softening point has contributed little that is worthwhile, remembering that PP is indicated anyway when enhanced heat resistance is wanted. However, it was used as the acetabular component in early work on a prosthesis for the total replacement of the hip, the orthopaedic surgeon preferring this material to PP. After a number of alternatives involving devices which featured acrylics, vitallium metal, PTFE and silicone-impregnated PTFE in various combinations had failed rather disastrously, Charnley in 1963 successfully reverted to HDPE (this time on stainless steel) as an alternative to vitallium on itself. The merits of the two latter systems are discussed in depth in an article by MAR Freeman entitled "Plastics in orthopaedics", (Brit J of Hospital Medicine, May 1969, p 1007). Cold-curing acrylics are used to cement the prosthesis to bone and this is an essential technique for the successful total joint replacement of the hip (and possibly the knee), as well as of fingers (see later). The wear of plastics materials in artificial hip joints, with special reference to HDPE and PTFF has been reviewed by J Charnley (Plastics & Rubber, 1 (2), 59, April 1976). The wear rate with the latter material is unacceptably high, but it is excellent in the case of HDPE. In this connection it is worth mentioning a special grade of HDPE (MW about 4 million, MFI zero) made by Hoechst.

8.3 Polypropylene

One major use for PP is in the form of dishes and bowls for the operating theatre, replacing stainless steel which tends to produce rattling noises and can distract the surgeon's concentration in delicate operations. PP stands steam autoclaving and (unlike nylon) does not stain. It is also cheaper than nylon mouldings and the low density is useful. A number of other accessories (clamps and hinged forceps) are also in common theatre use. PP is not much used for cannulation tubing because it is too stiff for intravenous work.

However, there are some important special prosthetic application developments featuring PP. Thus, hinged finger joints have been implanted into about 100 patients (J S Calnan, Plastics & Rubber 1 (2), 91, April 1976). Because the hinged area occupies only a small area, the space becomes filled with scar tissue and to overcome this a silicone rubber bulb was fitted over it. Breakage of the hinge occurred in 10% and of the bulb in 20% of the cases. The integral hinge design has therefore been abandoned and replaced by a joint with a PP head clipped into a PP-hooded socket; although problems may arise due to small particle sequesttation this may not be important in non-load bearing joints. An alternative is a similar joint with a stainless steel head on a PP post which abuts onto a nylon cup, but this design tends to squeak in use and is more difficult to produce. Cementing of the shaft to the bone is achieved using a cold-cure acrylic cement such as has been extensively used in dentistry; clinical experince has shown that there was little reaction to that cement by either the bone or the polymeric component.

The requirements for a satisfactory finger joint are listed as follows:

i stability during movement

ii an adequate range of the kind of movement which a normal joint of the type which is being replaced can perform;

iii good wearing properties, avoiding the need for frequent replacement;

iv allowing solid anchorage so that it will not be displaced;

v minimal tissue reaction to the implant

vi reasonable cheapness.

PP seemed to meet most of these a priori requirements and the possibility of exploiting the "integral hinge" also seemed attractive at first, despite later disappointments which, as stated above, led to the abandonment of that particular feature.

Most important, the medical profession had become very confident that PP is an excellent permanent implant material as a result of earlier experience with PP for the replacement of the mitral heart valve.

The "Portex" PP heart valve was developed at Hammersmith hospital in the mid-sixties. A "kit" of 5 different sizes, together with gauging tools, costs about the same as a single valve of the earlier US design based on woven PTFE. The valve is a self-retaining flap valve with low inertia characteristics and provides a large ratio of blood flow between it and the retaining ring. The flap incorporates three retaining feet which hook under the retaining ring designed such that the area does not become prone to thrombus formation. The valve kit comes in sterile autoclaved packs in transparent rigid plastics containers and is wrapped in nylon film.

The performance of artifical heart valves has been reviewed by A K Yates (Brit J of Hospital Medicine, November 1969, p 4). He stated that the early American PTFE fabric valves (which had been coated with PU or fluorosilicone rubber to prevent stretching) caused longer-term malfunction due to mechanical fatigue failure and artificial woven valves are no longer considered suitable. A ball valve was developed by Starr and Edwards (1961, 1963) which has since been widely used for aortic, mitral and tricuspid valve replacement. It consists of a stainless steel cage coated with silicone and enclosing a silicone ball, with a knitted PTFE ring at the base of the cage for suture fixation; but the risk of thromboembolism remained a problem; attempts to overcome this resulted in a number of modifications including the replacement of the ball by a flat disc, as in the "Portex-Hammersmith" valve described above.

In general, the advantages and disadvantages of prosthetic as against biological valves are as follows:

Advantages:

- i simplicity of sterilisation and storage
- ii guaranteed competence
- iii comparatively simplicity of insertion

Disadvantages:

- i the thromboembolic risk
- ii the need for life-long anticoagulation treatment of the patient
- iii the turbulent flow pattern associated with a transvalvar pressure gradient
- iv the cost (in the case of the Starr-Edwards ball valve, though not in the case of the "Portex-Hammersmith" valve).

8.4 Ethylene - vinyl acetate copolymer (EVA)

EVA has been used occasionally as an alternative to PVC in prostheses for facial restorations because the material has excellent flexibility without containing an external plasticiser.

It has also solved a number of problems encountered in the design of hearing aids. The insert which holds either a small loudspeaker button or a thin tube leading to the speaker button remains tight in the channel, retains flexibility indefinitely, remains dimensionally stable and does not cause allergies or sweating that lead to infection.

I Hinds (Plastics Today No. 10, Winter 1980/1, published by ICI) reports that EVA is superseding PVC tubing for intravenous feeding. The system includes an EVA pouch which contains the nutrient liquid. A miniaturised pump causes the solution to flow into the vein (usually the deep-set large inferior vena carva) at the correct rate without requiring a gravity drip feed, so that the patient can carry it about with him and change the pouch himself. As distinct from PVC there is, of course, no problem involving the potential extraction of plasticiser. The pouches are sterilised with ethylene oxide gas before filling. The system can give extra years of life to patients whose alimentary canal has been damaged beyond repair and their survival is not necessarily restricted to a hospitalised existence.

8.5 Acrylics

Acrylic cements have already been mentioned in connection with the bonding of polyolefins to other substrates, notably bone and metals.

The most important use of acrylics, however, is undoubtedly for prosthetic applications of which artificial eyes and dentures are probably the best known.

Artificial eyes. These do not, of course, restore sight, but they do camouflage a person's affliction, especially when only one eye is affected and can therefore confer considerable psychological benefits and self confidence to people. These eyes, with a hand-painted matching iris is very life-like and has two major advantages over glass eyes made previously. They are much lighter and do not feel cold, so that the wearer is practically unaware of carrying a foreign body in his eye socket. They can also be easily restored to their original lustre by repolishing, if necessary.

Dentistry. The use of acrylic teeth and whole dentures is now standard. Acrylics have superseded hard rubber for denture plates but compete with special high modulus/high strength alloys which latter are better but much more expensive. Acrylic teeth are more easily colour matched than porcelain teeth and are tough, so that they are less liable to chip. The teeth are moulded in "flasks" (the dental mechanic's term for a tooth mould) using a thick paste which consists of a solution of acrylic resin in a prepolymer and includes crosslinking agents such as ethylene dimethacrylate in order to further increase hardness. The same material can also be used for cavity filling and this represents a small but lucrative speciality market.

Noses in hard acrylics have been made at one time, but they have now largely been superseded by noses made from soft PVC.

Surgical splints and collars. These are excellent lightweight structures which are much more comfortable and hygienic than the traditional plaster casts used for immobilising fractured or dislocated bones during the healing process after they have been reset. Hand and forearm splints and cervical collars are in common use. Cast acrylic sheet is also used for orthopedic appliances for the gradual correction of malformations such as club feet in babies and young children.

Surgical and diagnostic instruments. A wide range of these are available from Vann Bros. Ltd (London). These are made from machined clear cast acrylic sheet and are often complex assemblies in which the polymer material is combined with stainless steel or chromed metal parts such as

<u>Plastics in Medicine.</u>

Insert the following after line 4, p.14.:

One of the most spectacular (in every sense of the word) applications of acrylics developed recently is in the field of contact lenses.

Contact lenses are made from cut blanks of a sophisticated partially cross-linked cast acrylic copolymer which is machined into lenses to conform to the ophthalmic optician's prescription. When immersed in water the lenses swell to form a hydrogel containing an amount of water which may exceed 80% of the total weight, without any extractables being leached out. The hydrogel is completely transparent and resembles rubber in its mechanical properties, and especially in its toughness. The abrasion resistance is of a very high order. Recently developed formulations have resulted in the supply of hydrogels suitable as lenses for extended wear with perfect safety and without causing irritation or any other discomfort to the wearer. Cleaning is easy and the lenses are stored in water when they are not inserted in the eye. Although the cost per unit weight of the cast acrylic is high it is a negligible proportion of the cost of the lense as supplied after adding the markup of the lense maker and the dispensing optician.

screws, plates and springs.

Attention must be drawn here to a unique property of polymethylmethacrylate (PMMA). This material can pipe, that is to say, conduct light like copper conducts electricity, and round bends too! This makes it possible to use PMMA rod - or better still, for obvious reasons of flexibility - bundles of small-diameter PMMA monofilaments in "fibre optical systems" for illumination, observation, photography and surgery with a minimum or in the total absence of incisions which would otherwise be necessary in order to reach cavities and other awkward locations. Moreover, the light emerging from the end of the fibre bundle is far removed from its source, and is therefore a "cold-light" which does not affect the tissues adversely. This is of particular importance in delicate microsurgical procedures and/or pathological examinations which may be carried out under the microscope.

A storage bank for arterial homograft tissue. This consists of an inner box made up of clean cast acrylic sheet joined with brass screws and having a light acrylic cover. This sits in an outer box of similar ⅜ inch thick acrylic sheet with a vacuum-fit heavy acrylic top lid. The two containers are insulated by glass wool and dry ice is also placed into the space between them to refrigerate it at -80°C. The tissue is sterilised with ethylene oxide gas before being placed in long tubes inside the box which is 3 ft high.

Miscellaneous items. These include the following:

- Thermoformed bassinets from clear cast acrylic sheet in obstetric wards;
- Baby incubator covers from similar moulded sheet material;
- Processing units from white cast acrylic sheet for X ray departments (Victoria Hospital, Worksop, Notts.)
- An "icterometer", a simple device for estimating quickly the depth

of jaundice in newborn babies without the need for taking blood samples. It consists of a strip of clear cast acrylic sheet on the reverse side of which five yellow transparent strips of different shades of yellow are painted. The yellow colour of the skin is matched with the strips on the scale after blanching the skin as the painted side is pressed to the tip of the baby's nose.

- Disposable springs. These are sometimes moulded from an extrusion or injection moulding grade of acrylic copolymer, but they are more commonly made from clear PS which is cheaper.

8.9 Silicones

These materials have already been mentioned in conjunction with joint replacements and heart valves, but there are several other (and probably more successful) applications on record:

Disposable membranes for kidney machines. The development of a pinhole-free silicone rubber membrane by solvent-casting which is ½ to 1 thou thick has made it possible to produce a kidney machine which is one-fifth the size of the originally designed hospital machine and thus becomes suitable for home treatment. The silicone rubber film is four times as efficient as the cellulose film which was used as the dialysing membrane in the first generation equipment. It comes in presterilised packs and is easily fitted into the machine. The ultimate aim is a throw-away membrance. Similar (but thicker) membranes are also in use in heart/lung oxygenating machines.

Miscellaneous. Silicones have been used for the treatment of arthritic joints.

Silicone implants have also been used for the treatment of children born with hydrocephalic shunt and silastic caps have been used to cap the ends of amputated nerves. A silastic scleral sponge, a tiny implant for the eye, has been used to facilitate reconstruction following detachment of the retina. New improved silicone rubbers with increased tear strength have been produced and these have been used to design a second generation of finger joint prostheses which have succeeded where earlier designs had often failed (see before). (Plastics & Rubber Weekly, August 29 1981). Silicone liquids have been used for prostheses following mammary amputation.

8.7 Nylon

Nylon is readily extruded into layflat film and thin walled tubing and it is in these medical applications that the film material is commonly encountered. It is also used for the moulding of adaptors, connectors and the like. Its water absorption is advantageous for several reasons.

As a wrapping film of about 1 thou thickness nylon 6 admits live steam into a sealed pack during autoclaving and allows moisture to escape thereafter without trapping water of condensation within. Sterile packs wrapped in nylon film are invaluable for emergencies and field surgical use because they can be stored and kept sterile indefinitely. As a moulding nylon prevents the build-up of static electricity. Nylon 6 is fairly flexible and reasonably translucent if thin, but nylon 11 is sometimes preferred for intravenous cannulation because of its greater flexibility. Very small bore nylon tubing is well established for intravenous work - bores down to 10 thou diameter and less are available and these are both stiff enough yet sufficiently flexible to be inserted into small vessels without causing damage to the tissue lining. Solutions of nylon in cresol can be used for cementing together complex assemblies of the material. Nylon tubing is used for the introduction of liquids under high pressure for the radiological examination of blood vessels. It has also been used as an alternative to PVC for urethral catheters.

8.8 PTFE

PTFE has excellent thermal stability, good strength, is not affected by body fluids and has the lowest coefficient of friction of all known materials, so that it would appear to be a prime candidate for implanted prostheses despite the fact that it is not easily processed. However, its attempted use in the design of a hip joint replacement has been a total failure owing to its poor wear properties and the experience with silicone-coated woven heart valve prostheses has also been largely disappointing because of insufficient tear strength (see before). There is, however, at least one implant application where PTFE in the form of coated tubular woven hose has proved eminently successful, namely as an implant for the repair or partial replacement of arteries damaged by disease or severe injury. The prosthesis is stitched in place and is not subjected to inordinately high shear stresses eventually tissue growth around it consolidates the repair. PTFE has occasionally been used for prolonged cannulation because its low coefficient of friction largely prevents clotting and damage to blood corpuscles and because of its complete inertness to blood.

The difficulty of processing PTFE has prompted medical researchers to experiment with other fluoropolymers such as fluorinated ethylene/propylene copolymers which largely retain the inertness and low-friction properties as well as adequate thermal properties, but in which the softening temperatures are sufficiently reduced to make it possible to process the material by normal polymer processing techniques.

8.9 Epoxy Resins

There are not many instances of the medical application of this material, but one most remarkable example must be cited. It involves the cardiac pacemaker developed originally at St. George's Hospital, London.

The normal heart has a built-in mechanism which maintains the rhythmic beat by balancing the sequence of muscular wall contractions and also acts as a triggering impulse. In the event of this mechanism becoming diseased the result is vascular insufficiency which is eventually fatal.

The prosthetic cardiac pacemaker consists of a transistorised pulse generator complete with its own power supply of a low voltage long-life battery. The unit is encapsulated in an epoxy resin which is cured with a cold setting hardener; it is implanted into the abdominal cavity just below the diaphragm and highly flexible leads running below the skin connect it to the heart. Once the initial chest operation has been carried out no further major surgery is necessary and the battery replacement is a very minor matter which need not be repeated more than once every 3 years or so.

8.10 Acetal Polymer

Acetal is an excellent engineering plastic which has good strength, thermal resistance and chemical inertness and can be moulded to extremely close tolerances. It is therefore used for the proportioning piston pump and its associated rotary valve in artificial kidney machines (Plastics & Rubber Weekly, 14.3.1969) and this has eliminated the need for bulky solution reservoirs.

8.11 Thermoplastic mouldable polyester

This is yet another advanced engineering plastic capable of excellent dimensional accuracy. An example of its application to prosthesis design is an arm prosthesis for thalidomide victims. Most of the prosthesis (which incorporates a complete jacket and harness with straps) is made from plastics, including most of the hydraulic system but excluding the hydraulic power pack. The thermoplastic polyester is used for the injection moulded rotary actuators which form the skeleton of the unit. These in turn are covered by resilient PU foam "flesh" while the arms themselves are attached to the jacket which is moulded in nylon.

8.12 Other polymer materials

GRP has been used in wholly external prostheses such as artificial limbs which also feature polyurethane elastomers and a number of other polymers including some that have been discussed in detail above.

One rather droll application reported refers to the repair of the beak of a stork which had been bitten off by a fox in Hamburg zoo. GRP was used for the job but there are no long term clinical observations on record.

PS has been used for disposable syringes and disposable pre-operative safety razors for shaving off hair have been moulded from high impact PS. Other styrene polymers such as ABS and SAN have been used to mould various vessels and containers such as theatre kidney dishes as an alternative to PP.

Summary

The above review is intended to show that the advent of plastics has first improved traditional surgical techniques and then led to remarkable and revolutionary advances in surgery, medical treatment and organ replacement which would have been out of the question without the prior development of a wide spectrum of these new and often highly specialised man-made materials.

9. Plastics in Lighting, Display and Electrical Applications

Introduction

The combination of lighting, display and electrical applications is justified on the grounds that they are generally associated with and attuned to the electrical properties which feature importantly in the design of specific components. The only exception is found in the case of some signs for information and advertising, but even here it is desirable to have the option of providing for a power supply for internal illumination if the structure is to fulfil its intended function at night as well as during the daylight hours. Electronic devices such as monitoring, testing, control and laboratory gadgets, computers and the like for commercial and industrial use are largely excluded from consideration under the present heading, though plastics do play an important part there, especially for housings and basic support structures, as well as for electrical insulation. Suffice it to state that this type of sophisticated equipment is the product of the same age as that which gave rise to the entire spectrum of both general purpose and speciality man-made materials, so that material selection is naturally and instinctively invoked from the moment that the device concerned is first put on the drawing board.

The properties relevant to designers of components considered in this section are one or more of the following:

1) Appropriate electrical properties such as low conductivity, low dielectric loss, high electric strength, arc resistance and non-tracking;

2) Optical properties such as transparency, translucency or opacity;

3) Adequate mechanical strength and toughness, especially under impact stress, as well as good weathering and environmental stress resistance;

4) Nonflammability and a measure of heat resistance;

5) Acceptable materials and processing costs;

6) Maximum scope for functional and aesthetic design purposes.

In many of the applications material alternatives to carefully selected plastics are glass and ceramics with the occasional use of speciality papers. Glass and ceramics have good mechanical strength and excellent thermal properties but they are prone to fracture in brittle manner and they have high densities compared with plastics. Although all plastics are combustible, a number of them are nonflammable and many have acceptable heat resistance; their mechanical strength (especially on a weight basis) can be high; their flexural modulas can be such (depending on the material) as to provide either high rigidity or high flexibility as may be required in each particular application. Not least, a range of "tough" plastics are available which will not readily fracture on impact loading and so provide a measure of safety against catastrophic failure resulting from negligence, accidental impact or mindless vandalism. Moreover, their advanced processing technology makes them exceedingly suitable for mass production with low energy and labour costs and with maximum efficiency both in the use of virgin material and the recovery of scrap.

The following classification of the field is proposed:

9.1 Lighting

9.1.1 Indoor illumination

Shades and diffusers

Translucent ceilings

"Piped" lighting

Casings for fluorescent tubes

9.1.2 Outdoor illumination

Street lighting

9.2 Display

9.2.1 Road and traffic signs

9.2.2 Advertising

9.3 Electrical and electronic insulation

Moulded items for domestic use (plugs, sockets, lamp holders and switch housings)

Domestic wire coating and sheathing

Industrial cables

Switchgear

High Voltage insulators

Batteries

9.1. Lighting

The objective of lighting is obviously the provision of the correct level of illumination and is therefore intimately bound up with optics. However, problems arise in interpreting what should be regarded as a "correct level". This must always, to some extent, be subjective, since it involves notions of comfort and aesthetics. Nevertheless, there are certain guidelines for each applicational category, and these, although differing substantially, affect one's approach especially when applied to indoor and outdoor illumination problems.

9.1.1. Indoor illumination

Indoor illumination principally involves lighting fittings for domestic, public and institutional locations. Acrylics, polystyrene and PVC are extensively used here, but other materials such as polycarbonate, cellulose acetate/butyrate (CAB), acrylic copolymers and polypropylene (PP) are also frequently found in this application. The key elements revolve around performance criteria such as light transmission, heat resistance and UV resistance.

The lighting industry represents an important outlet for plastics, the bulk being polystyrene for <u>indoor</u> institutional lighting. Glass is the principal traditional competitor and the main problems confronting plastics is the heat produced by an incandescent lamp and the UV rays produced by a fluorescent or mercury lamp.

For light shades a straightforward transparent material is obviously a non-starter and traditional opague materials such as ceramics and metals have a continuing role to play. However, every transparent plastic can also be made translucent or opaque and if translucency is required plastics only compete with opal glass and certain woven or non-woven fibrous sheet materials. It is here that aesthetics rule supreme and that the advent of plastics have opened up an enormous scope for structural design to suit individual tastes, especially in the domestic lighting fittings market. A huge variety of ceiling fitting and pendant shades as well as shades for standard and table lamp are on the market. Provided that they are made from a sufficiently heat resistant material shades for incandescent lamps can be made from plastics, while in the case of UV producing light source (which is relatively cool) UV resistance is obviously more important and this may require the use of yet other plastics. Impact resistance is another criterion which will govern the particular choice of plastic that may be recommended. Among the commonly used types the following order of preference is commonly agreed:

Impact resistance:	Polycarbonate; CAB; acrylics
Heat resistance:	Polycarbonate; acrylics; PP, CAB
UV resistance:	Acrylics; Polycarbonate, CAB
Cheapness :	Polystyrene (PS), PP, Acrylics, CAB, Polycarbonate

It should, however, be borne in mind that heat resistance may be less critical when the design incorporates generous venting and/or a shade of sufficient size to assure that it is kept well away from the incandescent light source.

Spirally wound cellulosic shades were among the earliest bowl-shaped plastics shades but they are no longer frequently seen. Injection moulded and rotationally moulded shades from PP have good thermal resistance but they look as cheap as their are. Acrylics, mostly in the form of extruded channels, are widely used as diffusers for fluorescent tubes.

False ceilings come in a variety of designs and may include units of translucent flexible PVC panels, or panels of translucent and opaque acrylic sheet to provide the desired degree of illumination in exhibition, conference and concert halls, hotel foyers, restaurants and prestige show-rooms. This has already been referred to under the heading "plastics in building", as has cast acrylic rod of large diameter as a decorative source of cold and low level lighting which exploits the unique capability of PMMA to "pipe" light. This is sometimes used as a supplementary lighting device in order to achieve particular artistic effects as specified by the interior architect or designer.

Light diffusers may be constructed on an open structure principle as an alternative to solid or perforated structures. Such rather skeletal (yet often very attractive) designs may take the form of grilles and honeycombs and may be moulded or assembled from extrusions. Such grilles and honeycombs can be based on one of the plastics already mentioned or on a variety of others such as nylon, polyurethanes, polyesters, acetal or UF, the main criterior of suitability being rigidity with long-term dimensional stability, attractive appearance and reasonable cost. Plastics compete here with wood and metals on the basis of subjective aesthetic preference.

An important design trend is the moulding or embossing into plastics of prismatic lenses that can direct and control light distribution, with visual aesthetic features build in so as to supplement the functional requirements. Considering the number of processes available for use with plastics (notably blow moulding and thermoforming, in addition to injection moulding) the incorporation of a variety of lense effects or shape variations is much easier with, say, acrylics than with glass. The heat resistance problem associated with high-intensity lighting becomes more manageable with larger panels which are further away from the incandescent light source. Another way of dealing with the heat resistance problem of, say, PMMA, is the replacement of the homopolymer by a copolymer which includes methylstyrene since the latter has a heat distortion point of up to about 130°C.

In outdoor illumination the choice of materials is very significantly influenced by the efficiency of light transmission in addition to the general requirements of heat, impact and UV resistance. Here PMMA is outstanding with 94% transmission, followed by clear CAB (90%) and polycarbonate (86-89%), while a translucent white CAB globe can give up to 80% transmission, depending on formulation and thickness.

9.1.2. Outdoor illumination

Effective street lighting is an important social requirement for urban communities. In addition to enhancing the amenities of a locality it assists the flow of traffic at night and reduces road accidents. The choice of plastics materials which are suitable for transparent or translucent covers, canopies and optical systems is essentially confined to the ones with the best light transmission, i.e. acrylics (virtually exclusively PMMA), polycarbonate (PC) and CAB; these are also the ones best able to withstand long term weathering (including exposure to UV light) and are superior to glass in their impact resistance and toughness in the face of vandalism. Heat resistance problems may well be more severe in outdoor than in indoor applications because the required lighting intensity may be very high and this will naturally affect the ultimate material choice. (PS (which has a large share of the institutional indoor market because it is relatively cheap) and PP are never used for outdoor illumination because of their poor UV and weathering resistance).

CAB has been extensively used for street lighting fittings in the USA, and PC as well as PMMA have been popular in Europe and Japan. PMMA is in general use in most countries and in the UK it is virtually exclusively used for this purpose. The extreme clarity of the base material with an absorption of light of less than 0.3% per cm has made it possible to develop opal formulations for street lanterns where accurate light control is unnecessary. The tensile strength of PMMA at 20°C is 7MN and this makes it possible to manufacture covers of adequate strength to withstand the stresses imposed by strong winds and fracture by accidental impact from sheet not thicker than 4.5 mm. Moreover, when the sheet is heated and stretched during manufacture the toughness is further enhanced due to orientation. If fracture does occur the cover will not disintegrate like glass. The increased safety which this affords is particularly welcome in large covers such as those for fluorescent lamp fittings: In some cases such mechanical damage as has been inflicted can even be repaired.

The tensile strength of PMMA at 80°C is still a respectable 2.8 MN m^{-2} its flexural strength at 20°C us 11.25 MN m^{-2} and at - 40°C PMMA is still tough rather than brittle in its failure mechanism and these properties are very welcome in street lighting covers and canopies.

Above 80°C PMMA sheet tends to distort. This limit is not normally reached with fluorescent tubes or sodium vapour lamps, but when designing a cover for incandescent light sources it is generally advisable to check that the service temperature does not exceed 80°C.

Plastics generally (and PMMA sheet in particular) have an important advantage often glass in that there is no risk of breakage due to thermal shock when sleet or snow falls on the hot cover. As regards the actual conversion process, the shaping of cast PMMA sheet is quite straightforward. On heating the material to 150 - 160°C it becomes rubbery and can be shaped by mechanical means or by a low pressure or suction and the tools required are quite inexpensive. This makes it economically feasible to make up simple moulds (e.g. by carpentry) for production runs of small or moderate batch sizes. Moreover, machining is easy and can be accurate and this is exploited when producing light-controlling refractor plates which are found in a number of street lanterns. The prisms are cut in one operation by means of a multiple drilling cutter, the refractor plate is cemented to the inside of the cover using an acrylic prepolymer cement and the optical system is thus hermetically sealed against dirt, rain and water vapour as well as against the corrosive gases present in polluted urban or industrial atmospheres. According to W E Harper (British Industry & Engineering, May/June 1960), street lanterns can be categorised under

3 headings depending on the lighting function which they are intended to fulfil:

i) Lanterns for city and town centres

ii) Lanterns for major traffic routes

iii) Lanterns for minor roads

The first type of lantern is designed to give a high amenity value in illuminating buildings and open spaces and this is best achieved with diffusing type fittings with a good colour-rendering light source without necessarily affording accurate light control at the same time. Thus, the City of London has installed twin lanterns, each with four 80-watt fluorescent tubes mounted vertically on a concrete column. The lamps are shielded by diffusing acrylic covers which are capped at each end by decorative metal caps. Another type of lantern towering tall over a pedestrial-crossing bollard refuge uses an acrylic cover of a lightly diffusing type and has a canopy of aluminium sheet. The cover fits into a threaded aluminium alloy casting and can be used with two 250/400-watt high-pressure mercury vapour lamps or two 500-watt incandescent lamps.

For the lighting of major traffic routes optical efficiency is the first consideration. The maximum amount of light must be directed at the road surface at an angle that produces good visibility without glare. Since colour rendering is of little importance here sodium lamps are widely used because they are twice as efficient as fluorescent tubes and mercury vapour lamps, and seven times as efficient as incandescent lamps. Moreover, sodium vapour lamps have much lower brightness than the other light sources and thus produce much less glare. The light from these lamps is controlled and directed by specular aluminium reflectors or prismatic refractor optics, the latter being preferred because of easier maintenance. Where good colour rendering as well as low brightness are desired fluorescent lamps are used; thus bowls from acrylic sheet measuring 180 x 40 x 40 cm have been mounted in a suitably angled position on top of a tall support column carrying a fluorescent light source. Refractor lanterns for use with 200-watt sodium vapour lamps have been constructed on an integrated principle, the shaped bowl of clean acrylic sheet with machined refractor plates being cemented to an opaque acrylic canopy with an acrylic prepolymer cement.

Lanterns for minor roads are intended to assist traffic and provide general lighting for pedestrians. A large variety of designs is available which depend in some measure on the actual lighting level demanded, but opal acrylic sheet diffuser bowls combined with an opaque canopy of the same material and enclosing small fluorescent lamps are often seen in neighbourhoods which have been developed or redeveloped in recent years.

In Charleroi (Belgium) the housings of street lamps - often diecast aluminimum - has been replaced by mouldings in glass filled nylon. The housings are 5ft (21½ m) long, and the mouldings include mounting points for the reflectors, for the electrical fittings and for the acrylic lamp bowl.

9.2. Display

Display has two principal objectives:

1) To advise, direct and instruct road users;

2) To advertise to and influence the general public.

These two objectives have a number of features in common:

i) The structures involved are erected in prominent positions in the open where they are subject to the weather and to the effects of atmospheric pollution.

ii) They are usually (though not invariably) illuminated so that they can function at night as well as during the day light hours. This means that they are usually connected to a power source.

For display purposes cast/acrylic sheet stands out as the material which possesses all the combined properties required in this application to a degree which is unsurpassed by any other plastic material or by glass.

Before the advent of plastics signs of all types were made up in timber or enamel-glazed sheet metal and if they were illuminated the light source was external to the message and often exposed to the elements.

The use of cast acrylic sheet in this application was reviewed by P H Collins ("Plastics Today" No 23, Jan 1965, ICI publication) with special reference to the Anderson report (Traffic Signs for Motorways, H M S O, 1962) and the Worboys report (Traffic Signs H M S O 1963).

Road signs and signals are recognised as an essential part of traffic engineering. They need to be conspicuous at all times and in all weathers. They must therefore be prominently positioned. They must also be internally illuminated. Internal illumination provides two important advantages over external illumination: The first is the same as that already noted in street illumination, namely cleanliness and protection of the light source from the aggressive influences of the environment; the second is the fact that internal illumination ensures that the message is often still clearly discernable through dirt and snow when externally illuminated signs have become totally illegible.

Free standing and well-fixed road signs are often lentil shaped, with a slim clock-glass-type opal cast acrylic sheet on one or both sides. This still provides plenty of space for the fluorescent tubes inside. The message is reverse printed or painted on the inside. The light transmission depends on the sheet thickness and on the coloration recipe and an increase in the first can be balanced by changes in the second, so that internally illuminated signs and fascias can have the same specified brightness and constant transmission in all the installation. Furthermore, this applies to a wide range of colours.

In the advertising field one is confronted with essentially the same problems as those encountered with road signs, but the scope is wider. Thus, the requirements are individual rather than standardised ones and the various items such as signs, slogans, logos, fascias and display columns are custom-crafted rather than mass produced.

Modern shopping precincts, whether of the open pedestrian plaza or the arcade type have attractively designed and illuminated shop fascias, direction finders and poster sites. Shop fascias and orientational signs are commonly made from cast, opal acrylic sheet; possibly of different colours for background and message, while paste-up poster columns have occasionally been replaced by columns of similar sheet material which is internally illuminated and to which the posters are affixed internally and thus protected from being effaced. Unfortunately the column itself is not vandal proof. An excellent example of a modern shopping precinct generously equipped with cast acrylic signs and fascias is Birmingham's bull ring centre which has a retail market, a fish market, department stores, supermarkets, 140 retail shops, banks, offices, car park, and a bus station, all clearly identifiable by illuminated signs and fascias.

When it comes to advertising on a scale which exceeds the modest shop front sign or illuminated display column poster one of the most impressive is that which advertises the Dagens Nyheter and Expressen newspapers from the top of the Dagens Nyheter skyscraper building in Stockholm. In actual fact it is not one but many signs - one for each letter of the longer newspaper title - fourteen in all, including one for the space between the two words.

The overall display area is 42 x 2 m and each letter consists of a metal box mounted on a vertical shaft on which it rotates, the drive being provided by six 5 h.p motors. As the fourteen boxes rotate they alternately spell out the names of the two papers by displaying the faces covered with translucent opal cast acrylic sheet that carry letters and opaque metal-covered faces for the blanks. The acrylic sheet is spray-painted on the outside to blank out all except the letter itself. Each box contains ten 40-watt and ten 20-watt fluorescent tubes which illuminate the letters by night. The names are alternatively spelled out every 20 seconds and they can be read plainly from a distance of 3 km away.

9.3. Electrical insulation

In the preceding section dealing with lighting and display optical and aesthetic properties were the decisive factors, although mechanical, thermal and weathering properties also played a part. Electrical properties of the highest order were not essential, although internal illumination made it necessary that wires and fittings should always be safely enclosed and properly protected from dirt and moisture.

In electrical insulation the emphasis is almost entirely on the electrical properties and appearance is almost always irrelevant, provided that the design is functionally right. The exception is in plugs, sockets and switch housings which should also look neat, should be easily cleaned and be preferably white or cream in colour. The natural material is UF resin or rubber, the former being by far the most important. Being a thermoset, UF is not affected by moderate heat and although phenolics have higher heat resistance they are also liable to "track" and good practice does not consider them safe for mains use. Lampholders are often made from similar UF compounds, with brass fittings, but the colours are not important and the mouldings are either white or brown or black. Such fittings eventually fail mainly due to thermal degradation but they have nevertheless completely replaced the earlier (and much better) ceramic/brass holders because they are so cheap.

Wire coating for domestic lighting and power supply was once done with natural rubber but is nowadays achieved by means of plasticised PVC. Although PVC is a polar polymer its dielectric loss factor is unimportant provided that it is confined to a relatively narrow peak at frequencies far removed from those used in domestic mains circuits. The loss peak can be shifted about by variations in the plasticiser content, but exposure to elevated temperatures will also shift the absorption peak to higher frequencies and it is necessary to consider the three-dimensional temperature frequency spectrum of dielectric loss in the light of the expected service conditions (including ageing) before specifying the insulant formulation. One strand or several strands of coated wires are often combined into cables by sheathing. The sheathing layer is intended to protect the insulated wire from mechanical damage during installation and in service and it is not necessary for it to be a particularly good dielectric. Plasticised PVC, being highly abrasion resistant, is commonly used, but for field telephone lines laid over rough ground a nylon covering is sometimes preferred.

In both telephone cables and in other low voltage applications such as small condensers and the like speciality papers (including, for example, papers from non-cellulosic fibres such as polyester and polyaramide fibres) and films from certain polymers such as nylon 11 or thermoplastic polyesters have been used to twist round insulated conductors prior to covering cables or as separators in coils, condensers and capacitors.

The coaxial cables for television aerials need to be as nearly non-polar as possible since they do not operate at a constant frequency and polyethylene is therefore used to insulate the conducting core. The insulating material is, in turn, covered by a woven network of copper wire in order to provide a screen protecting the core from being disturbed by stray and induced currents and this screen is in turn protected against damage due to abrasion by a covering sheath of (usually) brown plasticised PVC.

In telecommunication cables polyethylene plays an absolutely vital part. Thus,a modern PE-core submarine telephone cable requires an ultra-low-loss dielectric to minimise the number of repeaters which are a major factor in the heavy cost (S Matsuoka & L D Loan, Plastics & Polymers, October 1975, p 188), but other properties dependent on density and molecular weight such as retraction, mouldability and adhesion to the central conductor need to be considered as well. The cable jacket also consists of PE, it must conform to mechanical performance criteria which minimise stress cracking and degradation in storage and guarantee a service life of at least 25 years.

A modern submarine cable can carry several thousand conversations on a single pair of conductors by multiplexing over a wide frequency range. It is mainly for this reason that polar polymers like PVC could not even start to be considered, quite apart from the dielectric hotchpotch which a PVC compound represents. Indeed, even ordinary PE still has much too high a dielectric loss factor and special grades are marketed for cable use which have been made under virtually aseptic conditions.

The causes of dielectric loss in PE are to some extent due to weak dipoles at the chain ends, to branches and to residual vinyl groups, but the major factors are due to polar impurities such as catalyst residues and antioxidants; dramatic improvements have been achieved by the introduction of symmetrical phenolic antioxidants with a very weak dipole. The introduction of better catalysts and methods for removing the residues has helped to reduce losses (at 30MHz) by about one-half.

The effect of pressure on the permittivity also needs to be considered, since the cable will be under considerable hydrostatic pressure on the ocean floor. Because the loss factor is so low the permittivity of the dielectric is virtually independent of the frequency. Knowing the density and compressibility it is possible to calculate the permittivity using the Clausius-Mosotti equation.

Satisfactory stress crack resistance is generally found to be obtained when using a polymer of MFI 0.3, but this does not make for easy processing.

When the cable is laid it must support its own weight between the ship and the bottom. The necessary strength is provided by the central steel strand, but in order to ensure structural integrity the layers surrounding the centre must have good adhesion across the section, the most critical being the adhesion between the conductor and the dielectric; it has been found that contraction during cooling in cable manufacture and a low degree of orientation lead to improved adhesion.

The dielectric is surrounded by an outer metallic conductor (copper or aluminium) which, in turn is covered by the outer extruded jacket of PE; the latter is intended to protect the outer conductor from abrasion and wrinkling during manipulation. It does not, of course, have any special dielectric properties, but it must be resistant to environmental stress cracking and to UV and thermal influences in storage. This requires a suitably stabilised jacket of appropriate thickness and stiffness. Polyethylenes must have a tensile modulus exceeding 1.03 kN mm^{-2} as a jacket since polymers of lower tensile modulus give rise to conductor failure. The modulus, in turn, increases by about 30% as the density of the polymer increases from 0.95 to 0.962.

For the repeaters (which are necessary at intervals to boost the alternating signal) components of high reliability are again required. Plastics with low water absorption are preferred and any thermosets used must be fully cured in order to ensure that no corrosive gases are later evolved. Various polymers were used including PMMA and Orlon - reinforced diallylphthalate (DAP) and these were followed by reinforced DAP which proved to be a more readily processable material. The most recently designed repeaters additionally use glass reinforced poly(butylene terephthalate) (PBT) as part of a shock and vibration absorption system which replaces the metal used earlier.

Returning to cable and wire covering the technique of irradiation-cross-linking has begun to be used for wires in telephone central offices, radio and television receivers and all manner of other static or mobile electrical and electronic equipment. Irradiation crosslinking improves a number of properties including thermal, chemical and flammability resistance and dramatically improves the mechanical properties above the crystalline melting point of the plastic. (D C Alexander, Plastics & Polymers, October 1975, p 195).

PVC is probably the most commonly sold polymer in irradiated insulation systems. In locomotive, automotive, aircraft and nuclear plant control cables irradiated polyolefius have begun to replace a variety of rubbers and plastics such as conventional PVC, nylon, silicones and lacquers for insulation purposes. The service requirements for modern cables have been reviewed by H F Nye (Plastics & Rubber 1, (2), 87 April 1976) who points out that these requirements diverge considerably, depending on the precise service conditions.

Thus, cables for lifts present some unusual design problems: they must withstand constant flexing with relatively small bending radii, and variations in suspended length, and some lifts operate at considerable speed! These cables, moreover, must not twist, they must not throw out of the shaft and must also have some flame retardance and grease resistance.

In X-ray equipment small-sized flexible cables must be able to withstand voltages of up to 150 kV (dc) or 75 kV (ac). In these cables a highly flexible earthed screen is included, with additional cores to energise the equipment. An abrasion resistant sheath is finally applied.

Power cables for overhead travelling cranes require special flexibility. Mobile trolleys or reeling drums are used to reduce the problem to manageability, but the cables must have grease as well as abrasion resistance and since they carry heavy currents (even though the voltages do not exceed 1 kV) they may not be able to dissipate heat sufficiently when running in a confined space, so that they require insulation and sheathing materials that are capable of withstanding somewhat elevated operating temperatures.

Electric are welding cables require mechanical properties of a high order to withstand damage on industrial sites and they must be flexible, yet reasonable light so that they do not cause fatigue to the operator of hand-held equipment. The cable will get hot and the welding operation must be phased to allow accumulated heat to dissipate. The cables are nowadays insulated and sheathed with a single extruded and fairly heat- and tear-resistant layer of chlorosulphonated PE or ethylene/propylene elastomeric copolymers.

The use of plastics in switchgear and both high and low voltage insulation has been reviewed by Rothwell and Manley (Trans. & J. Plast. Inst, 29(82), 1‘0, Aug.1961).

Nylon (and especially the moisture resistant and virtually amorphous nylon 11), polycarbonate, acetal and PP, as well as phenolic resins have been found sufficiently strong to replace metals for certain operating parts. Nylons and acetals are used for gears and bearings because of their low coefficient of friction and their solvent and corrosion resistance, while polycarbonate has been used for insulating poppet valves which have to resist a rigid succession of blows.

Micro-switch housings in clear thermoplastic polyester moulding material have come into use because of their excellent dielectric and stress-crack resistant properties, especially when metal inserts are involved.

Cable terminals are often moulded in a variety of plastics and moulded cases of up to 660V rating have been moulded in phenolic. Cable tails are separated at the crutch by a PVC moulding and are passed through a PVC cover made by dip coating. The flanged cones are compression moulded from HDPE. The assembled terminal is filled with a thiokol-modified epoxy resin using a pressure gun and such a terminal is particularly suitable for cables which have been insulated and sheathed with thermoplastics.

Most of the electronic control equipment is associated with switchgear. Such equipment may be encapsulated for mechanical support and environmental protection. Epoxy resins are preferred because of their low shrinkage but since many components (notably transistors) should not be exposed to temperatures exceeding 70°C the curing agents used must not generate a high exotherm and any fillers included should have good thermal conductivity; aluminium oxide gives a good compromise between the conflicting requirements of thermal conductivity and electrical insulation.

Sometimes a cold-curing silicone rubber is used for coating subassemblies so that some components can be recovered by splitting the encapsulating block in the event of partial breakdown of multicomponent assemblies. If the silicone rubber also contains nitrogen-filled phenolic "microballoons" this system additionally affords a high degree of protection against mechanical shock.

Phenolic laminates have been used as a base for printed circuits, although a variety of speciality thermoplastics (e.g the newer polyesters) have begun to compete in this application. Where the insulating level is low and the danger from moisture is slight foamed resins (PU and PF) or the inclusion of glass or PF microballoons have been found suitable. Foamable encapsulants may use plastics moulds which are retained as permanent casings. Such moulds can be made from a variety of plastics (e.g. PS or acetals) which are selected for their mechanical, thermal and solvent resistant properties.

High voltage applications involve mouldings which may range from modest to massive size.

Epoxy and polyester resins which are readily moulded into complex shapes without the application of high pressures and which are of sufficiently low initial viscosity to be able to impregnate fine wire coils have been widely used since 1947 because they do not lose volatiles during the curing process and because of their excellent electrical and mechanical properties.

Suitable flexibilisers such as dodecenyl succinic anhydride have been used to reduce the tendency to crack around metal inserts, but pyromellitic anhydride is sometimes preferred because it increases the heat distortion point; however, because its melting point is 266°C pyromellitic anhydride is difficult to incorporate and it is therefore sometimes used in combination with maleic anhydride. There are a number of other anhydride alternatives all of which have their devotees and which confer advantages with respect to either cost or flame retardance or the pot life of the liquid resin. Amine hardeners were widely used for low voltage applications, but the exotherm is too high to allow one to make large castings and these hardeners are also highly toxic substances which should be avoided.

Advances in epoxy formulations have led to improvements in heat resistance. This includes epoxylated novolaks and more heavily crosslinkable polyepoxides. Mixing of the casting resin with silica cheapens the material and improves the resistance to tracking, while at the same time reducing shrinkage. It is essential to cast components under a high vacuum to prevent void formation and to rigorously exclude traces of moisture since moisture causes premature gelling. Distortion and craking are avoided by precoating the conducting copper parts with soft PVC. In medium voltage applications (440-660V) PMMA and PTFE are preferred because they depolymerise to gaseous monomers.

Electromechanical applications involve such structures as circuit breaker driving rods and busbar supports and they are largely made from glass fibre reinforced materials, although poly(phenylene sulphide) and, more recently, poly(ether imide) resins have become important here (P & R W 27.2.1982.) * . In matched-die mouldings (which are pressed at 50-150 psi) polyesters with a filler - rich formulation involving mats and preforms are generally used. For simple and fairly flat shapes (such as driving links for contact breakers) woven cloth impregnated with epoxy resin provides the best control of the glass/resin ratio, but this is not suitable for complex mouldings.

Filament winding processes are mainly used for tubes and cylinders with closed ends, epoxy resins being preferred because they are best able to

* The latter material, incidentally, has also replaced glass in the reflector of medical lamps for operating theatres because of its infrared light transparency and heat resistance (up to 200°C) under load. (A special dichroic coating on the reflector surface allows the I.R. rays to pass through the light reflector and so protects the patient from exessive heat.

resist high internal pressures without leakage due to better cohesion between the resinous matrix and the reinforcing fibre.

As regards switchgear, epoxies are widely used in indoor airbreak circuit breaker panels which may, for instance, be rated at 1600 amp and 11 kV. The resin is used as an impregnant in rotatable cranked bushings for earthing a cable or a busbar through the circuit breaker (or, conversely, for establishing the service position). The roof barriers of the arc - chute are made of polyester/glass and the joints between the connectors are covered with resin after assembly.

In order to avoid exposing live busbars or cable connections to explosive atmospheres when the contact breaker is withdrawn, an isolator is placed between the circuit breaker and the terminals. The isolator consists of six high-voltage and low-voltage connectors which are cast into a single block of resin whose circular flanges are machined to close tolerances so as to ensure a flameproof path where it fits into its cylindrical metal casing. The corresponding plug contacts of the circuit breaker are also cast in a single block of resin.

The complicated arrangement of conductors could not be readily insulated with anything other than epoxy resin in the limited space available. The busbars are lightly insulated with a plastic which is stripped off when alterations are required. The wound primary current transformer is insulated with epoxy resin in each phase and is given a sprayed metal layer on the outside which is connected to earth through a neon lamp which provides a live-line indication.

In indoor air-insulated oilbreak switchgear both feeder and busbar orifice insulators are cast in epoxy resin and they also form a post for supporting the busbar. The main busbar insulation is air, but an additional coverage of extruded PVC is given which can stand the full test voltage. The turbulators are made from nylon 6 and the driving links are moulded from woven glass roving preimpregnated with epoxy resin. The current and voltage transformers are also insulated with epoxy resin.

Dough moulding is used for many electrical switchgear items for various reasons. (i) the processing time is short; (ii) the process is suitable for long production runs; (iii) fairly accurate dimensions can be achieved; (iv) the material has reasonably good mechanical and electrical properties. On the other hand, the shapes are limited because of the use of a compression moulding method and it is best to limit the method to low voltage applications. There is also a tendency for the moulding to crack in thick sections; although this does not necessarily seriously impair the mechanical properties, trouble may arise under radial electrical stress from discharges at the cracks. Polyester dough mouldings are therefore limited to where the main electrical stress is across the insulator surface, e.g. in busbar supports. Cracking does not occur with the more advanced epoxy dough moulding compounds because these have a longer cure time, lower shrinkage and better adhesion of the matrix to the disperse phase than have polyesters.

One of the most familiar examples of the massive use of cast epoxy resins and outdoor circuit in the electrical field is their employment in alternator terminal bushings for transformer stations. A skeleton structure consisting of alternate layers of corrugated paper of suitable flute depth, and aluminium foil, is built upon the conductor. Casting is then carried out in a high-vacuum autoclave and the filled moulds are transferred to ovens and cured as usual. The finished insulation is identical to conventional cast epoxy resin, but has suitably shaped creepage paths and the shape (incorporating flanges) is obtained by a single casting process. A number of detailed descriptions of the design and manufacture of similar high voltage equipment is found in the Technical Note entitled "Araldite in stress-graded insulators" published by CIBA in March 1966.

Finally, mention must be made of batteries. These are often quite large mouldings and involve separators as well as casings and screw top fittings.

They represent a large market, especially in the automotive field and the original ebonite and phenolic containers have now been almost universally replaced by mouldings made from PP. These batteries are cleaner and lighter in weight than the earlier types and are much less prone to leak electrolyte and cause corrosion under the bonnet or to crack. Nylon 11 or PP are used as separators and the screw tops are moulded in PP or PVC.

SUMMARY

The use of plastics in lighting, display and electrical applications covers a wide range of products many of which require highly specialised techniques and materials in order to fulfil widely differing functions. In general, a combination of good optical thermal, mechanical and electrical properties as well as chemical and environment stress crack resistance and good dimensional stability are required.

The large choice of materials presented to the designer by the polymer scientist, technologist and engineer makes it possible to produce consumer items and industrial components of great complexity and sophistication for which no traditional type material could possibly be used.

It is a field in which even marginal improvements on existing materials still holds out very worth while prospects for substantial advances in performance and market economics in an age which constantly looks for ways to enhance the quality of life and which is, at the same time, acutely aware of the need to make the best use of far from unlimited energy and manpower resources.

Postscript

Future plastics - future applications

(A personal view)

In the preceding nine essays problems of material selection were presented in general terms and this was followed up with a review of the use of plastics and their advantages and limitations in what were considered to be the most important, the most interesting and/or the most illustrative fields of application. Apart from the most obvious applications such as building and packaging the choice of fields was inevitably slightly arbitrary. Thus, a good case could be made out for further extending the coverage, for example to:

- plastics in clothing and footwear;
- plastics in railways;
- plastics for aircraft, rocketry and space applications;
- plastics in sports and leisure equipment;
- plastics in toys and educational aids;
- plastics as art and craft materials.

However, the indiscriminate stretching of the theme will ultimately become tiresome to author and reader alike, all the more so when the method of treatment must remain essentially the same throughout.

When all is said and done there arises the pertinent question: "Whither plastics now?" It is always invidious to try and predict the needs - let alone the means of their fulfilment - of future generations. Even assuming the absence of any unexpected emergence of an entirely new class of materials (and the Victorians certainly did not visualise the discovery of the plastics!) one cannot be confident that an apparent trend over a few decades is sufficiently characteristic to enable one to extrapolate it to the medium (let alone long-term) future. Looking at tonnages it would appear that a plateau has been reached, although this will ultimately be raised to a higher level as the underdeveloped countries catch up. Looking at types, on the other hand, one can certainly add that the "heroic age" of plastics, that is to say the time of the great researcher of Carothers, Staudinger and others and the discovery and proliferation of the vinyl type polymers is over. This was a period which covered a mere two to three decades. Since then there has certainly been a steady trickle of speciality polymers such as the fluorocarbon and silicon polymers, polycarbonate and acetal polymers, the polyaramides, poly (phenylene oxide), the polysulphones, poly (ether ketones), poly (etherimides), etc. However, it was more a question of filling in the remaining riches rather than touching off another big move of innovation, with the possible minor exception of filler reinforcement technology as exemplified by the development of carbon and boron fibres.

The position today is that speculative research is expensive and the expected rewards when set against the risk are uncertain. Moreover, there is now comparatively limited scope left for new products in the plastics field. Not many people expect that another multi-kilotonner such as PVC or Polyethylene, or even rather more modest bulk polymers comparable (in volume significance) to, say, acrylics or nylon still await discovery, if only because any alternatives to already existing plastics would have to be significantly superior in service and/or substantially cheaper to produce in order to justify a substantial and fairly long-term investment. Some speculative research and development work for speciality products of low production volume in electronics, aerospace and military applications (where performance is of greater importance than cost) will doubtless continue, although presumably mainly at tax payers' expense. Even so, this presupposes that the nations which presently lead the world in scientific sophistication, technological expertise and commercial and managerial skills will also continue to have ready access to essential raw materials and to the necessary energy resources, when it cannot necessarily be assumed that the family of Man will behave in a way which will ensure the preservation of

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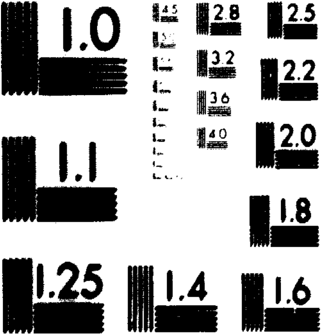

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existing standards or, indeed, the survival of the species itself.

If we cannot therefore expect any impending revolutionary advance in materials technology comparable to the bursting upon the scene of say, the vinyl type thermoplastics, what are the prospects for more modest yet important progress?

(i) There is continuing scope for "tailoring" of plastics to particular applications, the improvement of existing grades and some diversification of grades within a particular range of the same chemical type. This can be achieved by variations in compounding, blending and copolymerisation (including block and graft polymerisation) and processing modifications.

(ii) There is a continuing need for improving existing processes of synthesis, polymerisation and conversion methods in an effort to obtain the best possible product at the lowest cost. In the past cost reduction has often been achieved by scaling up, but in a climate of overcapacity this is not likely to yield much in the near future.

(iii) It is always important to re-examine suitability criteria and to investigate the possibility of combining plastics with other types of materials in an effort to exploit to the fullest possible extent the cost/performance efficiency of each component within the overall structure.

(iv) There may well be a renewed realisation that cellulose is "a polymer that grows", that is to say, that it derives from renewable (ie, non-fossil) resources. This should lead to an important resurgence in the production of cellulosics. By the same token, it could well be that starch will also provide a starting material for useful polymeric products.

(v) As regards the material and energy base for plastics and the organic chemicals industry generally, the exploitation of biomass and waste utilisation should hold out good prospects for achieving and ultimately eliminating our dependence on oil and coal.

Clearly, much yet remains to be done, but the emphasis will tend to be on engineering design rather than on the discovery of new classes of materials.

R.S. [illegible]
March 1982.