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PLASTICS AS BUILDING MATERIALS
WITH SPECIAL REFERENCE TO DEVELOPING COUNTRIES 1/

by

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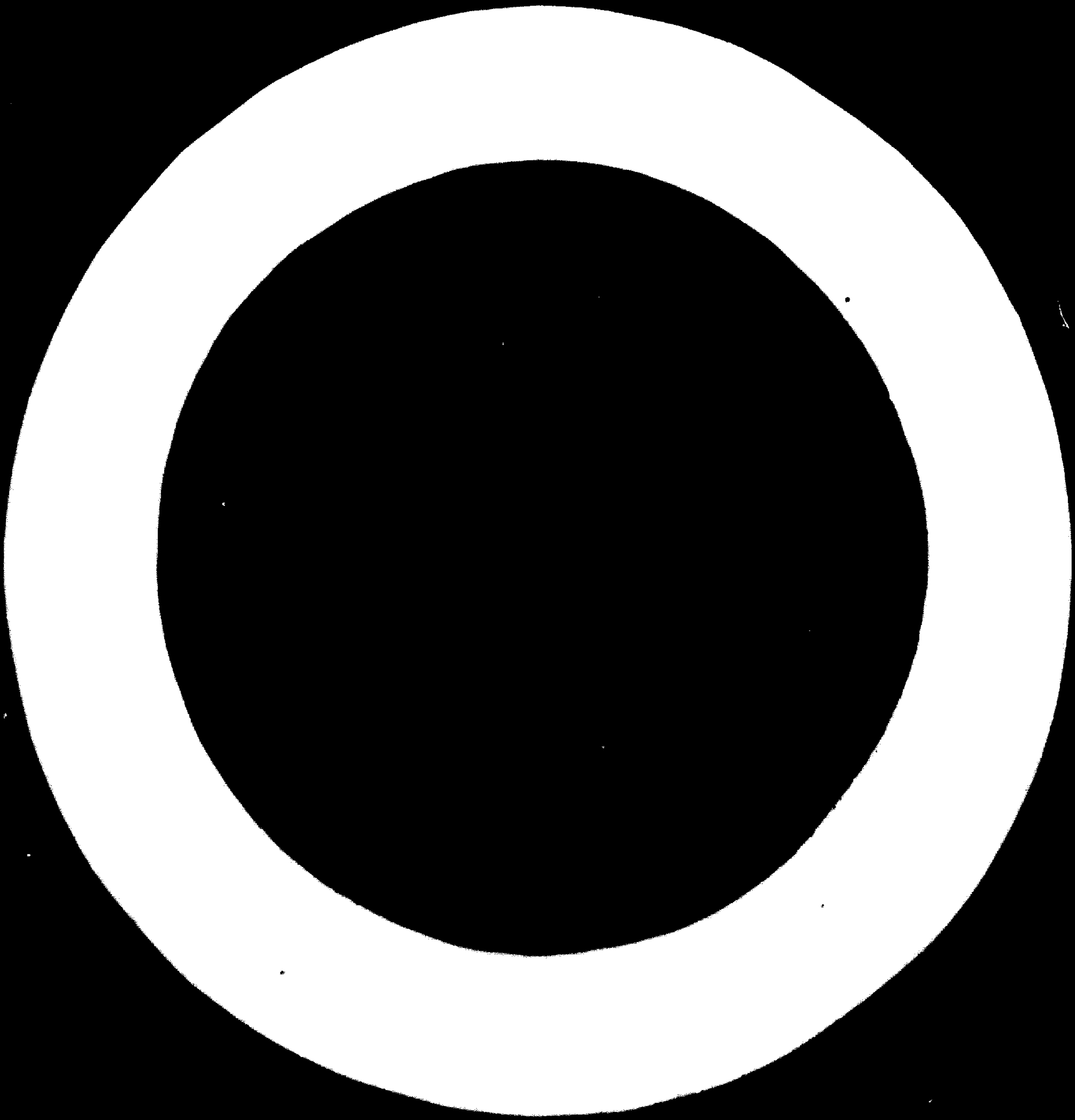

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I. Representative physical properties of the main plastics used in building, with average U.S.A. and U.K. prices, and some typical applications

I. WHAT ARE PLASTICS?

Plastics are the modern materials of construction, the products of chemical synthesis and of emancipated chemical thinking. They are indeed the products of the combined efforts of chemists, physicists and engineers, and through their many grades and types offer a combination of properties which cannot be equalled by any other family of materials. The classical text book definition will tell us that plastics are organic materials which can be formed to a desired shape under the action of heat and pressure. In some cases this process of softening and forming or reforming can be repeated indefinitely: these are the thermoplastics materials; in other cases the formation or moulding having once been effected, the material cannot be resoftened by further heating, and logically enough these are called the thermosetting materials.

Though the actual chemistry of the formation of plastics is frequently complex and in some cases even today obscure, it is relatively simple in principle. Simple chemical units or monomers are joined together in a chain to give the more complex materials which we know alternatively as polymers or plastics, and it is for this reason that so many individual plastics carry the prefix 'poly'. Thus for example polystyrene means that many units of liquid styrene have been built up into a solid molecular aggregate which industry and indeed the lay public at large know and use in one or other of its many physical forms as polystyrene. Today polystyrene, polyethylene and polyvinyl chloride or more simply just 'vinyl', are part of the normal vocabulary of people and nations throughout the world. Year by year plastics, polymers, call them what you will, are having an increasing influence on the life of individuals and of nations, and nowhere is this so manifest as in the industrial sector with building construction.

A. THE GROWTH OF THE PLASTICS FAMILY OF MATERIALS

In order to appreciate the significance of plastics and their current and possible future impact on industrial development throughout the world, brief reference must be made to their historical background.

Although it is over a century since the first plastics material celluloid was discovered and used, the plastics industry is less than half that age, indeed it was only the intensive search for supplementary materials just before and during the last war which brought plastics into world-wide significance. Quite logically early developments centred on the chemical modifications of naturally occurring materials such as cellulose and casein, but this was extended following the pioneer work of Baekeland, to include products of chemical reactions. Once the industrial viability of these materials had been established, the search for others was rapidly and effectively pursued, but it was only when Hermann Staudinger established the family relationship of these macromolecular materials in the period 1920-30, that the foundations of the plastics industry were well and truly laid.

Quite naturally when conventional materials were in short supply owing to the excessive demand during the last war and in the post-war reconstruction period, intensive research was devoted to the development of plastics materials, and their numbers increased rapidly. Some idea of this growth rate can be obtained from the world production of plastics of all types which has been given as 1,000,000 tons in 1930, 800,000 tons in 1947, and 1,500,000 tons in 1950: today it is conservatively put at 16,300,000 tons.

Not unnaturally during this period there was intensive competition not only between the newly developed plastics and the traditional structural materials, but also between the various types and families of plastics themselves. The result as far as the inter-plastics competition was concerned was the logical one, namely the restricted production of new materials and the gradual concentration of commercial effort on known and tried types. This does not mean that research effort has been relaxed, or that new plastics are not produced, quite the contrary, but it does mean that to attain commercial success a new plastics material must offer significantly improved properties, or advantageous commercial viability. As one expert put it recently, to get a footing in the plastics catalogue today, a new material must offer advantages over competitors of at least an order of magnitude. One result of this trend has been the concentration of research and development effort on known plastics, and much of this in the line of what is in effect combining one plastic with another, either by the process of co-polymerization (that is building up polymers from two or more monomers) or by what actually amounts to a blending process. This is likely to provide the main stream for plastics development in the future, since in this way the complex molecular structures can be tailored to give the desired physical properties with the maximum of certainty and the minimum of development cost.

B. THE ROLE OF PLASTICS IN BUILDING CONSTRUCTION

Rapid as has been the advance of plastics in the past twenty years, these modern materials of construction have not made the progress in the building industries which might reasonably have been expected. In Britain particularly hope ran high for use of plastics in the extensive building programmes which obviously had to be envisaged after the war. This was reflected in a far-sighted report published by the British Stationery Office for the Minister of Works in 1944 under the title "Post-War Building Studies No. 3: Plastics". This publication reflected a mixture of optimism and pessimism; optimism that plastics would be able to play a significant role in the rehousing schemes, and pessimism that the plastics-producing industry could be geared to meet this: in the event both have been disproved.

Strange as it may appear, the main difficulty barring the extended use of plastics in building has been as much psychological as technological. The building industries the world over are among the most traditional, and in an expertise which is more of a craft than a science, experience with materials and the processes of applying them counts for a lot. Inevitably potential users of plastics have been faced with the lack of performance data, without which even the most optimistic architect or contractor would be loath to specify them. Added to this it must be conceded that traditional materials have a reasonable performance record, and they are cheap, at any rate on a weight basis. Offset against this are the many new design possibilities which are open to plastics, and the fact that they lend themselves admirably to methods of mass production and off-site assembly so essential to the economy of modern building. To date Britain has been less progressive in the use of plastics in primary building work than America and Germany for example, but there are indications that this state of affairs is changing. Current reports on the actual and possible uses of plastics in building now available from all over the world are optimistic and in some cases most imaginative, but it is evident that skill and caution are still necessary if some of the early examples of misapplication are to be avoided.

II. THE CURRENT PLASTICS MATERIALS

A. THE PROS AND CONS FOR PLASTICS IN BUILDING CONSTRUCTION

At a time when large areas are being opened up in developing countries, many of which would present extreme problems by reason of inaccessibility of location due to distance or difficulty of terrain, the use of plastics must inevitably receive serious consideration. Where this is the case several critical questions have to be answered, the most important being the selection of the plastics to be used, and the economics of their supply. In some cases, particularly where the demand is limited or uncertain, there can be no doubt that the proposed industry would be launched on the basis of imported materials, imported that is either as raw plastics or partly manufactured materials.

Where the demand is larger and assured in a developing country, it will be logical to consider the manufacture of the raw plastics materials, and in such cases the possibility of using indigenous raw materials and local labour would naturally be examined first of all. Particular consideration should be given to the production of those plastics materials which, though perhaps no longer in high priority use in the highly industrialised areas of the world, are nevertheless able to meet local needs elsewhere, using both indigenous raw materials and drawing upon local labour. It may in some cases be necessary first to establish the end-product manufacturing plant, importing the required raw plastics materials from one of the large plastics exporting countries, as already suggested. If this is successful then the subsequent manufacture of the raw plastics would follow logically at a later stage. If this in turn proves satisfactory, then eventually the manufacture of the basic chemical raw materials might naturally follow.

From this it will be clear that the problem facing those who may be planning to meet the needs of the building industry in developing countries is not an easy one, and is indeed one which is further complicated by the fact that no single plastics material or family of plastics can meet all expected needs. The decision may resolve itself into one of several alternatives. If the indigenous raw material and labour positions are favourable, or if these can be met by convenient imports, then it may be advisable to start right away and make the necessary plastics, bearing in mind of course that plastics is a capital intensive industry, and it may thus require both financial courage to make the initial outlay and, if this is below the minimum capacity for economic break-even as it may well be, then it may need protective legislation until it has become established as a viable industry. Even if it is decided to do this, it is highly improbable that the whole range of plastics could be attempted initially, having regard to the fact that for any single plastics material there is a minimum production tonnage below which manufacture is not economic. How complex this may be will be seen from Table I which gives the production breakdown for plastics used in building as it was in the U.K. in 1965. Inter alia it will be seen that the 149,000 tons of plastics so applied was roughly 20% of the total U.K. production at the time.

TABLE I Tonnage of Plastics used in Building Construction in the United Kingdom 1965

Plastics Material	Long Tons* per annum
Polyvinyl chloride	80,000
Thermosets (phenolics, amino-plastics)	35,000
Polyethylene	12,000
Polystyrene	10,000
Acrylics	5,000
Polyesters and Epoxides	4,500
Polypropylene	1,500
Others	1,000
TOTAL	149,000 tons

*NOTE: There are three different types of 'ton' in common use: the 'Long Ton' equals 2240 pounds (avoirdupois), used in the U.S. and the U.K.; the 'Short Ton' equals 2000 pounds (avoirdupois), used mainly in the U.S.; the Metric Ton' (Tonne) equals 2204.62 pounds (avoirdupois) or 1000 kg., used throughout Europe.

1. Local Manufacture or Import? This vital question must be answered

The decision whether or not to manufacture plastics materials and/or products in a developing country will depend on many factors, of which those classified as wholly technological are by no means the most important; political, geographical and social factors are frequently more effectively weighty. It may be decided that in some cases it is unwise to establish an industry which is entirely dependent on imported raw materials, but except under war conditions this is a diminishing risk, having regard to the number of plastics manufacturers the world over who are only too anxious to extend their export markets. If in the end it is decided to go ahead and manufacture the basic plastics, or at least some of the more important such as the polyolefines and the vinyls, then the minimum economic production unit has to be decided upon. In this connexion it must be stressed that it is impossible to specify a minimum economic size for any plant without regard to the locally prevailing circumstances. What might be an economic possibility in one country might be completely unviable in another, and to a large extent the position varies according to the type of plastics material it is intended to manufacture.

It may alternatively be decided that initially at any rate, the raw plastics materials will be imported, in which case the problem is much simplified, since the whole of the available capital can then be devoted to the plant necessary for fabrication and end-product production. Such a procedure would of course broaden the variety of end-products to be covered initially, so that these could embrace indiscriminately those produced by compression, injection moulding, extrusion and extrusion blowing, indeed the whole manipulative range, depending on the available capital and available markets.

In both raw plastics and end-product production there is still the compromise course which might have much to recommend it in the initial stages of development, and that is to manufacture within the developing country the material likely to be in greatest demand (e.g. PVC or polyethylene), and to import the remainder, providing always that such a prime demand reaches the economic production minimum for the plastics material in question. The same procedure may be applied to the plastics end-products; it may be found advantageous to fabricate PVC conduits, gutterings, wall and floor coverings, and import the more costly and intricate plumbing and electrical fittings. As in the case of the raw plastics, there are custom fabricators the world over who are only too anxious to open up new markets for their products, and to do this they will be prepared to offer very competitive prices. It is appreciated that this suggestion may be at some variance with those made earlier, but at any rate it emphasises that careful market research, coupled with the unbiased guidance of experts in the field, is absolutely essential before any manufacturing project is launched. If in the last analysis it is decided that partial or total import of the raw materials and/or the end-products is most advantageous, it makes possible a period of consumer market trial for the new products. This point is sometimes overlooked by the planners: it cannot always be assumed that because plastics have been successfully used in buildings in Europe or America, they will be equally successful with developing countries. This point is dealt with more fully later, but it may again have stress here, at the point when vital decisions involving considerable capital expenditure have to be taken.

B. WHICH PLASTICS TO SELECT FOR BUILDING CONSTRUCTION

Having decided that in general terms plastics can meet the needs of building construction in relation to considitions obtaining in a developing country, and having decided that, having regard to those conditions, it would be desirable to import or manufacture the necessary plastics as the case may be, next comes the vital question, which plastics materials to use? In many cases the selection will ultimately be decided by cost considerations, but frequently there will be a selection within the possible price range, so that basic performance may be the final arbiter.

To assist such a selection comprehensive data relevant to the commercial plastics most widely applied in building consctruction, have been collected in Appendix I. These include not only data on the average physical properties of available commercial grades, but also average cost in the U.S.A. and the U.K., and a list of applications for which the materials have been successfully used. By its very nature such a collection of data can only be a first approximation, but it can at least indicate the direction in which further and more detailed enquiries should be made.

III. THE MANIPULATION OF PLASTICS

It is probable that the initiation of the manufacture of plastics building components in a developing country will, except in the most special circumstances, be on the basis of imported end-products, or if prospects are more propitious, on the manufacture of these end-products within the country, using imported raw materials. If it is the latter then it is merely a question of available capital, since their fabrication is a footloose industry, and can be established anywhere in the world where services (electrical power, cooling water, labour) and factory space are available. All the plant required can readily be purchased from well-established manufacturers the world over, and the prices are keenly competitive. In many cases it may not be necessary to purchase new plant, as reliable second-hand plant can usually be obtained, but new or second hand, reliability at the start should be insisted upon. Since moulds are costly units it will be worth while considering the question of hiring them, albeit modification may be needed to establish final designs. One thing most essential to the setting up of an efficient moulding, extrusion or calendering unit, is the availability on or near the site of an efficient engineering service unit. Excellent though the functionality is of the modern highly automated machines, they need considerable maintenance if top performance is to be ensured. This point may be considered when plant orders are placed, since if this has to operate several thousand miles from the maker, it may be wiser to select on the basis rather of the more fool-proof than on highly automated operation, a selection incidentally which would automatically be favoured in a land with no labour problem as in a developing country. Such have been the advances in machine design, production and service in recent years, that today this problem is becoming less serious, indeed some manufacturers maintain a fleet of light aeroplanes ready to fly spares or a repair team to sustain plant in remote areas. Even so, a degree of self help on the maintenance side must be allowed for, and is a valuable insurance policy, since economy of working will be adversely affected if the continuity of production is interrupted through machine failures.

Such is the variety of plant available for the manipulation of plastics that it can only be treated in briefest detail in this survey. Wherever possible when alternative processes could be considered for the production of similar units, then comparative costs (both plant and operational) will be given.

A. INJECTION MOULDING

This process, which was evolved out of the die-casting of metals, today accounts for the conversion of 35% of all thermoplastics materials: thermosets can be injected but at present this is less frequently applied. In injection moulding cold plastics material in granular ('nib') or powder form is fed into a heating cylinder, where it is softened to a point where it can be forced under pressure (i.e. 'injected') into the mould cavity, which is of the shape required in the finished article. The mould consists of two or more parts, and is closed under pressure at the time of 'injection'. After filling with the fluid plastics material, i.e. after 'injection' the moulded unit cools sufficiently to solidify in the mould which is then opened, and the solid moulding is removed. The lead-in points (sprues and runners), and any 'flash' which may be squeezed out where the mould sections join, is subsequently trimmed off.

Injection moulding is widely applied in the manufacture of products for the building industry. An exhaustive catalogue is impractical here, but the following items are among the most important: - fittings for water systems, soil and rainwater pipes; flushing cisterns for water closets; electrical fittings; ventilation grills; door lock fittings; water tanks up to 300 litres capacity; lavatory seats and accessories; drawers for built-in furniture.

1. Injection Moulding Machines, Range and Capital Cost

Injection moulding machines have to be very strongly constructed since they have to withstand injection pressures of up to 1,680 kilogrammes per square centimetre, and mould closing forces of from 50 to 3500 metric tonnes are necessary to keep the moulds closed against the pressure of the injected material. It is common practice throughout the world to classify injection moulding machines in terms of injection capacity, usually in grammes (or ounces) or cubic centimetres of injected material, and current commercial machines offered by some 150 manufacturers throughout the world range in capacity from a few grammes up to 1000 oz. per injection 'shot'. Naturally the speed of injection will show correspondingly considerable variation depending on the material used and the size of the injected unit, and may vary from a few seconds up to several minutes.

Injection machines are costly units, and the question of capital cost of the machines has often to be balanced against production capacity. For example the choice may be between a smaller machine operating a single impression mould at fast cycling, and a larger more costly machine operating a multi-impression mould on a much slower cycle.

The capital cost of various sizes of injection moulding machines is given in Table II. These cover the range most suitable for the production of most of the articles that are injection moulded for the building industry. It should be borne in mind that these are the costs at the manufacturer's works, and to these must be added that of transporting the machine to the country in which it is to operate. In Africa for instance, it is necessary to add between 9% and 14% depending on the distance from the manufacturer's works. This addition to the cost covers: packing for export, land and sea freight, insurance, clearing charges and import duty if any, land transport from port of unloading to place of installation.

TABLE II The Capital Cost of Injection Mounding Machines

Injection capacity of machine	Mould locking force	Prices	
		From	To
78 to 113 grammes	80 tonnes	$12,300	$16,000
120 to 190 grammes	150 tonnes	$20,000	$24,000
250 to 480 grammes	225 tonnes	$23,000	$28,000
750 to 1350 grammes	350 tonnes	$43,000	$48,000
2150 to 3450 grammes	700 tonnes	$85,000	$92,000

2. The Conversion Cost in the Injection Moulding of Plastics

Conversion cost is usually expressed as a percentage of the cost of the material that is fed into the machine, and in injection moulding the total conversion cost is between 55% and 95% of the cost of the actual plastics material manipulated, depending on the size of the machine and the extent to which the capacity of the machine is exploited in the moulding that is produced. This means that a moulding, the material of which costs $ 1.0, will have a total production cost of between $ 1.55 and $ 1.95. Such a cost is built up from a number of individual items of cost, which include the following: (1) the capital cost of the machine, its amortisation or depreciation, and the cost of its maintenance in good working condition; (2) the rent or cost of the floor space on which it stands; (3) the cost of electric power for heating the plastics materials and for operating the machine, and the cost of water for cooling the mould and the mouldings; (4) the cost of the mould, its amortisation or depreciation, and the cost of the maintenance of the mould in good working order; (5) the cost of the labour for operation of the machine, for changing the mould from time to time, keeping the machine supplied with material and taking away from the machine the mouldings produced; (6) the number of hours per day, and the number of days per year, that the machine is engaged in the production of useable mouldings; (7) the cost of supervision of the employed labour, the management of the moulding plant, and warehousing and despatch of the mouldings.

B. THE EXTRUSION PROCESS

In this process plastics material is softened by the application of thermostatically controlled heat, and is then forced continuously through a tool or die, profiled to a desired geometric cross section. Extrusion is used for the manufacture of materials which can be produced in continuous lengths such as pipes and tubes, sections such as rain-water gutters, also for ancillary materials such as films and sheets. About 27% of all thermoplastics materials are converted to useable products by the extrusion process.

As has already been emphasized in the case of injection moulding, it is impossible to give a comprehensive catalogue of the use of extruded plastics products in building construction, but those described below will be illustrative of the possibilities.

1. The Extrusion Machine or 'Extruder'

The extruder, as the extrusion machine is colloquially called, consists essentially of a long, cylindrical barrel, within which rotates a close-fitting Archimedean screw. The barrel is heated along its length, usually by electrical band heaters which embrace the barrel. The material to be processed is fed into one end of the screw from a feed hopper which allows free flow of the 'nibbed', granular, or powdered material, and in sufficient quantity to fill completely the flights or grooves in the screw, and in its travel through the barrel this is heated and becomes plastic in the true sense of the word. When the material reaches the end of the screw, it is semi-molten, and in this condition is forced through a tool or die so shaped that it moulds the material to the desired profile, as for example that of a pipe or tube. The final shape of the extruded section is determined by the cooling arrangements, and the equipment used to 'take off' the section from the die. The type of pulling or haul-off equipment varies with the type of product that is desired.

2. Extruded Plastics as Building Materials

Pipes of one type or another make up the bulk of the extruded plastics used in the building industry. These range from the narrow-bore rigid PVC pipe used for electrical conduit, and the slightly larger flexible polyethylene or polypropylene pipe used for cold water pipes, to the large-diameter rigid PVC pipe used for air ducting and ventilation and rainwater down-pipes, and in half sections for guttering. Pipes are under development for conveying hot water, and indeed some are reported to be fully commercial, but manufacturers are currently reluctant to give the necessary guarantees for the lengthy performance which most architects require.

Sheets of PVC, ABS, or polyethylene up to one and a half metres wide and up to about five millimetres thick are produced by fitting a sheet die, of the required width, to a suitable extruder, and providing haul-off rolls to take the sheets from the exit of the die, through rollers, and on to a cooling and cutting table, where they are cut to the required length. In the production of corrugated plastics sheets for roofing and cladding, usually from unplasticised polyvinyl chloride materials, it is common practice to take an extruded sheet still hot from the extruder, and to pass it to ancillary equipment, which either gives it a corrugated contour longitudinally (i.e. in the direction along the sheet) or transversely (i.e. across the width of the sheet). Such equipment is available in forms which will corrugate the extruded sheet at the same speed as that at which the flat plain sheet is produced by the extruder. As may be imagined this is a reasonably precision process so that the machines are quite complicated and have a high degree of automation.

In the building industry it is common practice to protect building work in progress against the effects of rain, and this is now usually done by erecting over the work area a light wooden framework, covering this with thin plastics sheeting, generally polyethylene film. Film of this type is produced by extrusion followed by air blowing. A large diameter tube, of small wall thickness is extruded in the normal way, and as this tube leavesthe die, it is inflated with air so as to increase its diameter thereby reducing its thickness. This tube is taken over haul-off rollers, flattened and slit along its length, thus converting a flattened tube into a sheet or film of what is effectively double the width of the flattended tube. For this reason the tube and the film produced therefrom is frequently referred to by manufacturers as 'lay-flat'.

Another variant of the extrusion/blowing process is used to produce a variety of hollow articles. Although not many of these are used directly in the construction of the actual buildings, many of the liquids used in the building industry are packed in bottles and similar containers produced by this process. Many ancillary tanks and cisterns used in buildings are produced in this way, and with the elaboration of the technique and its extension to the production of more massive units, it is being applied to the production of baths, shower sections and hand-wash basins, one extrusion/blown unit being divided at the 'half-way' line to produce two finished products.

3. Capital Cost of Extrusion Machines

Extruders are usually classified by the diameter of the screw with which they are fitted, and quite expectably prices for different sizes show a considerable range; those given below in Table III are the manufacturers ex works prices. The same remarks already made concerning the actual cost of injection moulding machines apply also to extruders, namely that the cost at the works must be increased by 9% to 14% to obtain the price delivered to the factory in which they are to be installed. The prices quoted are for the basic extruder only, but include the electric motor to drive it, the control gear for the motor and temperature controls; they do not include the cost of any tools or dies to produce the required sections, such as pipes and sheets. In assessing the capital cost of extrusion equipment it must be remembered that quite apart from the specific dies, the ancillary equipment may well cost as much as the extruder itself. In addition it must be appreciated that the manufacturers rated output of their extruders is really only a comparative figure, and what may be termed the useable or effective extrusion capacity must be directly related to the product envisaged. For instance the output of an extruder producing thick sheeting in widths in excess of one metre, will be considerably greater than that of a similar machine producing say 3-5 mil. lay-flat polyethylene film.

TABLE III <u>Average Prices for Standard Extrusion Machines</u>

Screw size in mm.	Prices	
	From	To
20	$ 5,300	$ 7,400
30	$ 8,300	$ 10,200
40	$ 11,700	$ 14,500
60	$ 13,700	$ 17,100
90	$ 15,400	$ 18,500
120	$ 22,000	$ 38,000

4. Cost of Conversion of Plastics Materials by Extrusion

As in the case of injection moulding, the cost of conversion of raw plastics into useable end-products depends on a number of different factors, of which factor (6), the number of hours per day and the number of days per year that the plant is operated, is of material significance. Some average costs are given in Table IV, which will serve to show how the ultimate cost varies both with the type of product manufactured, and with the size of the extruder used.

TABLE IV Conversion Costs for Thick Walled Pipe and Thick Sheets, Large Dimension Sections, Heavy Guttering

Type of Product	Screw size of extruder in mm	Conversion Cost as a percentage of raw material converted
Thick-walled pipe;	60	35% to 60%
thick sheets;	90	28% to 50%
large dimension sections;	120	25% to 40%
heavy guttering;		
Thin-walled pipe;	20	85% to 95%
thin sheets;	30	70% to 80%
lay-flat tubing;	40	60% to 75%
	60	55% to 65%
	90	35% to 45%
	120	30% to 50%

C. CALENDERING

As the name implies, this is a process for forming plastics sheets from a dough-like mass, and is indeed one which has been widely applied for many years in the processing of rubber. With its extended potential for the production of sheets and films in a variety of plastics, it is not surprising that it has received considerable attention from plant manufacturers in recent years, and today the latest plastics calenders represent exceedingly sophisticated and costly plant units. In the calender machine a number of precision-ground rollers gradually reduce a plastics mass to a sheet of film. The dough-like mass produced from basic plastics material, with the addition of anti-oxidants, plasticisers, lubricants, etc., is prepared in a special mixing machine (usually of the Banbury type) and, in a pre-heated form, is fed between two heated rollers. From this first pair it passes to further rollers, until it is reduced to the required thickness. It is common practice for one pair of the rollers to have a pattern engraved upon it, thereby making possible the production of plastics sheeting with surface embossing suitable for the upholstery of furniture and motor car seats, for curtains, clothing and simulation leatherware. The calendering machine itself is a precision machine, for which strong and elaborate foundations have to be provided, and very highly skilled labour must be employed in its erection, assembly and operation. Each pair of rollers must be accurately aligned to within 0.01 of a millimetre. The cost of a calender machine can vary between $ 300,000 and $ 1,000,000 for the machine itself, and as already stated this is only a part of the necessary expenditure. The preparation of the strong and elaborate foundations, the cost of erecting the calender, the cost of the provision of premixing and heating equipment can amount to another $ 75,000. Quite obviously before such a costly and high-production unit is contemplated, an assured market must provide a steady round-the-year load for the machine before installation becomes an economical proposition.

D. VACUUM OR AIR-PRESSURE FORMING

Sheet plastics produced by extrusion or by the calendering process, can be formed into finished products by several methods, the most attractive of which is thermoforming with the application of suction, usually styled vacuum forming. Limited only by the imagination of the operators and their creative ability, thermoforming has today developed to become one of the most profitable and widely used of plastics manipulation processes. The process is basically very simple consisting essentially of heating a plastics sheet to the point at which it is limp. and in this condition 'draping' it around a mould, either by applying a vacuum or with air pressure. In such processes, a sheet of plastics material is usually clamped into a frame, and heated by the application of infra-red heaters until it softens. It is then transferred into a tool profiled to the desired shape in which either a vacuum is applied underneath the sheet, or air pressure is applied above it to bring it into the required form. Articles that can be made by such processes are: panels for illuminated ceilings, lighting fitting shades, trays for kitchen fitments, door liners and interior liners for refrigerators.

1. Costs of Vacuum and Air-Pressure Forming Plant

Vacuum forming machines are currently available in a range of sizes from the smallest units capable of dealing with sheets from ten centimetres square, up to units which will convert large sheets of one and a half metres square. Prices vary from $ 800 to $ 50,000. In addition to the actual vacuum- or pressure-forming machines it is necessary to have equipment for cutting standard sizes of sheets to the size required for the machine, and to trim the finished unit from the unwanted portions of the sheet after forming. Vacuum or pressure equipment is also essential.

2. The Cost of Vacuum Forming and Pressure Forming Compared with Injection Moulding

In most applications, vacuum-forming and pressure-forming cater for completely different demands from those filled by injection moulding, but there is a limited field that can be covered by both these processes. There are actually not many applications in the building industry that can be covered by both processes, except perhaps the production of doors and interior liners for refrigerators. In this latter case vacuum-forming is a cheaper process up to a total production run of about 28,000 mouldings, but any production above this quantity would be more cheaply met by injection moulding. It is possible to produce articles in thicknesses down to 0.20 mm. by vacuum and pressure-forming; by injection moulding on the other hand, the thinnest articles that can be produced economically vary from about 0.50 mm to 3.0 mm depending on the total area of the article to be produced.

E. FLUIDISED BED COATING

This process is normally applied to the coating of metal objects with plastics, to protect them from attack by rust or other adverse influences. In the process a finely powdered plastics material is placed in a tank, the bottom of which is air-permeable. Compressed air is blown through this material, thereby raising the plastics material in the tank, so that it assumes the nature of a dense cloud, almost fluid-like in properties. Metal parts to be coated are first heated, and in this state are plunged into the air-blown plastics powder in the tank, so that they become surrounded by the dense cloud of this powder. Material making contact with the heated surface of the metal partially melts and becomes attached thereto, so that by this means a skin of plastics powder is built up on the surface of the heated article. Excess powder is removed by tamping, and the plastics layer thus formed is then fused by further heating, finally forming a homogeneous coating layer. This process is applied to such articles as shelves and racks for refrigerators, metal articles that have to be exposed to outdoor conditions, hardware for use on farms, etc.

1. Conversion Costs by the Fluidised-bed Process

The cost of such equipment is quite low, from $ 400 to $ 8,000 depending on the area to be covered. The process is covered by world-wide patents, and in most cases the patent royalty is covered by an extra charge on the finely divided plastics material used for the process. A variety of thermoplastics materials can be used in this process, notably polyethylene, cellulose acetate butyrate and Thiokol, and in most cases, it is preferable to buy the finely divided material from a commercial source, since to make it requires an investment of from $ 16,000 to $ 60,000. The fine grinding of plastics materials involves a lot of technical 'know-how', and in addition to the cost of the plant itself, involves heavy expenditure on the equipment necessary for explosion prevention, since finely divided plastics materials are highly explosive when mixed with air in critical proportions.

F. MOULDING BY THERMOFUSION

In thermofusion, powdered plastics material is put into a sheet metal mould which is then heated (usually by means of hot air) in an oven sunk into the floor of the production shop. By the subsequent application of heat a skin of the plastics material is built up on the inner wall of the mould. When a sufficiently thick layer has been built up, the unwanted material is emptied from the mould, which is then returned to the oven to enable a smooth surface or 'glaze' to be put on the film of plastics layer adhering to it. After this operation the mould is withdrawn from the oven, the mould and the moulding cooled, first by a jet of cold water, and then by immersing in a cold water tank. As the mould and the moulding cool, the latter separates readily by reason of the greater shrinkage of the plastics material. This process is used where the total production quantity would not justify the necessary large investment on an injection moulding tool, or where the article is of such a size that the investment on a mould and an injection moulding machine of suitable size would be prohibitive. A plant of this nature suitable for the production of articles up to one metre cube would cost about $ 40,000. The moulds are relatively cheap to make, and vary in price from about $ 200 for an article ten centimetres cube, to about $ 1,500 to $ 2,000 for an article one metre cube. The process is covered by world-wide patents, but countries in the British Commonwealth and the French Colonial Territories may usually operate this process without the payment of royalties, since the techniques normally used in Britain and France do not infringe these patents.

G. ROTATIONAL MOULDING

Rotational moulding is a development from the above process, by which closed or nearly closed articles can be produced, by contrast with the thermofusion process in which only articles that can be drawn from a one-piece mould can be produced. In rotational moulding a two- or more-piece mould is charged with a sufficient quantity of finely-divided thermoplastics material to make the required moulding. The mould is then rotated simultaneously in two directions at right angles, and whilst being so rotated it is heated either by hot air or by a heated liquid. During rotation the material is tumbled around inside the mould, with the result that a gradually increasing thickness of softened plastics material builds up on its interior surface. When all the material has been softened and spread on the interior of the mould, this is cooled, thus also cooling the moulding inside. In the final stage the mould is opened and the moulding is withdrawn.

Among the units used in building construction which can be produced by these processes, the following are the most important: water tanks; waste containers; ball-valve floats; plastering trays; wheelbarrow bodies; large rain water gutters; large roof ridge tiles; special profile baths and ornamental pond linings.

1. Plant and Conversion Costs by Thermofusion and Rotational Moulding

Conversion costs by these processes vary very considerably according to the type of article produced. As an example, the conversion cost of a waste bin 41 centimetres diameter and 50 centimetres deep would be about 55% by the thermofusion process, and a lid for such a bin about 200%. If made by the rotational moulding process, the bin and lid would be made in one operation and the lid cut from the bin; the combined conversion cost would be about 60%, these percentages as in the case of injection moulding already quoted, being on basis of the raw material cost.

Plants of this nature vary in cost from $ 4,000 for a relatively small unit to $ 40,000 for a large plant. Mould cost from $ 350 for an article ten centimetres cube to $ 2,000 for an article of one metre cube, must usually be allowed for.

H. COMPRESSION AND TRANSFER MOULDING

These are the original processes which were applied for the manipulation of plastics and were those on which the plastics industry was virtually founded; they represent the bucket-and-spade operation which most of us applied as children in the building of sand castles. Compression moulding is applied exclusively to the working of thermosetting plastics, and in this the moulding operation not only forms the desired shape, but also converts the plastics material into the insoluble, infusible or cured state. In some cases the thermosetting material is first heated in a cylinder and then transferred to the mould by a piston: this is very logically designated transfer moulding. Recently machines have been developed by which thermosetting materials may be processed by a form of injection moulding.

Typical units produced by compression moulding include the following: door handles and miscellaneous door 'furniture'; a wide range of electrical fittings such as switches; junction boxes and lamp holders; bathroom fittings; water closet flushing cisterns; kitchen fittings; furniture components such as stool seats; lavatory seats.

1. Plant and Conversion Costs for Compression Moulding

Compression moulding presses are, in some cases, supplied with hydraulic power from a central hydraulic pumping installation, but in giving approximate costs of compression moulding plant, only self-contained presses which have built-in hydraulic power, are here considered. Presses may be equipped with platens (i.e. press plates) that are heated electrically, and they may be automated in various ways to make the task of the operator more simple, indeed the modern tendency is towards self-contained and reasonably fully automated units. In Table V approximate costs of a limited range of the latest type of self-contained compression presses are given.

TABLE V Average Cost of Compression Moulding Presses

Pressure (total thrust) exerted on platens	Cost	
	from	to
60 tonnes	$ 3,800	$ 7,000
80 tonnes	$ 4,250	$ 9,000
150 tonnes	$ 8,400	$ 12,000
300 tonnes	$ 12,500	$ 16,500

The sizes of mouldings that can be produced on these presses is calculated on their depth and effective or projected area. In the case of shallow mouldings pressure of the order of 200 to 300 kilogrammes per square centimetre is needed, whilst in the case of a deep moulding 400 to 600 kilogrammes per square centimetre is needed. On this basis a 150 tonne press will produce a shallow moulding with an area of 600 square centimetres, or a deep moulding of 300 square centimetres area. Moulds for thermosetting materials are usually a little less costly than those used for injection moulding of thermoplastics, but the actual production cost of the required mouldings is usually higher by compression than by injection moulding. The conversion cost in the operation of the compression moulding process varies between 66% and 120%, depending on the type of moulding produced and the type of thermosetting material that is used.

I. THE PRODUCTION OF LAMINATES AND COMPOSITE MATERIALS

Of all the plastics available to the architect and building contractor, laminates and related materials are likely to be the most attractive, and in certain areas at any rate, initially the most functionally satisfactory. The reason for this is again both psychological and technological, since laminates being available as sheets, rods, and tubes most nearly resemble traditional structural materials. The main drawback to their extended use as building materials is of course that they are costly, albeit they offer quality for cost.

1. High-pressure Laminates

The production of reinforced laminated plastics is virtually a separate industry within the body of the plastics industry, and indeed the need to produce synthetic bonding agents for paper to replace natural materials such as shellac, accounted for much of the early research in plastics, including Baekeland's pioneer work. The idea at the time was to bond paper, fabrics or mica (or indeed loose fibres or fibrous materials such as sawdust or wood chips) to give laminated materials among others for the rapidly growing electrical industry, but it was natural that such materials once commercially available were applied for their structural as well as their electrical properties. These early materials were produced by bonding layers of paper, fabric, or loose fibres, impregnated with thermosetting resins such as phenol-formaldehyde or urea-formaldehyde, under considerable pressure and at elevated temperature, so that they emerged as fully cured rigid boards. The keynote of the processing of these materials was the high pressure applied (of the order of 1000 lb. per square inch) and not surprisingly the products were, and indeed are referred to, as high-pressure laminates. This rather complicated and plantwise cost-intensive process inevitably means that these laminates are costly, and of course they are limited in sheet size to the size of press available. Intensive research in recent years has done much to balance out those difficulties; sheet size has been increased, and the plants have such a remarkable degree of automation that production costs are well down compared with those of but a few years ago. Even so the cost of the plant is such that a considerable and assured market is essential to justify its installation. This need not deter a developing country from using these materials wherever possible, since they are available world-wide in many grades at very competitive prices.

For those developing countries which embrace large areas of forest, the production of resin-bonded sawdust or chip-board has attractive possibilities. The basic phenolic or amino-resins will present no problem as they are readily available throughout the world, and could be imported until the industry is sufficiently established to warrant home manufacture. The disintegrated wood 'filler', in the form of sawdust or wood chips can be collected from sawmills in the neighbourhood, but eventually it will be essential to produce the wood-chip at the laminating plant, using forest offcuts and trimmings. In the manufacture of chipboard the economy of the process depends largely on the local availability of wood of the required quality, just as the quality of the final pressed board depends both on this and on the shape and size (often referred to as the geometry) of the wood chip. From being a Cinderella industry a decade ago, the production of chip-board is now a thriving industry in many parts of the world, and world production is currently of the order of six millions tons per annum.

Building construction is developoing countries will find many applications for all these laminates. Chip-board will come in for internal partitions and ceilings of low-cost houses, whilst the more elaborate laminates so familiar under trade names such as 'Formica', 'Warite', 'Perstorp', will find use for better class panelling, table and work tops, and general house fittings. These items would undoubtedly be imported.

2. The Production of Glass Fibre-reinforced Polyester Laminates (G.R.P.) (low pressure laminates).

The functional and financial limitations referred to above applied to what may be called the traditional laminates, that is those based on the use of phenolic and aminoplastic resins, so that it was a great step forward when towards the end of the war other thermosetting resins (the so-called polyesters) were developed for bonding reinforcing fibres which, by reason of the fact that they eliminated no chemical products (e.g. water) during the curing process, could be worked at comparatively low pressures. These were indeed only the pressures needed to keep the resin-impregnated fabric or paper layers together in contact as as a cohesive mass, and for this reason the products were for some time referred to as low-pressure or 'contact' laminates. So simple indeed did this form of laminating appear to be by contrast with the original high-pressure process, mainly due to the fact that large and costly high-pressure plant was no longer required, that it came to be looked upon as a 'poor man's process', and for a time it attracted manufacturers who did not fully understand what they were doing, with the expectable result as far as the quality of the goods and the good name of contact laminates was concerned. Fortunately this is now old history, and today the materials produced in this category world-wide are of high quality, and, for reputable grades, quite reliable. They are variously known in the trade by the initials of the fibrous material now most widely used as reinforcement (since glass fibre has long since replaced paper or fabrics for many purposes) as G.R.P. (glass fibre-reinforced plastics) or more colloquially and quite erroneously in the U.K, fibreglass. Since these materials have such a considerable potential in the building industry, particularly since they can be produced if necessary on or near the building site, they will be described here in greater detail. Glass fibre-reinforced plastics should certainly rank high in the priority list of any developing country considering the manufacture of plastics for any structural purpose.

The processes employed in the production of these materials may vary according to the size and quantity of the articles to be produced, and range from those in which no demands on plastics machinery need be made but where a high level of craftsman skill is needed, to highly mechanised processes allowing fast production rates and being largely free from operator skills.

The most widely employed process, known alternatively as the wet lay-up or hand lay-up process, places virtually no limit on the size or complexity of the moulding to be produced, and is consequently widely used for such items as boat hulls, storage vessels, car bodies and dwelling units. The wet lay-up process, in its simplest form, makes no demand on expensive moulds or presses, and is eminently suitable in situations where initial capital costs must be kept at the lowest possible level and where manpower is readily available.

In essence this process employs a single open mould in which the glass fibre reinforcement and polyester resin are formed to shape and allowed to harden naturally without the application of heat. Moulds employed in the process may be made of either plaster, wood, or indeed of G.R.P., according to the number of mouldings to be made in them. Where a prototype is to be made and only 1-3 mouldings are required, a plaster mould, sealed with a shellac varnish, may be employed; the life of such a mould is short and the surface finish of mouldings produced from it is relatively poor; mould cost however is very low. Where possibly 200-300 mouldings are to be produced, G.R.P. moulds are made by first preparing a plaster former in the shape of the final product and, after sealing the surface, forming a G.R.P. moulding around it. This moulding, after removal from the plaster, forms the actual mould subsequently to be used in production.

The individual stages of the wet lay-up process are as follows:

(a) The mould is cleaned of any residual traces of the release agent remaining from its previous usage, by wiping out with a clean wet cloth and drying.

(b) Where a high surface finish is required the clean mould may be given a coat of wax polish and polished to a glossy surface; this is in general only necessary every 3-4 mouldings and may be omitted where the highest gloss finish is not required. It is then coated with a release agent which will allow the final moulding to be easily removed. The most widely used are aqueous solutions of polyvinyl alcohol; these are lightly smeared on with a cloth or sponge and allowed to ry.

(c) The mould, coated with the dried film of release agent, is painted with a coat of polyester resin to which a catalyst and an accelerator have been added to initiate the hardening process. An even coat of resin is applied over the whole mould surface at a coverage of approximately $1\frac{1}{4}-1\frac{1}{2}$ oz. per square foot, and this coating allowed to set moderately hard (just markable with the thumb nail), before proceeding to the next stage. This first coat, applied without any reinforcement, is termed the 'gel' coat. If it is required that the moulding produced should be self coloured to avoid the necessity of later painting, pigments or dyestuffs are incorporated in the resin before its application to the mould.

(d) With the mould coated with a release agent and the hardened resin 'gel' coat, the reinforcement layers are next applied. The most widely used reinforcement, chopped strand mat, is a lightly bonded mass of glass fibre strands randomly laid to form a non-woven fabric; the binder holding the strands of glass together is soluble in polyester resin so that, when resin and reinforcement come in contact, the binder dissolves to leave the glass fibres floating freely in the resin.

(e) The open mould is first coated with a layer of a polyester resin to which catalyst and accelerator have been added and a cut sheet of chopped strand glass mat is draped over the mould. The reinforcement is lightly tamped into place against the contours of the mould and further resin applied on top of it by brush. As the binder dissolves, the mat becomes more pliable until it may be pressed firmly by brush against the mould surface, and into corners and recesses, and lies flat against the mould.

.) Perhaps the most important stage of all follows the placement of the (glass mat) reinforcement on the mould, that of consolidation of the mat and the removal of all air trapped in the resin/glass fibre matrix. This is accomplished either by stippling the resin/glass mass with the tip of a brush, or by rolling the laminate with a soft roller; in either case the object is to work the wet laminate and ensure that the glass fibre is thoroughly wetted with resin, leaving no dry patches, and also at the same time physically to exclude as thoroughly as possible bubbles of air trapped in the wet mass. When consolidation of the mass is complete, further layers of glass and resin may be applied to build up the thickness, strength and rigidity required in the final article. Finally the lay-up is allowed to stand and cure to a rigid mass.

(g) The time elapsing between the completion and setting of a resin/glass laminate and its removal from the mould is largely dependent on the ambient temperature conditions, the size of the moulding and the particular resin employed. Small mouldings whose weight is not such that they would deform under their own weight may be removed from the mould after a few hours but larger mouldings are better allowed to remain in the mould overnight to develop strength before removal. In many cases, such as boat hulls and dwelling units, the moulding may be pulled out of the mould and held in jigs to prevent deformation, as the full strength of the moulding is developed over the few days following its preparation. Such time loss can be avoided if facilities are available for storing the mould and moulding for a few hours at temperatures of 60-80°C before they are parted.

(h) The moulding, after release from the mould, is trimmed at the edges and washed free of traces of release agent. Other than painting, if a pigmented resin was not employed, the laminate is completed and ready for service.

A moulding made by the wet lay-up process is characterised by possessing one surface which is smooth, glossy and reflects the contours of the mould in detail, whilst the reverse surface shows the rougher pattern of glass fibres in the resin-rich surface. Where the laminate is to be exposed to the elements it is the gel coat which is normally exposed.

Whilst the process described above represents the simplest and the most widely adopted fabrication method, it is capable of adaptation by degrees to a more mechanized basis. Equipment is available which allows resin to be applied by spray gun to the mould and the glass mat, whilst other equipment dispenses with the need to use glass in the form of a mat, by chopping glass from a continuous reel and spraying it on to the mould, where it only remains for the wet mass to be consolidated by rolling. Such spray units allow faster production of laminates and, when used in conjunctionwith a larger number of moulds and curing at elevated temperatures, production rates can be greatly increased.

The production of glass-fibre-reinforced polyester laminates is by no means limited to the wet lay-up process and its variants, but these methods represent the process in which tooling costs and equipment expenditure can be reduced to a very low level. At the other end of the scale reference may be made to the matched-metal die process, where very expensive heated metal dies are employed mounted in hydraulic presses.

In this process polyester resins are employed with catalysts which become active only at elevated temperatures, and the resin/glass composite is hot moulded under pressure to give laminates with a good surface finish on both faces, and an accurate control of laminate thickness; the hot moulding process between metal dies allows very rapid production rates of smaller laminates and greater consistency of quality is obtained. However in this case mould costs are high, and this must be amortised over many thousands of mouldings produced; furthermore the capital cost of a hydraulic press and ancillary equipment must be borne.

J. THE PRODUCTION OF CELLULAR OR EXPANDED PLASTICS

Contrasting with the high pressure laminates in that they come at the end of the density scale, yet resembling them in that they are rapidly attaining the status of a separate industry, is the family of expanded, foamed or cellular plastics. As a class these materials are not novel, since they have been commercially available in the form of synthetic viscose sponges and foamed rubber for a number of years. The great step forward came with the development of new and more efficient methods to expand or 'blow' the plastics, with an increase in the number of plastics which could be thus treated, and with new and imaginative methods of applying them commercially. Their production is basically very simple, and consists of adding to the plastics material in suitable liquid or solid form, chemicals which will generate inert gases such as carbon dioxide or nitrogen, which when liberated under controlled conditions will 'blow' the plastics material up into what is virtually an agglomeration of bubbles. Alternatively polymers such as polystyrene beads can be caused to take up controlled quantities of volatile hydrocarbons which, under suitable conditions of temperature, will be liberated in gaseous form, thereby increasing the size of the plastics globule, and uniting a number of these into a compact mass. According to the method used, the resulting expanded mass can have an open-cell or a closed-cell structure.

Initially foamed plastics such as phenol formaldehyde, urea formaldehyde, rigid PVC and polystyrene, were formed in large blocks, which were subsequently cut into sheets down to something like one eighth of an inch thickness. A real break-through in plastics foam technology came with the development of foam-in-situ materials. This meant that a plastics composition in liquid form (such as a polyurethane) or the ingredients thereof, could be poured into a mould or cavity wall where it would foam, filling the cavity no matter how complex the shape. This was of course a great advance for the builder who could avoid the rather time-consuming procedure of lining a room with say polystyrene sheet, but could obtain the same result by pouring the calculated quantity of polyurethane syrup into the wall cavity.

Whether in the form or more or less conventional blocks or sheets or as expanded-in-situ material, it is already very evident that there is a considerable future for expanded plastics in building construction. Whilst in the main they will be used as ancillary materials co-functioning with conventional building materials, they can function in their own right as primary structural materials. Reports are already optimistic about the use of expanded polystyrene for example for the building of small igloo-type houses, using blocks of the foamed plastics just as the Greenlanders use blocks of snow. Once the structure has been completed the expanded plastics can be coated with a layer of concrete or of other suitable plastics material such as a bituminous composition. Such a method of construction is particularly to be recommended in a developing country, since the blocks of expanded polystyrene can be produced on site, using imported impregnated polystyrene beads.

IV. THE SIGNIFICANCE OF PROPERTIES OF MATERIALS IN THE APPLICATION OF PLASTICS IN THE BUILDING INDUSTRIES

To formulate a balanced view of the potential of plastics in the building or any other industry, we must of course carefully weigh the favourable properties against those adverse to their use, and indeed the extent to which current or future developments are likely to enhance the one or ameliorate the other. Against those properties which favour the use of plastics in building construction, must be set a number of limitations, some of which indeed are determined by those same properties which in other circumstances are favourable. Additionally of course the case for or against plastics must take account of properties which may be broadly designated as short term, and thus subject to relatively quick change, and those of a long term nature which may expectably remain constant over the specified life time of a building. Under the former category we consider such properties as tensile strength, flexural and impact strength; under the latter the less easily defined creep, stress relaxation, apparent modulus, fatigue strength and ageing characteristics. Although, by their nature, plastics are the ideal materials for mass-production in that they can be moulded (and in general the more copies of a single product required the more economical does their use become), the fabrication from thermoplastics of large units such as might be required for building is still in the realms of a technology that is only now being developed. Large stress-free thermoplastics mouldings have been produced, but in most cases these are not self-supporting and require to be fitted into a suitably designed structure. As has already been suggested the most practicable method of producing large plastics units is by lay-up or hot-pressing of glass fibre-reinforced plastics. These may provide the necessary properties, but by their nature they are a less economical approach to the problem, since mass production in the sense of truly mechanised working has not so far been achieved. Well known though the properties of plastics may be, it may be helpful to recapitulate them briefly, and then to consider more objectively the pros and cons with specific reference to their potential in building construction.

A. A SURVEY OF THE PROPERTIES OF PLASTICS WHICH ARE SIGNIFICANT IN BUILDING CONSTRUCTION

The engineering properties of plastics differ markedly from those of traditional materials, mainly in the following features: (i) stress-strain curves are not usually linear up to the point of failure, and their moduli of elasticity and rigidity are very low; (ii) plastics can exhibit anisotropic behaviour; (iii) the mechanical performance of plastics is affected by the rate of straining of the material, and also by the temperature and by other environmental conditions to which they are subjected; (iv) plastics 'creep' considerably under load with time, and may show a reduction in ultimate strength with time even under static loading.

When considering the mechanical, thermal and other properties of plastics it is important to remember that, while as a class they differ from traditional materials in many ways, they must really be considered as individuals because of the wide spread of their properties. As an illustration of this, most plastics materials have a relatively low modulus of elasticity, which shows up as a low stiffness when compared with metals, but when a polyester resin is reinforced with glass fibre a considerable increase in stiffness occurs. If, further, due allowance is made for the fact that the glass/resin composite has a much lower density than, say, a ferrous metal and, therefore, for the same total weight, can be used in thicker section, stiff structures can be achieved. This argument, based on the property of stiffness, can also be related to other mechanical features, e.g. strength. One can thus talk of 'specific' strength and thereby include a factor for the low density of the plastics material, and discover that weight for weight its properties can be impressive. Because of the low Young's Modulus for plastics materials, most of their applications have been limited to stressed skin construction in which the skin not only forms the enclosure but contributes substantially in carrying external loads. On these lines domes, hyperboloidal and pyramidal structures have been built, many of them using plastics as the main load-carrying material.

Since not every plastics application envisages the material as being used on a comparable weight basis, the detailed behaviour of plastics materials under more stringent conditions then needs to be known. This subject of engineering design with plastics is now being studied intensively, with the result that there are many new applications in which some plastics (e.g. polyacetals and polyamides) are replacing metals as engineering materials based solely on their superior performance. For example as a result of long laboratory study, plastics pipes can be made from low and high density polyethylene and from PVC, to established specifications covering a wide range of operating pressures. These specifications have been based on bursting and stress rupture tests carried out at specified temperatures over wide pressure ranges, so that prediction of stresses which could be withstood for, say 20 years, can be achieved. If the stress characteristics of an application can be specified (pipe under internal pressure is a particularly simple case) then the problem can be studied, specifications prepared, and the behaviour of plastics material in such an application predicted. Metal engineering is, in many ways, the application of classical elasticity theory; engineering in plastics requires a different basic theory to take into account the inherent time and temperature effects. This theoretical background is now being obtained through intensive research and development work on a hitherto unprecedented scale.

B. THE ADVANTAGES OF PLASTICS

The current general world trend for almost all materials of construction is for them to become increasingly expensive. This is not so for plastics materials for which prices have steadily fallen over recent years, and continue slowly to fall even for the well-established materials, though there is now a definite indication that they are about to rise or have actually done so. At any rate with plastics planners can at present count on a degree of price stability which is not encountered in any other area of commercial materials. This fact, allied to their advantageous properties, makes them worthy of detailed consideration for major applicati such as building.

The advantageous properties of plastics are: (a) light weight, (b) formability, (c) self-coloured , (d) resistant to a wide range of environmental conditions. As has already been stated, plastics materials used in building are generally low in density, ranging from about 0.9 for the polyolefines, to about 2.3 gm/cc for glass-reinforced polyester heavily reinforced. This clearly means that plastics structures require relatively light supports, and that handling and erection is an easier matter, not requiring undue mechanical aid. Plastics materials are eminently formable, and offer design possibilities over other materials. The range of processes for the production of plastics units is wide, as we have already seen, and provided electrical power can be generated on site, and water is available, there is no reason why these processes should not be carried out at any place in the world. A limited amount of skilled labour is required, but generally speaking and by comparison with many others, whilst being plant 'intensive', plastics is an industry which makes smaller demands than most on labour, although this is a characteristic likely to be of minor interest in developing countries where labour is usually freely available. In such cases it is important to remember that the use of plastics in building can assist the developmen of prefabrication or in-factory assembly, and in the main relatively unskilled labour can be put to good use in such operations.

Plastics materials can be considered to be permanently self-coloured though this statement requires some qualification in the light of the potential effects of environment (especially that of strong sunlight) upon the colouring matters added to the plastics. Resistance to ultra-violet light varies over wide limits. Some materials show excellent intrinsic weather resistance (polyvinyl fluoride is an instance) while in other cases resistance to ultra-violet light can be enhanced by the use of U.V. absorbing additives. By correct selection of materials, resistance to difficult environments can be achieved. There is no risk of corrosion as occurs with metals, and within certain limitations, plastics materials require little maintenance.

C. THE LIMITATIONS OF PLASTICS

Despite the foregoing impressive catalogue which obviously makes plastics highly qualified for use in building, some of their desirable properties cannot conveniently be accommodated in design. For example in order to obtain sufficiently rigid structures which will show a minimum of change with time, it is necessary to ensure that plastics components are subjected to stress levels very much lower than the ultimate failing stress as determined by a short-term test. In consequence plastics structures are frequently 'over-designed' to provide the necessary rigidity at low stress-levels, or alternatively, structures are designed which differ radically from those of traditional building, e.g. stressed skin and folded plate structures. In direct consequence plastics may well be unacceptable either for economic or aesthetic reasons, in largely functional structures, although they undoubtedly have a place in unusual applications such as exhibition buildings.

One property inherent in all plastics which stems from the long-chain molecular nature of the basic polymers, is large thermal expansion relative to that of almost all traditional materials. This can be reduced to a significant extent by the use of silicate-based fillers and reinforcements, but even then allowance must be made in design for differential movements, which will take place between plastics and other materials. This will be particularly significant in many developing countries, where large temperature fluctuations between night and day, or between seasons, are a dominant feature.

A problem perhaps of less significance in developing countries than where building requirements are more sophisticated is that of acoustics. Although there are a few exceptions to the Mass law, in general lightweight construction provides little barrier to sound transmission, and the lightness of plastics components, advantageous for other reasons, is a distinct disadvantage when it comes to this question of sound insulation. Some open-cell expanded plastics are effective in absorbing sound energy within an enclosed space, but lightweight materials are of little value for sound insulation except where effective sealing can reduce the level of airborne sound.

Plastics are broadly resistant to the corrosive influences that affect metals, and on these grounds often offer advantages of durability compared with metals, but in situations where they are exposed to the weather they are often at a disadvantage to other materials. Although only a limited number of plastics products have been in use for more than a decade, and to that extent prediction of durability must be based on restricted data, some authorities predict that few plastics products can hope to last for as long out-doors as the expected life of the building of which they form an integral part: on the other hand some equally eminent and experienced say that properly formulated, the life of a plastics component could be 50-100 years. Sunlight, particularly its ultra-violet component, is the most significant factor in the out-door exposure responsible for the breakdown of plastics, since it initiates many of the chemical reactions by which plastics are degraded. These reactions are often of a 'chain' nature, and they are accelerated by favourable conditions of warmth, atmospheric oxygen and moisture. It is evident that exposure in tropical regions (which includes some of the largest developing countries) would be expected to produce more rapid and severe degradation than occurs in temperate climates. This is borne out by a considerable body of evidence, not least by the use of tropical exposure as a form of accelerated weathering of products designed for use in temperate regions, which dates from the establishment of the West African Testing Establishment during the war.

The property which imposes perhaps the most severe limitation on the use of plastics in building, and particularly on purely structural applications, is their flammability. By their very nature most plastics are combustible (they are in the main carbon-based compounds), and although they differ in the ease with which they can be ignited and the rate at which they spread flames and propagate fire, and can be modified to effect improvements in these properties, the basic weakness cannot be overcome, so that allowance must be made for it in design.

D. BIOLOGICAL ATTACK ON PLASTICS

Biological attack on plastics could be an important limitation, particularly in tropical countries. Plastics are of course not alone in being subject to biological, as well as chemical and physical degradation; many natural (organic) traditional building materials are so short-lived that their preservation is a matter of economic necessity. Plastics are unlikely to suffer so badly but some forms of attack are possible, the most important being fungi (including moulds or mildew), algae, bacteria and insects.

1. Fungi and Algae are organisms prevalent in the wet tropics and are frequently confused, but because they are different in nature, metabolism, effects and cure, it is important to distinguish between them.

Algae are the best known as the slimes on water, and seaweeds, but terrestrial varieties are found growing on land in wet situations; on rocks and on the roofs and external walls of buildings. They contain chlorophyll and are able to synthesize their food from water and carbon dioxide with the aid of light and traces of mineral salts. Rough surfaces which retain water favour growth, which is nearly always outdoors; the smooth surfaces of glass, paint and plastics are less affected but by no means immune. The principal effect of growth is disfiguration rather than damage. Translucent polyester/glass fibre roofing sheets can permit growth and thereby lose much of their light transmission; PVC is also affected. Algicidal compounds include some of the common fungicides, but their effect in paints in not long-standing and probably no better in plastics, where their use has not been explored.

Fungi occur in enormous variety, from the large and even edible to the microscopic. They are devoid of chlorophyll and thus cannot photosynthesise their food; they require organic (carbon) compounds as nutrients, and the conditions for growth are high humidity and moderate temperature, light being detrimental to some but tolerated by others, these being usually dark pigmented for protection and rather obvious on building surfaces. The most serious effects of fungi are the complete destruction of cellulose and woody matter, both in damp air and in the soil where they are part of the natural cycle of decay and growth. Organic synthetic polymers have not appeared to be so seriously affected, but paints are subject to surface growths whose main effect is discoloration; prolonged resistance is difficult to achieve in materials exposed to the weather. Plastics are likewise affected, many of the ingredients such as plasticisers providing the organic food source even when the polymer base itself is resistant. PVC is such an example, in which plasticisers containing fatty acid chains of even short length render the compound susceptible; a pink stain as well as black patches has been a source of annoyance on such things as PVC shower curtains. Fungicides are available, varying in their effectiveness, durability and possible toxicity to humans, and their evaluation is by no means a matter of simple laboratory tests. Plastics for use in the wet tropics will certainly need exhaustive testing for this one property. However, serious weakening of structural members or penetration of cladding or roof sheets is not envisaged as a likely result of fungus attack. The extra cost of added resistance is unlikely to be more than one or two per cent.

Of the plastics types considered for building uses, PVC and polyester are most liable to attack; polyethylene can support light growth while remaining little affected, and phenol formaldehyde behaves similarly. Roughening of the surface after weathering leads to easier establishment of colonies of spores, and this is true of most materials; at the same time weathering tends to cause loss of fungicides and this again increases the rate of attack. Polyvinyl fluoride, indicated as of high potential as a roofing and cladding protective coating, has a rather non-adhesive surface, but even this has been found to support mould: the growth is easily removed by washing and does not appear to cause weakening of the plastic. Foam insulation (of the types described) is probably unlikely to be at much risk from fungus attack, but if partly saturated by water entering the structure it would be expected to offer little resistance to growth, even though it may have little nutrient value.

2. Bacteria

Bacteria are minute organisms invisible to the eye even in colonies; their presence is therefore unlikely to be known except by their effects, and these are fortunately slight or nil in regard to constructional materials, however profound and dangerous they may be to food and to health and life itself. Bacteria play an important role in the decay of organic materials in soil (and can lead in some circumstances to the corrosion of metals in soil) but no evidence of any attack on PVC or polyethylene pipes underground has yet appeared. In any case it is unlikely that plastics in structures will be in contact with the ground, a concrete slab being a suitable base.

3. Attack by Termite, Insect and Rodents

This is a matter of serious and economic significance in tropical countries. Wood provides the food source of the large family of termites, and timber (except a few resistant species) and a few other soft materials, are liable to attack in many of the hotter regions; in temperate lands there are also numerous species of beetles and other insects which attack timbers. The tunnelling of these of their larvae seriously weakens and eventually destroys the wood. Plastics in general are likely to be much less susceptible than wood, since they offer nothing of food value, but termites will make persistent efforts to get through protective sheathing and non-wood materials in their search for food, and will tunnel long distances. The softer and cellular-foam types of plastics will therefore be prone to such attack, and will harbour and conceal termites. Timber impregnation treatments are not applicable to plastics, but means of preventing attack could include the use of very hard fillers such as silicon carbide, and the inclusion of insecticides. However the latter presents difficulties of toxicity and lack of performance; there is a need for harmless repellents to be evolved. Thus pentachlorphenol is both fungicidal and insecticidal but probably too volatile; 'Dieldrin' is highly effective against termites but unacceptable in houses. Underground plastic pipes would be at risk in the termite areas, and the desirable or necessary protective sheathing or coating would reduce their economic attraction. Foamed insulation would also be difficult to protect unless totally enclosed in sandwich form. Rodent attack is an ever-present hazard, but one likely to be less successful on hard plastics than on wood: extermination of the rodents is the only real control.

It can be deduced from the foregoing observations that, although plastics have many undoubtedly advantageous properties, they also suffer from several severe limitations. Some of these can be overcome by suitable design of plastics components. The most rational approach to their use is to combine them with other materials - often the traditional ones - in composites in which full advantage is taken of the properties of all the component materials, to provide a practicable and economical solution to building problems. A summary of the average properties of the range of plastics most usually applied in building construction is given in Appendix I.

7. THE APPLICATION OF PLASTICS IN BUILDING CONSTRUCTION

The progress of plastics in this most traditional of all industries in the developed countries began slowly and in a modest way after World War II, but quite clearly it was expected to figure significantly in the re-housing in Britain in the post-war years, as is evidenced by the study made by the British Plastics Federation in 1944, and presented to the Government in the publication 'Post-War Building Studies No. 3'. Although consumption of plastics in building construction world-wide is now beginning to increase more rapidly, progress is still hindered by four major factors: (a) the lack of knowledge of plastics by many designers and architects who are faced with a wide selection of materials each having its own particular characteristics, (b) insufficient long-term ageing and weather data, (c) the 'preference' among users for the proven and long-standing materials, and (d) the inferior 'tag' which plastics gained (through mis-application) in the early days of the industry, which still lingers to a degree in many quarters, particularly in Britain.

A. THE PSYCHOLOGICAL FACTORS INFLUENCING THE USE OF PLASTICS IN BUILDING CONSTRUCTION

In the U.K. where tradition has perhaps greater influence than anywhere else in the world, the use of plastics in building has in recent years been aided by two factors, the sensible and realistic attempt by plastics materials manufacturers to lead the way with practical examples and well-written publications, and secondly the short supply of the 'preferred' (i.e. traditional) materials. The latter point is well illustrated by reference to rainwater goods, where shortage of cast iron guttering at one time more or less forced builders to accept the alternative PVC units, with the result that a number of those who gained confidence in the plastics units and their many advantages, have not reverted to metal.

It is obviously more difficult to exploit an entirely new group of materials and their consequent design forms in highly developed countries, where direct substitution is not the only criterion, and where the demand for quality and reliability, coupled with functionality, forces the plastics 'exploiter' into producing goods which have been soundly tested both mechanically and functionally, e.g. from the point of view of weatherability. Cost of the unit is of course of importance, but providing it can offer some distinct advantage such as ease of erection, aesthetic advance, and perhaps greater design freedom, then both architect and builder will consider its potentialities more closely. At the outset it is important to appreciate that the application of plastics in the developing countries cannot be directly related to, or assessed by, their impact and acceptance in more highly developed countries, for on the one hand there is the urgent need to bring about a very considerable and immediate improvement in living and working conditions, whilst on the other it is more a question of 'sophisticated progression'; i.e. to improve still further upon conditions which are, in the main, comparatively good and acceptable.

There are of course other and more specific factors to be borne in mind. In some highly developed countries - and the U.K. is typical - very great emphasis is placed for example on the fire hazard of plastics, and this to an extent where many materials can no longer be used because they do not come within the exacting regulations introduced in 1965. Whilst such regulations are a necessity in their country of origin, they are perhaps too limitative in other instances, and certainly need only to be used as a 'recommended practice' when considering plastics for building in developing areas. On this basis for example, if wood was put forward today as a new material for construction, it is extremely unlikely that its use would be allowed in many countries for rafters, etc. in houses, because of its relatively high and ready flammability.

B. PROBLEMS IN THE APPLICATIONS OF PLASTICS IN BUILDING

The basic problem facing plastics is that they are endeavouring to replace a family of materials which in many cases have proved satisfactory over centuries of service, and which still offer an attractive range of properties when measured by present-day conditions of application and use. It is true that plastics are ideally suited to mass-production methods and off-site fabrication, but they lack the obvious stiffness and tensile properties which are the characteristics of the traditional materials with which generations of architects and builders have been accustomed. To effect any entry against this almost vested interest in the known and tried materials, will take time and perseverance.

Heading the list of objections to plastics one usually encounters the question of cost. Pound for pound compared with bricks and mortar, plastics are costly materials, but it must be remembered that this material cost is in many cases more than offset by reduced labour costs; indeed the great argument in favour of the extended use of plastics is that they are less labour intensive. A recent survey of the break-down in man-hours as between the various trades in the building industry prepared in the U.K. by the Ministry of Works, shows that of the 13 trades listed as essential to the construction of a building by traditional methods, the major proportion of the total man-hours expended is accounted for by four trades, thus: preparation of site, excavation drains, etc., 17.2%; bricklayer, 36.0%; carpenter and joiner, 14.3%; plasterer and painter, 16.0%. From this it will be clear that as far as major constructions are concerned, plastics have much to offer over traditional materials and procedures. Plastics can be made available in convenient sections which require neither paint nor plaster, and which can be erected on the building site quickly and with the minimum demand on labour. In some cases plastics have been developed to follow traditional lines, as for example the plastics 'bricks' recently introduced on a commercial scale in the U.K. It must be remembered of course that where they are being used these new plastics 'bricks' are on a volume basis, the actual weight of the plastics material in these hollow bricks being relatively small.

C. WHAT PLASTICS HAVE ACCOMPLISHED SO FAR IN BUILDING CONSTRUCTION

Fortunately today the cost question is not entirely a theoretical one, as we have a number of actual case histories which show that plastics are realistic possibilities in major structures. In 1963 a plastics building was erected at Bakelite's Birmingham (U.K.) factory, based upon reinforced plastics upon a steel frame with timber flooring. It weighed 15 tons as against a calculated weight of 84 tons for a conventional brick building, and was estimated to have cost about 20-25% in excess of a conventional building of the same total floor area, but on a commercial scale, even at low production levels, it was thought that this form of construction could be offered at cost levels close to that of conventional buildings.

Council houses built in Middlesex (U.K.) in 1965 by Wm. Old Ltd. which comprise a basic panel made up of cement asbestos sheet on a single angle framework with an outer weatherproof skin of glass fibre-reinforced polyester resin, provide another example. The houses, built in just eight weeks, have their own garage, central heating, double glazing, airing cupboards and built-in wardrobes. Other houses built by Howard Farrow Construction in Hertfordshire (U.K.) each of which contains some 655 lbs. of plastics, were designed and constructed to ascertain and establish installation costs for the various products included in the houses. In another example, the I.C.I. Building Development Group was ruthless in its selection of applications, and items such as nylon window fittings and hinges which might have been expected, were not in fact used. The houses, which sell at under the £6,000 level, have urea foam insulation in the cavity walls, and other plastics items include: polyacetal taps; polyethylene film damp courses and moisture barrier; PVC drainage, soil and waste, cold water and rain water systems; PVC electrical conduit and sheathing; PVC floor tiles; an acrylic bath; urea glues; polypropylene and acetal lavatory cisterns and seats.

Two experimental houses designed by the plastics laboratory of the Royal Dutch/Shell Group at Delft in the Netherlands should give valuable data both on design and material functionality, when the current intensive tests are completed. One is now occupied by a tenant who sends periodic reports to Delft; and the other is used for laboratory tests including sound and heat insulation. These houses are built round a steel frame with exterior sandwich wall panels of asbestos with a polyurethane core, and with an external finish of a sand-filled epoxy resin composition. Plastics are used wherever possible for floor coverings, pipes and ducts, insulation and finishes. Only the kitchen and bathroom, the so-called service areas, are fixed on the ground plan, so that the rest of the layout can be altered at will. Data collected on this development will eventually be used in building a new multi-storey laboratory at Delft. In Belgium it is reported that a very simple structure has been developed for small single-storey agricultural buildings, which could well be elaborated for low-cost dwellings. This consists essentially of a concrete base into which is fixed four or more uprights of rigid extruded PVC, the space between these primary pillars being filled in with plastics laminate panels, door and window frames, etc., similar panels but suitably modified being used for a flat roof.

In assessing the success achieved to date by plastics in the building field, too much stress should not be laid on the all-plastics house as such; indeed it is possibly the fact that after so many years of endeavour the all-plastics house is still not a reality, that has convinced far too many people that plastics have no significant role to play in building construction. Plastics can indeed be eminently successful in building without ever an all-plastics house being available, and simple logic or at least basic economics make it plain that, as in so many other fields, ultimate success will be achieved by a combination of the traditional with the modern materials.

Plastics are already playing a very significant part in building construction, but they are spread so widely over newly emerging structures that they are rarely self-evident. The following brief survey will bring the position into better perspective.

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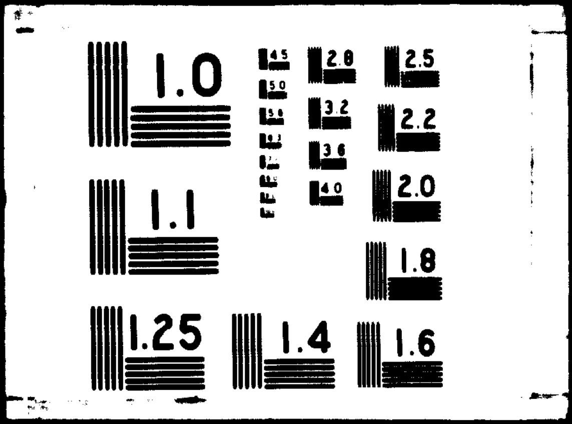

1. Plastics in Structures, Shells and Panels

Whilst builders are likely to continue to rely on traditional materials for the foundations and the general supports for their buildings, they will turn more and more to plastics for the covering and infill panels. The availability of large sheets of plastics, particularly where suitably reinforced, has made possible the development of off-site methods of construction, which depend largely on the high strength/weight ratio of the plastics used.

The size and cost of moulds limited the use of plastics as enclosure materials for a long time, but with the development of simple and effective methods of jointing, the value of repetition in production is being realised. For small buildings, strength can be provided by the curvature of the units or shells, but larger structures still require stiffening by a frame of wood or steel; the design then tends to the use of flat or corrugated sheet cladding. For this PVC has already been found useful, but fixing is not without problems, arising mainly from the high thermal expansion of plastics already referred to. Reinforced polyester can also be considered for this purpose, and there are many alternative materials using only a coating of plastics. For panel cladding the frames require fairly close tolerances in production and erection, and the waterproofing of joints can be difficult. Plastics offer considerable possibilities for cladding high (21-storey) buildings, either of the SFI-type based on an outer skin of G.R.P. with a polyurethane paint and a core of formed cement, or the I.D.X.-type for low buildings widely used in Germany and Scandinavia in which plastics function mainly as adhesives. Traditional materials such as asbestos/cement and sheet metal are cheaper although each of these has its own disadvantages; in the ultimate the solution may be in a combination of these with plastics.

2. Windows and Door Frames

This was an area in which high hopes for the successful application of plastics were early entertained, but these were initially delayed largely by the use of either unsatisfactory materials or methods of fabrication or both. Early manufacturers followed too slavishly the design of the pioneer wood frame or metal grille type of window, which had been successfully produced for decades in the respective traditional materials. Eventually from bitter failure they learned that the design must be suited both to the material and the method available for its manipulation. Once this was appreciated, then the way was opened for what will clearly be a good growth area for plastics development.

At present relatively few of the numerous designs for all-plastics or metal- or wood-cored plastics window frames have reached full commercial acceptance even in the countries with advanced plastics industries. Although they appear to offer the attractions of resistance to corrosion and good durability without maintenance, the latter frequently falls short of some of the claims made, and there are accompanying problems of dimensional stability and water-tightness, and failure at joints deriving from the high thermal expansion. But the principal obstacle to their wider use is still cost, which exceeds that of traditional types. In the production of windows plastics have not yet reached the stage that they can provide the answer to the shortcomings of wood and metal types in developing countries, but progress is rapidly being made. In severely corrosive conditions their use could be contemplated to avoid early replacement which would have to be faced if traditional materials are used. Internal door frames, and hollow channel skirtings which carry electrical wiring, are also available in plastics such as PVC, and find use in prefabricated buildings; they might replace timber in areas without an indigenous source, as steel has in some cases already done. Fixed ventilating louvres in the walls or as part of a window assembly, are a desirable feature, and many such units are already in production in plastics (e.g.PVC) and offer great advantages over metal or wood. Asbestos cement is a suitable and probably cheaper alternative, but such units are much less durable and are frequently of indifferent appearance.

Plastics can frequently replace glass for the actual window panes in special locations, more particularly where in case of breakage danger from glass splinters has to be envisaged, such as public buildings, schools, sports arenas and promenade shelters. Despite the high cost comparative with glass of 'Darvic' (PVC) and 'Perspex' or 'Transpex' (polymethyl methacrylate) which are most widely used in the U.K. at the present, and poly-carbonate particularly in Germany, this market is definitely growing.

3. Roofing Materials

Flexible plastics, which can be produced in widths of up to 4 ft.6 in. (1½m) and continuous lengths, have an obvious use as roof coverings, and two elastomers, butyl- and polyisobutylene rubbers, are already used for this purpose on a commercial scale. When reinforced with carbon black their weather resistance is good for many years. They need full support, and concrete (which if properly laid should need no covering) is the best; boarded roofs can be covered, but such a use will place a high strain even on elastic materials unless they are only loosely bonded, a procedure which is not permissible in areas of high winds. Design details are all-important in ensuring their effectiveness, particularly in respect of edges and joints. Liquid-applied plastics which solidify to thick film coatings, such as polymers in solution or suspension, appear a simple and convenient method of waterproofing poor concrete or leaking sheet roofs, but the same limitations apply to these as to flexible sheet bonded overall, and their durability may be no higher than that of bituminous emulsions similarly used, although the difficulty can be reasonably overcome or at least moderated by using plastics such as epoxies combined with bitumen or pitch, and a number of materials of this type are now commercially available.

Two other flexible plastics are of value as secondary materials in building construction, polyethylene, which is used as an intermediate layer between fairly lean concrete and an even weaker screed, especially on small houses, and polyvinyl fluoride in the form of a very thin film (0.001 in.) on a supporting composition of asbestos fibre and chloroprene rubber. The latter polymer shows excellent durability even when white pigmented, which makes it especially suitable for roofing in hot countries; at present cost is the limiting factor.

Rigid plastics have already achieved considerable success in the roofing of buildings. In many cases these take the form of small sheets of PVC or resin/bitumen compositions, which are used nailed or otherwise secured to rafters in the fashion of conventional tiles. Corrugated sheets of plastics, such as transparent sheets of rigid PVC or polymethyl methacrylate or acrylic copolymers, provide not only a conventional roof covering, but also offer the dual service of illumination. Here again cost is a serious deterrent, but this can frequently be offset by low weight, and the greater safety factor offered by the plastics. Moreover transparent plastics can be suitably tinted to counteract excessive sun glare, or indeed to give necessary protection from sunlight in tropical countries. Somewhat more economical from the cost angle, but meeting much the same function, sheets of glass fibre/polyester are being increasingly used. The early history of these materials in the U.K., particularly for use in difficult locations such as seaside bathing huts, was not a very happy one, but experience and the ability to prevent the glass fibre separating from the resin surface, has remedied some of the early difficulties. Today these materials are available at reasonable cost, and should be particularly useful for the construction of both small and large buildings in tropical countries. Quite naturally such exposure is extremely exacting, so that materials have to be specially manufactured for this purpose, and attention paid particularly to the complete wetting of the reinforcing glass fibres and the complete removal of all volatiles from the sheet.

Plastics laminates in the form of resin-bonded wood beams, have been used with considerablesuccess as the load-bearing members in building construction. These were used initially by marine engineers in the production of spars and yard arms for the ship building industry. Such materials, offering as they do considerable strength/weight advantages, can have definite advantages in the developing areas where in situ production of these materials will have distinct possibilities. Function for function these materials are clearly more costly than the comparable steel girders, but again quite clearly the plastics laminates will have advantages to offer in the developing areas where distances for transport of materials are considerable, and where building areas may be in remote and often inaccessible locations.

4. Thermal Insulation

Plastics foams produced either as sheets and board (rigid and flexible types), or injected in situ into wall cavities or on the underside of roofs, are of low density and high thermal insulation, and are now firmly established in the building industry. Although they have some limitations by reason of flammability, relatively low working temperature, and loss in insulating value if they become wet, materials of this type would certainly be among the early products of a developing plastics industry, and would find a ready use in building in cold or temperate climates; in hot countries their application is likely, but expectably confined mainly to industrial and cold store uses.

5. Plumbing and Related Fittings

This is an area of plastics application in which much has been achieved particularly in Europe and America, and although in line with normal pattern Britain lagged behind the leaders, in recent years there are indications that early trade prejudices have been overcome, and that the new materials are being and will be used on their merits. It is interesting to note in this connexion that the first incentive towards the use of plastics in plumbing was encouraged with the publication of British Standard 1972 (1961) which laid down not only the specification for plastics for cold water pipes, but also gave what amounts to guidance to users, and it certainly gave encouragement to doubting plumbers who hitherto had been reluctant to depart from traditional materials in which they had been brought up, and in which their expertise mainly centred. Today polyethylene and PVC waterpiping are well established for cold water supply; for hot water, difficulties have not been entirely overcome because of the limited working temperatures and high thermal expansion of most thermoplastics, but polypropylene and post-chlorinated PVC may have much to contribute in this direction. Waste pipes also need fairly good heat resistance for which PVC has not always been adequate, particularly for water near boiling point, but here again ABS and polypropylene promise well.

One direction in which solid progress has been made in the more sophisticated countries, is the use of plastics in the manufacture of bathroom and kitchen fittings. This is an area in which, based on this user experience, considerable potential lies in developing countries where the demand for these amenities, which contribute so much to the standard of living, could offer what may be literally vast markets. These bathroom and kitchen fittings for large mouldings or pressings lie mainly in the direction of acrylics, but reinforced polyester water cisterns (at present mainly cold only), hand basins and sinks, are also accepted outlets. Complete bathrooms installed as a unit in prefabricated dwellings are now offered in Europe and America, but would not yet appear an economic proposition for export, or for production on site or near user locations without the availability of the most advanced techniques. Such however is the relative simplicity of some of these techniques, that these could and will be made available in developing countries in due course.

In this same general field reference must be made to the use of plastics, notably rigid PVC, in the manufacture of rainwater gutterings, down pipes, and soil pipes for buildings. This again was a development which traditional builders were reluctant to adopt, but which in the process of time economics and functional advantages have forced them to accept. The use of plastics in this way has had consequential advantages in that it has meant a reduction in the load which roof members have to carry, an advantage which should be particularly attractive in developing areas where the houses in the main are likely to be smaller and of lighter construction. Furthermore there is the advantage that transport of the plastics guttering etc. to the remote building sites in developing areas will be less costly, and the eventual production in or near location would be readily possible.

6. Fittings, Furnishings and Finishes

Plastics have for many years provided a wide range of fittings and furnishings for the building industry in the form of the ancillaries which are added to the finished building to make it functional. Some of the early products were not too successful mainly because they followed too slavishly the design of metal prototypes, but manufacturers have learnt their lesson, and today the wide range of what is generally styled door 'furniture', and the miscellaneous decorative beadings and panels which are used as embellishments for walls and built-in furniture, are mainly well designed and very functional. Today metals are faced with formidable competition from fittings produced in phenolics, aminoplastics, nylon and ABS. In addition laminated sheet, usually pleasantly decorative, is widely used for lining kitchen and bathroom walls and for work tops. This material is no doubt one of the most versatile and broadly useful of all plastics products.

Plastics have a virtual monopoly of the electrical fittings used in and around buildings, and this is an area where steady expansion can be anticipated.

Plastics finishes play a significant role in the decoration of building structures of all types, and particularly in the domestic field offer much that is attractive to the do-it-yourself householder. Plastics are used increasingly for wall coverings, and plastics-coated metals (which are really metal/plastics laminates) add not only to the aesthetic appearance of dwelling houses, but can also make a definite contribution to their structure.

Plastics have for many years found growing use in the production of what is conventionally known as paint. Earlier this group of materials was mainly based on linseed oil, and natural gums in the case of varnishes. Today the main ingredients are either straight polymers such as acrylics which give remarkable glossy and hard surfaces, or polymer modified oils. In some cases plastics are combined with natural bitumens and pitches to give coating compositions which have functions not only as versatile adhesives, but also as anti-corrosion coatings for metals, and as moisture resistant coatings. Compositions of this type which are usually based on a combinationof bitumen and epoxide resins, should be particularly useful in tropical countries where rising damp in buildings has either to be treated or prevented. In this particular context plastics play an even more important role in the preservation of traditional building materials, particularly stoneware. The surface treatment of stonework with epoxide resin compositions, or with compositions based on one or other of the silicones or silicon esters, are most effective in the rejuvenation of old stonework or in the preventive protection of the new.

Furnishings are usually the responsibility of the house occupier, but in housing for officials, in schools and in hospitals, there is scope for moulded polypropylene chairs, floor coverings, curtain fitments, and many utensils; these again are among the more established products of the expanding plastics industry. In this field there is much to be said for the use of plastics in developing areas, particularly in the tropics, where the ravages of termite have to be faced. While plastics cannot be guaranteed as termite resistant, they are certainly more resistant than wood and the conventional furnishing fabrics.

D. THE SPECIAL ROLE OF PLASTICS IN THE PROVISION OF 'SELF-HELP' AND LOW-COST HOUSING

The provision of adequate housing at various levels is a priority objective of most developing countries, and if carried out in full would in some cases absorb the whole or much of the national income and massive aid as well. There is therefore great incentive to find ways of reducing the unit cost, as well as of the time taken in building. How far are plastics able to assist in both these objectives? This will depend very largely on the type of housing envisaged, and can best be considered under the separate categories ranging from the most simple up to structures of relative luxury, and structures in the public service and industrial sectors.

1. Self-help Housing

Let us consider first of all what is now broadly referred to as 'self-help' housing, that is the provision of houses where materials of construction alone have to be supplied, the labour needed for erection being drawn from the local community. The cost of even the lowest-priced house which can be made available by national or local authorities, even at heavily subsidised rents, is frequently beyond the means of many families, some of whom are living in what are literally assemblies of scrap materials - old sheet metal, discarded timber, boards, etc. - and natural products such as palm fronds. Small communities can exist like this for a time with little worse effect than discomfort and deprivation of amenities, but to envisage this with a larger population produces a grave risk of disease, discontent and lawlessness, and requires strong and speedy action.

Since many of the prospective occupants will not be in a regular job, often not even working the land at subsistence level, there is great attraction in mustering them to share in the work of building for the community simple but adequate shelter and amenity buildings. Since skills are likely to be low, especially at first, the design and materials of suitable structures must be carefully adjusted to the ability of available workers to use them, particularly since initial enthusiasm can soon die if results are not forthcoming. Hitherto the commonest method of construction has been the use of rammed earth or cement-sand blocks, with a sheet roof on timber rafters. Setting out and supervision for such work requires a skilled worker; a carpenter is also needed, but the rest of the work is soon learned. The cost of materials for a two-roomed house is around $ 300-450, and the labour cost involved need only be that due to the fraction of the few paid workers' time shared between the houses.

What are the prospects of plastics making the job easier or cheaper? At present the answer seems to be, very little, but the prospects are better. A principal objection is that the actual cost per unit area, for walls or roof, of any plastics used at a sufficiently substantial thickness, even in the form of sandwich panels or shells, is relatively high. Here the usual advantage of light weight of plastics counts for very little, since there are many willing hands to haul the materials to and on the site, and the units are small. A further difficulty is the much finer tolerances, and therefore the greater care and skill, which is needed in setting out and erecting the frames on which to mount sheets or panels of fixed sizes. For comparison it may be noted that timber or precast concrete frames would be difficult to erect to close enough tolerances, whilst prefabricated steel frames would cost more than the blockwork walls.

As an alternative to the on-site assembly of plastics sheets or panels, the erection on a prepared base of a prefabricated complete shell or unit may be considered. A simple cubic structure may be imagined, formed of square dished panels bolted together, one or more having door or window apertures. This would have certain attractive features: simplicity of erection, light weight for easy transport, strength to resist damage. But their production in large enough sizes - at least seven feet high - would require a fairly advanced production facility unlikely to be reached at an early stage in a country's development, with the alternative of importing such structures pre-formed from an industrialised country, thereby increasing costs, and reducing the possible percentage of indigenous labour. As part of a crash programme, e.g. in case of hurricane or earthquake relief, such units might have considerable use; they might in any case be provided as national aid, but as part of a steady rehousing project using 'self-help' labour, they would seem only suited as temporary accommodation while a slum site was cleared, and that only in countries with an already developed industry.

2. Low-cost Housing

Next to consider is low-cost housing; this presents a separate problem. At the next higher level houses of simple design, but offering more amenities and a more substantial structure, are provided by a local or national authority, but are built by a direct labour department or by contractors. Rents will usually be subsidised according to need. Costs of this type of house are in the region of $ 1200 for two bedrooms, up to $ 3000 for larger units, and for flats in multi-storey buildings $ 1500-2100 per unit, e.g. in Hong Kong and Singapore. The forms of construction most favoured here have been concrete blockwork, brick or timber where available, and concrete post-and-panel, for housing of one or two storeys: above that reinforced concrete is almost universal, sometimes with blockwork infilling. Roofs of flat concrete slab type are common although sheet (metal or asbestos cement) is much used. Windows are glazed, the frames being metal or wood, and often so poorly painted as to need excessive maintenance. These are very similar to the houses built in Britain for emergency housing immediately after the last war.

The The prospects for an early application of plastics in this region are again not great at present, and an all-out design effort is needed to utilise existing plastics technology in better ways to this end. Room sizes will be larger than in 'self-help' houses, necessitating either larger panels or more complex frames. Comfort will have to be studied and provided to a greater degree so that the thermal environment must be controlled, e.g. insulation may be needed, and here foamed plastics can be useful. Deficiencies in construction can lead to leaky roofs, and in this connexion it must be remembered that liquid-applied plastics may not be such a good remedy, especially in hot climates. Sheet polyethylene can find a use as a water-proofing layer between concrete slab and a lightweight insulating screed, and as a damp-proof course. But for the major units, walls and roofs, plastics of any type are not an immediate economic proposition. In-fill panels of single or composite sheet, in multi-storey blocks, are an exception. Bituminous compounds and emulsions have been the main stand-by for making up the deficiencies of roofs; they are not always successful, especially in hot climates, but are cheap. Of plastics compounds as alternatives, the best so far seems to be 'Hypalon', but this is far too expensive for low-cost housing: its whiteness is a very useful feature difficult to equal in or on bituminous compositions. As already mentioned bituminous or pitch compositions containing plastics are now being increasingly applied with success.

Polyvinyl fluoride film, used as a laminate on various bases such as metals, plywood or asbestos cement, and on flexible roofing sheets, holds out great promise as a durable protective and waterproof surface. But its present price puts it in the luxury class; reductions from increasing volume of production are hoped for, but it is not yet a plastic with foreseeable production in developing countries, and even the operation of bonding it to possible indigenous substrates calls for some fairly advanced technology and skill. Nevertheless, as a means of upgrading products such as chip-board, or plywood, which can be produced in countries with forest resources, it is a material of considerable potential.

3. Middle and Upper Class Housing

In the developing countries there is an appreciable demand for high quality houses, provided not only by private enterprise for the commercial world, but even by governments for their higher officials. This makes quite substantial demands on the economy, and any way in which the cost can be reduced or amenities enhanced would be welcomed. Since the permitted cost can be high (£20,000 to £30,000 per house is not unknown) and since styling and amenities may be of the highest order, this may be a fruitful field for experimentation and application of plastics, and although it relates to the favoured few, should not be ignored in any study which may principally be concerned with the needs of the great mass of people.

From the foregoing it will be apparent that the immediate prospects of a rapid application of plastics to the solution of housing problems, utilising the available materials and techniques, do not seem high, and there is little evidence of ready-made solutions. What seems to be necessary is a marginal improvement in certain properties of commercially available plastics, plus a strong attack on the design of appropriate building forms and methods to utilise them. This would call for a combination of architects and engineers experienced in tropical needs together with experts in plastics production and design, working always within the framework of an economic feasibility study, and provided with adequate funds to enable them to study a wider range of climates and needs than is possible on a purely national approach. Such a study would cover the requirements of the possible occupiers as much as the properties of plastics structures relevant to climate. Traditional housing in most parts of the world has evolved to meet, within the limits imposed by the available materials, the demands of both the structure and the occupants relevant to the climate. Thus the thick-walled mud dwellings of hot, dry regions, with their small windows, act as barriers to the heat of the day, but store this to ameliorate the cold nights; at the same time the durability of such structures is appropriate to the climate. Plastics can provide some of these needs quite well; they are obviously adapted to light open-sided structures, but whereas the loss of a palm or tree hut in a hurricane is not a monetary disaster, plastics houses would be vulnerable and expensive to lose. Insulation can readily and cheaply be provided by plastics but not thermal capacity, which demands massive and weighty materials. To a large extent concrete, ranging from massive to lightweight, which is the immediate and most serious competitor to plastics, can provide both.

4. Schools

School building as a social necessity follows closely on housing or indeed parallels it, and even in Europe and North America still absorbs a substantial proportion of national expenditure. At all but perhaps the highest levels of educational requirements there is in school buildings scope for much standardisation and the production of similar if not of identical structures. A modular system is useful here, offering variation and expansion within the limits of standard sizes and shapes of individual units. Plastics must certainly be considered on all these counts.

Single-storey buildings are generally preferred, and frame or cross-wall construction with infill or cladding panels is a common approach, with both flat and pitched roofs. Requirements for plastics, in outer panels and inner partitions, are high impact resistance to avoid damage, smooth hygienic and easily-cleaned surfaces (which most plastics possess), and a wide range of colour. The melamine/formaldehyde laminated sheet is almost idea here, but of high cost. Plastics used as the basis of applied finishes on plastered walls are as yet the preferred method. Ahother valuable application of moulded plastics could be as the external sun-shading louvres which are essential in hot countries; the roofing of covered walkways between blocks is another.

5. Office and Prestige Buildings

The large size and height of modern office buildings, dictated by the economics of letting and by prestige, usually call for construction in steel and reinforced concrete, but there is scope for plastics as insulation and infilling panels. There is still some reluctance on the part of contractors to use wholly organic materials, and even organic exterior finishes certainly cannot be said at present to equal the life of a traditional building since they cause increased maintenance cost. Buildings of this type are already quite common in tropical countries, where as already stated the climate makes itsown demand on both materials and function. Thus, dissatisfaction with cement, paint and organic finishes, on which algae soon exert their disfiguring effect, has led to the use of expensive impervious facing material such as marble, mosaic and glass. Again, waterproofing of roofs demands good techniques, is not always satisfactory even with traditional materials, and can be greatly helped by the provision of heat-reflective surfaces, for which plastics can be used directly ('Hypalon', polyvinyl fluoride), or as liquid coatings on the waterproof layer. Office buildings can use large quantities of plastics for internalwork both functionally and decoratively, ranging from partitioning to plumbing, from ceilings to floors (acoustic and floor tiles), and from electric-light fittings to furniture. That they are a potential fire hazard is the strongest argument against the use of plastics in high buildings. In the U.K. the G.L.C. regulations are much more stringent for the fire resistance of materials used in high-rising buildings than for low buildings, and more than normal fire resistance is required in schools and hospitals.

6. Hospitals

Also on the large scale but completely different in function and specialised requirements, are hospitals. A large amount of data on materials and lay-out have been accumulated in this field, and it is often possible to decide the merits of a new product by reference to existing case histories. Plastics have much to offer, especially in hygienic qualities coupled with decorative appearance. Thus operating theatres for which glazed tiles were once considered essential, are now lined with vinyl sheet welded to form a continuous surface and thus with no joints or cracks to harbour bacteria. Existing theatres can also be treated with suitable plastics compositions of similar basis. Corridor walls which receive rough treatment from trolleys, can be lined with hard melamine laminates, or repaired with tough polyester compositions. Floors are covered with plastics or elastomeric compounds, and electrical conductivity, needed to eliminate static and the consequent risk of explosions, can be 'built in'. Even so the design of hospitals remains very much a 'one-off' job, and the merits of repetitive mouldings and standardised units do not so far appear to have been applied to any significant extent. The plastics usually used are the more sophisticated materials and therefore less likely to be available in the early stages of a developing industry, so that even a fairly large demand for this important type of building is unlikely to be a useful feature of economic progress, since it will inevitably require the import of suitable materials, at any rate initially.

7. Agricultural and Horticultural Buildings

Whilst this may be slightly outside the strict terms of reference of this survey, it is an aspect which is of supreme importance in developing countries, where the question of feeding the population is frequently as critical as that of housing them. The needs of the horticulturist in particular, call for relatively light structures to give protection during the germination and early growth stage of plants where the overall production cycle is relatively short. Naturally this is a subject which has for years received considerable attention in Britain where the vagaries of the climate make it essential to conserve heat and utilise sunlight to the full. Hitherto this need has been met by the use of glazed wooden structures, but these have many disadvantages, not the least of which is their cost and, by reason of their weight and the fragility of the glass, relative immobility, and vulnerability to storms of hail and wind in particular.

Whilst at present plastics (particularly glass fibre-reinforced plastics) cannot offer much cost advantage, they offer considerable weight saving, and can be made much more durable than the present wood/glass structures. So far the tendency has been to follow the traditional design of these structures, but current ideas are turning to more revolutionary design concepts which plastics alone can justify. Plastics have of course other advantages to offer in that if carefully selected, their use can avoid the ultra-violet and/or infra-red cut-off which is inevitable with glass. There is some division of opinion among experts on this point at present, but this is rather on matters of detail and in specific directions, and it has received world-wide attention in the past decade. An extension of this idea which is applicable to the growing of certain crops is the use of inflatable plastics structures, or of the relatively frail structures used for general building-site protection, where light wooden, metal or plastics frameworks are covered with a flexible PVC, polyethylene, or butyl rubber 'skin'. In temperate climates the plastics material would last for several years, but in tropical countries it would have to be replaced each season.

In addition to providing these more fundamental structures for both agriculture and horticulture, plastics can of course provide much of the ancillary fittings and equipment used with them. Again plastics can offer the great advantage of strength with light weight, and what is of paramount importance in the difficult conditions usually obtaining, resistance to corrosion. In the early stages of development both the structures and the necessary equipment can be purchased from countries in which their manufacture is already fully commercial, but it may well be an item worthy of consideration in a developing country for operation per se, or to operate along with the development of plastics for general building construction.

E. COMPARATIVE COSTS

Discussion of costs in a review such as this is inevitably limited to generalisations; too many factors are involved in any single costing for a material or a complete item or structure for this to be more than a rough guide. Labour costs can be assumed to be lower in underdeveloped areas, though this is likely to be partially offset by the inefficiency in working methods and of the labour involved. Indigenous materials may appear cheapest, but products of such a home-based industry are often higher priced (unless subsidised) than those of comparable materials imported from more highly advanced countries, in spite of the freight charges involved. So far there is no plastics production in a small developing country available to illustrate this point, but it can be quite definitely stated that only where there is a high labour content in the required product and the corresponding supply of 'cheap' labour, can prices expect to undercut those of advanced industry.

In attempting some cost comparisons, which regrettably prove at present quite unfavourable to plastics, it has seemed better to confine them to one country, and to indicate how factors such as freight and local labour costs might affect them. The following comparisons are based mainly on materials, but even where labour cost can be shown, the true comparison would still need to include other extraneous factors, for example a plastics roof may need a much lighter and therefore cheaper supporting structure. No manufacturer has provided a working figure for the cost of simple shell buildings or even of panels for assembly, thus precluding an attempt to assess the economic possibilities of these items. In the following table current U.K. prices provide a broad basis for comparison between traditional building materials and possible plastics alternatives.

TABLE VI Comparative U.K. costs for Traditional and Plastics Building Materials

Item	Traditional Material	Cost (sq.yd.)	Plastics equivalent	Cost (sq.yd.)
Walls	Concrete block 16 in.		G.R.P. (materials only)	34/- to 42/-
	by 8 in. (inc. labour)	40/-	PVC (materials only)	30/-
	Extra for rendering		PVC (wire reinforced)	35/-
	externally	7/-	Framing	60/- to 80/-
	Concrete block		Sandwich panels	
	(Trinidad price)	30/-	(incl. insulation)	63/-
	plus rendering	5/-	Sandwich panels	
			(on supporting frame)	112/-to 135/-
Roofs	Asbestos sheet (material)	10/6	G.R.P. (materials)	34/-
	(fixed)	16/-	G.R.P.	
	Aluminium 20g (material)	20/-	(self-extinguishing)	42/-
	(fixed)	50/-	PVC as 2-layer system	
	Copper 22g (material)	28/-	on boards or concrete	22/-
	(fixed)	93/-	(fixed)	35/-
	Galvanised steel sheet			
	24g (material)	13/6		
	(fixed)	18/-		
	Reinforced concrete			
	slab 6 in.	50/-		
	plus screed	9/-		

In the above comparison an even lower price may be taken for concrete blocks as they might be produced in most developing countries, even assuming no indigenous cement manufacture; the quality may be lower but quite adequate: one such example is given in the table. Thus without a supporting frame a single sheet of plastics (apart from very low quality products) would cost more than block walls. On the other hand rigid panels of 'structural' shape, needing no frame and capable of supporting a similar roof, would cost very little more. Transport costs might add 5% to those quoted. Sandwich panels would not seem economic, as a concrete crosswall building could more cheaply have non-load bearing block infilling. Local labour is fairly readily trained to the production of blocks, which are cheap even if production is far from automated, but occasionally lack of a suitable sand or aggregate would make them less competitive. Corrugated phenol-formaldehyde sheet approaches the cost of galvanised or asbestos sheet: its fixing cost would be about the same, but a rather lighter truss might be used. Whilst it might be considered as a useful addition to the economics of a cement plant, its questionable weatherability in tropical climates would have to be taken into account. Pipework has not been shown in this table, but it is a field where plastics are cheaper than metals in every way - materials, freight and fixing. On all counts the use of plastics for this purpose should be strongly pursued in all developing countries.

F. STANDARDS AND DIMENSIONAL CO-ORDINATION

Where plastics are applied on an industrial scale for any major 'service', and particularly one so vital to the community as building, the most rigid control both of raw material and end-product performance is essential. This is done through the medium of both local (that is as between supplier and user) and nationally formulated and agreed standards. In the early days of plastics they were supplied and used very much ad hoc but it soon became apparent that if ultimate chaos was to be avoided standards had to be agreed not only at national but if possible at international level, and thanks to years of effort some measure of success has been attained in this direction. Indeed in most of the industrially developed countries where many plastics products have now gained a measure of acceptance for building, standard specifications have been formulated for a considerable range of these products, e.g. for pipes and fittings, corrugated sheeting and thermal insulating materials. Ideally such standards should be drawn up before large and expensive manufacturing processes are installed, but in the nature of industrial progress, a product standard is not usually called for until such a product has found some degree of acceptance in use.

Such standards are usually designed to meet local commercial requirements, and to ensure among manufacturers the maintenance of an acceptable quality as well as an agreed dimensional system, and only indirectly do they serve to help the users' interests. However, the practice in developing countries which are setting up their own manufacturing facilities, of accepting these standards with the minimum modification, is a reasonable one at first, although it would be better for such countries eventually to formulate standards (both dimensional and performance) according to their own specific needs but taking advantage of previous world-wide experience, before they embark on any large-scale manufacturing expenditure on their own account. These ISO (International Standards Organisation) standards are already available, and every effort should be made to conform to them as a basis for national standards, but failing this the most widely accepted standards should be adapted to meet particular national requirements.

1. Codes of Practice

A somewhat different situation exists for constructional standards and codes of practice. A limited number of codes of practice is available for the use of plastics products, most of these being concerned with pipework, but for the most part these lag considerably behind product standards, and follow local requirements and building practices. They are designed to provide a guide to users, but are only issued as recommendations which may or may not be followed, except where building regulations and laws make parts of them mandatory. Because at present they cover only a very limited range of applications, there is little guidance for the users of most plastics building products, in particular those relating to structures, other than what can be offered by the manufacturers who, it must be admitted, often have only limited expereince of building requirements. In any case, varying local conditions in many countries, even in thos more highly developed, make it essential that any codes should have a degree of flexibility. It is essential to stress however that such codes cannot easily be translated into the requirements for developing regions, and because of different conditions of availability and skill of labour, good practice in developing regions is likely to be achieved in very different ways from that accepted in developed countries. There is a case for establishing, within the United Nations Organisation, codes of practice for the use of plastics building products in developing countries to meet the specific requirements of each, which would no doubt vary, yet show many common features. For newer forms of construction involving plastics, where there is no established practice, a common source of advice and information could provide a basis for satisfactory codes, which could be tailored to meet the requirements of individual countries. With its better access to the technical expertise necessary in drawing up codes and standards, the U.N. could formulate, within an overall framework, suitable codes for the different climatic regions, to be used with a minimum of modification in the different developing countries.

2. Dimensional Co-ordination

Dimensional co-ordination, as applied to building, is a subject which, although the basic concept is simple, requires a somewhat lengthy and expert discussion not appropriate to this survey. In any developing region, where the optimum usage of time, materials and money is necessary, this will best be achieved if a sensible basic system of dimensional co-ordination is applied. In appreciation of this, the United Nations Organisation has previously commissioned a number of reports on the subject[1], through the Committee on Housing, Building and Planning of its

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[1] Report on the Working Group of Modular Co-ordination in Housing, U.N. Department of Economic and Social Affairs (1962) ST/TAO/SER. C/59/Rev.1: E/C6/36/Add.8 New York 1965.
Alvaro Ortega: 'Modular Co-ordination in Low-cost Housing', U.N. Economic and Social Council, June 1961, E/CN.12/SC4/9.
Industrialisation of Building - Status of Modular Co-ordination in the Different Geographical Regions, U.N. Economic and Social Council, Aug. 1965. E/C.6/36/Add.9

Economic and Social Council. These discuss the requirements and problems in considerable detail.

The basic principles are that dimensional co-ordination would reduce costs through greater efficiency in the use of materials, at the same time resulting in a smaller number of standard types. This would create a bigger market for each type, and make large-scale production possible with a consequent price reduction. Recommendations have been made for the adoption of a basic module of 100 mm., and for a number of combinations and multiples of this for various units within buildings. It is clear that plastics components, large or small, could be designed within this modular framework without problems, and this approach is obviously to be recommended.

Despite the apparent advantages of this approach, it is clear from the reference cited that dimensional co-ordination is applied only to a very limited extent in developing countries, despite the fact that it is probably equally or more important in these than in the developed countries. To date, in the developing regions, only in India, Pakistan and Latin America has it received serious consideration, and it is clear that further encouragement from the United Nations Organisation is called for. The advantage of any new building-products industry tooling up to provide products co-ordinated with the dimensions accepted in the particular country is an obvious one, but if there is no accepted standard on which to co-ordinate, then the advantages of mass production of standard components are partly lost. The essential point to emphasise is that plastics products cannot be 'dimensionally' designed in isolation.

VI. OBSTACLES TO THE WIDER USE OF PLASTICS IN BUILDING CONSTRUCTION

A. ECONOMIC FACTORS

The fact that despite the many advantages they have to offer plastics have not so far been more readily and extensively used in building construction, is due to a combination of factors, some economic, some psychological, some traditional. Until the last year or so plastics have not been so readily available in the remote corners of the world, if for no better reason than that they have been more intensively applied nearer to the source of supply. There have of course been occasions when local over-production has resulted in surplus supplies of specific plastics, with the so-called 'dumping' of these in countries having user industries capable of absorbing them, but these cases are relatively rare, and are purely local and of short duration. Such fortuitous supplies cannot safely form the basis of a new venture in a newly developing country, and in any case this is a circumstance which is likely to become less frequent as time passes, since the current intensity of the application of plastics over the whole industrial front is likely to strain the established plastics material production to its limit in all the major producing countries. It has been stated in the past with some basis of truth, that if would be useless seriously to apply plastics in building, since if this were successful, the quantitites of raw plastics available could not hope to cope with the demand, and any attempt to control this below the economic limit would be foredoomed to failure. This fear is not one which is likely to influence policy in developing countries since no matter what the future demand for plastics may be, supplies will be forth-coming, but it certainly was a very potent factor in Britain during the development days of plastics, as the conclusions in the official survey referred to earlier will clearly prove.

Another aspect of the economic question is the basic one of cost; from whatever point we view them the costs of plastics are high compared with those of traditional building materials, but what is so often forgotten is that the basic material cost is only one aspect of the overall cost. In the first place plastics are bought by weight and used in the main by volume, so that in view of their low density compared with metals, concrete or even wood, their intrinsic cost is not so high as might at first appear to be the case. Yet again it must be remembered that by reason of their ease of manipulation, and the fact that such manipulation is possible on a mass-produced basis, some of the extra cost of the material is regained in lower labour costs. This may be of less significance when labour is initially plentiful and cheap, as it is in some developing countries, but it will certainly be an important factor in deciding whether or not a plastics industry is to be established. One final point on the question of cost; it must be remembered that plastics are continuing to move against the current trend of increasing commodity prices. There is of course a limit to this since there must be a production bulk above which no price reduction can be expected, and already of course supply and demand being the governing factor, the price of some plastics has tended to harden.

B. PSYCHOLOGICAL AND TRADITIONAL ATTITUDES

New ways and new materials are not always adopted quickly and without mistrust, particularly in sophisticated and industrialised societies, so that it would not be surprising if resistance were seen in the developing countries, more especially in the tribal societies and agrarian communities than in the partly urbanised and often desperately ill-housed masses which have gravitated to the cities. Traditionalists in all countries will cling to older ways, fearing change and believing that the past is best. This is certainly true of modern building methods in advanced societies, and limits the speed of introduction of industrialised building; a preference for laboriously brick-built houses often prevents the acceptance of the greater amenities offered in a factory product.

In an affluent society the older, traditional styles and materials can be a status symbol as potent as the opposite sign of progress and modernity which plastics may be said to typify. But these countries have overcome the initial resistance to plastics which have long since passed the stage when they were treated as inferior substitutes in so many fields; they are bound to be acceptable as building materials, provided always that they function efficiently. Cheapness is not necessarily a point in their favour; modernity may well be.

In developing countries the introduction of new materials sometimes tends to be pushed at a faster rate than might be reasonably expected or justified; the transition from the traditional (almost primitive) to the latest products of technology can be sudden, when the latter are being urged with the aid of all the techniques of high pressure salesmanship. Under such conditions difficulties may not always be appreciated in their true perspective. Quite naturally the so-called formerly underdeveloped countries have not been slow to adopt the mass-produced articles of clothing, household wares, transport, even some foods, of the exporting richer areas, since these are indeed preferable to an existence depending on the discarded products of the better-off, such as old petrol and oil drums beaten out as sheet covering for hovels, paint tins as containers for every purpose, army uniforms as clothing however unsuitable. Now in the markets and bazaars plastics are seen side by side with the traditional natural or hand-made products. If the price and function are right - or even only partly so - they are acceptable. Brightly coloured plastics bowls, buckets, and tableware have become accepted alternatives for the traditional gourds, earthenware and wood. Why then should attitudes be any different in respect of plastics for houses? Plastics materials are in fact so far removed from the normal experience that there should be less to fear in the way of religious or social taboos than there would be for familiar and natural materials; the standards by which to judge are peculiarly lacking in such peoples as are accustomed to rigid conventions.

Nevertheless there is always a possibility that misunderstandings, rumours and even genuine evidence of unsatisfactory performance in the early stages of development may create prejudices, rational or otherwise and some thought may have to be given to the necessity to precede the use of unfamiliar materials and styles of building by education and propaganda. The satisfaction of the huge demand for homes should make this tolerably simple.

One factor creating possibly greater resistance to use of plastics in building than in transient consumer goods is the permanence associated with a home. It is important that there should be no disastrous failures, no patently obvious short-comings in their early use. The development must be complete, as nearly as possible; the performance must be ensured for the relevant climate, and attuned to the needs and customs of the occupiers. Living in plastics houses will give a very full opprtunity for their appraisal; for the probable occupiers there can be no other way.

C. OFFICIAL REGULATIONS, BUILDING CODES

Regulation of building activities to ensure healthy, safe and orderly development has long been accepted in most of the older countries as a national or local authority duty, and it is increasingly seen to be needed in developing countries, at as early a stage as possible. In many of the new countries building regulations are at present being worked out or applied, largely by suitable modification (preferably simplification) of the standards long established and used elsewhere.

Building regulations are concerned with health and safety, and in small countries this has to be done within the context of low national and personal incomes; they must not unduly restrict economic progress, and particularly they must not restrain the use of materials and methods not yet fully appreciated or understood. Such regulations must also be reasonably acceptable to societies less accustomed to the 'regimentation' of the industrialised nations, and must therefore often permit the use of indigenous and traditional materials which are possibly not accepted elsewhere.

A common form of regulation has separate requirements for large (public) buildings and small dwelling houses; forms of construction, spacing of buildings, provision of services and other matters besides materials are determined. Having laid down requirements, examples of acceptable practice or products are quoted, and it is here that particular danger arises lest these restrict alternatives. Indeed, the British 'Building Regulations 1965' are being criticised on this score, most particularly in their limitation on the use of plastics. Of course, it is important that a new material should have the potentiality by reason of its known properties, to meet the specified requirements; but as some element of doubt must remain for a time, its use is usually permitted by a relaxation clause, the use or performance being reviewed in due course. A speedy acceptance of plastics will depend, in countries operating building regulations, on a wise and ready provision of such relaxations wherever possible or necessary, and especially where economically desirable. Such a review must be frequent and thorough.

The principal difficulty with plastics remains their behaviour in fire. Non-flammability is (even in the few plastics where it can be achieved) not sufficient. It is the loss of strength at quite moderate temperatures which excludes many uses, and especially structural (i.e. load-bearing) applications. Nevertheless the use of plastics as cladding, in 'self-extinguishing' or low surface-spread-of-flames grades, seems perfectly acceptable in small private one-storey dwellings. Structural use is at present very restricted, and as has been discussed earlier, novel methods are still required to enable fuller utilisation in housing. Even in minor uses it is desirable that plastics do not contribute to the total of combustile material in buildings; in point of fact most of them actually add very little, and some nothing of significance - foamed plastics for insulation are an example, though even these may be self-extinguishing.

From the health point of view, the use of plastics seems desirable rather than otherwise. Smooth, easily cleaned surfaces are a natural property of moulded or pressed sheet plastics; large mouldings are readily and indeed most easily produced without corners or crevices which harbour dirt and germs. Plastics materials themselves are non-toxic in any normal use; some of the minor components of plastics need to be chosen to avoid toxic or other undesirable effects in some applications, but this need present little difficulty because of the wide variety and exhaustive testing of such products: as already stated, some plastics actually have antiseptic additives. Of the plastics likely to merit wide use, PVC (even to a small extent the unplasticised type) is somewhat liable to retain dirt and finger grease; this is so much a function of the softness and resilience which are often desirable properties, that it is unlikely to be preventable and must simply be remembered or avoided where necessary.

Most plastics surfaces are as resistant to mildew as are the majority of painted or other organic surfaces, but for use in hot, humid climates where severe mildew occurs, the resistance may have to be increased by additives, or soft plastics avoided. Many fungicides are toxic and undesirable in uses such as toys where children may lick the surface, but may be quite acceptable for external surfaces of building fittings. Here again it behoves the vendors and sponsors of new applications to exercise due care, and in any case these factors can be safe-guarded in well drafted control regulations.

VII. THE FUTURE OF PLASTICS IN BUILDING CONSTRUCTION

Whilst it must be admitted that the case history of the application of plastics in building construction to date has not been an impressive one, it must also be accepted that many of the failures recorded can be traced as much to psychological as to the technological causes. In the United Kingdom at any rate plastics have been applied reluctantly in building, for the simple and basic reason that until recently architects had little faith in these man-made materials, and preferred rather to adhere to traditional methods and designs than to use plastics for which performance data have been limited and frequently unreliable. Fortunately designers in Europe and the United States have adopted a more progressive attitude, preferring to take some performance risk rather than forego the exciting design possibilities which plastics alone can offer. This process has been accelerated by design trends, which have given prominence to changes both in the form and methods of construction, many of which could not be matched by traditional materials. Thus from being materials which the architect would consider only in cases of absolute necessity, plastics have almost become his first choice for all jobs of a special or unusual nature, and the success achieved by some designers in the application of plastics has made others the more bold to progress on the same or similar lines. Following this success the manufacturers of plastics have renewed their efforts to develop improved materials to meet and extend this upsurge of enthusiasm.

Encouraged by what has been achieved in the constructional applications of plastics in the developed countries in the face of the most intense competition from traditional methods and materials, developing countries should be more ready to apply them, and so to share the modern and quite exciting structures once thought to be beyond either their scope or appreciation. Such indeed has been the recent progress made in the application of plastics in building, that it would now be impossible to view a future for this industry <u>without</u> plastics.

A. WHAT PLASTICS HAVE DONE FOR BUILDING CONSTRUCTION

In plastics as in most other industrial spheres, statistics speak for themselves. From such records as are available, the United States which leads the world in plastics production with something over 5,000,000 tons per annum, applies roughly 1,227,000 tons (25%) to building construction; W. Germany which is second in the world ranking with a total annual production of 1,750,000 tons, uses roughly the same (20%) for building. Both these countries may be regarded as plastics oriented, that is they will give plastics a chance to prove their worth for any application on their functional merits, as is evidenced by their per capita consumption of plastics, which is 50 lb. in U.S.A. and 56 lb. in West Germany. Going further down the scale of world plastics production, data for building applications are not available for Japan, although we can anticipate that these materials would be particularly favoured where possible for building in a country which is subject to earth-quakes. For the United Kingdom, fourth in world ranking, the picture is about the same pro rata, since out of an annual production of roughly 1,000,000 tons 200,000 tons (20%) go into building. This slightly lower figure we might expect having regard to the still partially anti-plastics mentality of the British using public, as their per capita consumption of 30 lb. bears witness, and when it comes to a question of house building the average Briton usually prefers bricks and mortar. Even this may be attained in some measure, certainly the 'bricks' if not the mortar, but these will be plastics bricks. A large consortium in the U.K. is planning to produce 20 million plastics bricks per annum, for a new building method which is being launched world-wide. The bricks will be of the interlocking type and will be injection-moulded. At an expected cost of 1s.6d. to 1s.9d. per brick it is estimated that they will cut the cost of a house by up to 30%, by reason of the low labour costs involved. Much development will no doubt have to be done before such materials and methods are widely accepted, but this is clearly an area of growth worth watching, and at any rate it shows that industry is 'thinking big' in the application of plastics in building. Quite apart from this, a three-fold increase in the use of plastics in building in the United Kingdom in confidently predicted before 1975.

If we accept this as a pointer for current plastics potential, based on statistics from leaders in world plastics with a total polulation of something like 400 million people using 2 million tons of plastics in building, we may reasonably extrapolate this to a world population of something over 3,500 million people, and arrive at a possible plastics application in building construction of something like 16 million tons, a figure which far exceeds total world production of plastics at the present time. Though the logic of this argument may be very much open to question, it cannot be denied that this figure could be accepted as at least a pointer to the current world potential for the use of plastics in building. Taking this to the ultimate it can be assumed that if the right materials could be made available economically at the many and diverse points of application throughout the world, then building construction could absorb within the foreseeable future a tonnage of plastics considerably in excess of total current world demands for all purposes. From whatever point the problem is viewed, the basic facts must be accepted, that plastics as a family of constructional materials have a considerable role to play in the future in housing the world's polulation. There are of course other highly industrialised areas which could logically be included in the top strata which might add statistical support to the argument, and some of these, such as Sweden, are certainlu fully alive to the potential of plastics both in the building and fitting of houses. As has already been suggestod, the pattern of the evolving use of plastics in building throughout the world could be expectably as varied as are the people themselvos, due to the varied conditions of climate and national traditions and of course economics, and this factor must be taken into account when assessing the future.

Added support for this optimistic view of the future potential for plastics is given by the fact that intensive research is being applied in all the major plastics-producing nations to improve the properties of existing plastics, and to develop new materials more specifically suited to the needs of building construction. In the United Kingdom for example, a number of committees have been set up by Government and public authorities and by industrial undertakings (among them the recently established Agrément Board which covers new materials for building generally), to examine the position on both a domestic and international basis. Although it will naturally take some time before the necessary data are collected and correlated and the relevant decisions are taken, this can expectably result in a considerable increase in the use of plastics in building within the next decade. Quite clearly this implementation will take time if only to make available the necessary supplies of plastics and of the plant needed for their manipulation.

B. GROWTH AREAS FOR PLASTICS IN BUILDING

Hitherto plastics have in the main been used as secondary materials in building, that is providing the accessories or fittings to structures of conventional materials and design. It is of course in these, the primary structures, that the bulk demand for materials lies, and current trends are increasingly towards the use of plastics for such purposes,

1. Plastics as Primary Building Materials

Here by far the most important are the so-called reinforced plastics. This development was a logical one following the construction during the last war of reinforced plastics motor boat hulls, and later of small mobile land craft or caravans. This latter has grown to a sizeable industry in Europe and America, and it was logical that architects should think in terms of building houses from a number of small units suitably interconnected, as could be imagined by joining together a number of caravans. An advantage of this method of housing is its complete flexibility. Suitably designed for the purpose, it would be possible to extend the size of the existing accommodation and add or remove complete rooms at will. From the construction point of view, the assembly line technique would speed production and bring a consequent reduction in cost. It would be visualised that the developing countries too could adopt this method of construction of dwellings. Larger buildings such as blocks of offices might be produced as in-fill cubes in an open framework of steel or reinforced concrete. An interesting development on these lines is the box and panel form of construction being used in the USSR at the present time for multi-storey houses. This consists of prefabricated concrete bathroom units complete with their own floor and ceiling which are simply stacked, one above the other, on precast foundations from a series of structural columns along the central spine of the building.

Glass fibre-reinforced plastics are particularly suited to the building of structures by the integration of standard regular geometric shapes. This geodetic form of construction has been pioneered with success by Prof. Makowski in the University of Surrey, England. To explore these possibilities a number of universities and research establishments throughout the world have included work on structural plastics in their research programmes, whilst the American Society of Civil Engineers has set up a committee on design criteria for plastics structural components. Triangular panels in glass fibre-reinforced plastics are bolted together to build up spherical or similar shaped buildings which have remarkable strength/weight ratio, and have a pleasing albeit somewhat unusual modernistic appearance. Whilst this technique has been applied commercially, notably in Italy, and is particularly suitable for the construction of large assembly halls, sports arenas, and generally where unusually large areas and volumes have to be enclosed, it is by no means limited thereto. It can be applied with great economic success to the building of individual dwelling houses, and is a technique which will be found advantageous in developing countries, where large numbers of relatively simple dwelling houses are needed, and these often located in remote areas. The unit panels are transported conveniently stacked, and may be rapidly bolted together on location, which notably reduces transportation costs compared with factory-made complete units, if not indeed the actual on site erection costs.

Prefabricated panels, in the form of more conventional laminated sandwiches, are being used in increasing quantities for the in-fill construction of buildings attached to more or less conventional steel girder frame works. Such panels usually have a semi-decorative and weather-resistant exterior, with an inner layer of thermally insulant foamed cement. The production of such sheets requires costly and very presses, such as the one recently installed in a factory at Luton, England (reportedly the world's largest) which is rated at 1200 tons, has a pressing area of 10 ft. x 8 ft., and a 50 inch daylight, and of course the panels leave the factory ready for on-site erection. Again they offer some economy in transport cost compared with units finished and transported in the form of huge 'boxes', an important factor when the final structures may be required in remote and undeveloped country.

In the past year considerable progress has been made in the use of plastics for what may be termed temporary primary structures, in the form of flexible inflatable units, which may range in size from the small 'igloo' to a cover for a sports arena. More usually these structures are used to protect building workers in exposed locations during the erection of a permanent building. Such structures fall into two types; one uses pneumatic ribs which are then covered with sheeting, and the other is the low-pressure balloon. The material used is vinyl-covered nylon fabric, which in the case of the balloon is anchored to the ground in various ways such as by a tube of the same material running round the base and filled with water. The structure is then inflated with an air pump which can at the same time heat the air to provide the desired inside temperature. Because of the low pressure and size of the structure, the opening and closing of the door makes very little difference to the cubic content of the balloon but an air-lock entry may be provided. Uses include exhibition halls, temporary meeting rooms and greenhouses. These can be fitted with windows of clear vinyl sheets or polyester film. Structures of this nature can be virtually any size and have been known to resist winds up to 150 knots.

2. Plastics as Secondary Building Materials

Whilst current indications are that almost every area of the application of plastics materials in the production of ancillary fittings in building construction is poised for considerable expansion, it is clearly in the provision of what is generally referred to as the plumbing, including rainwater and general ducting, that they will show greatest growth. This is particularly true in view of the cost and more difficult supply position of lead and copper, and the progress made in the provision of plastics suitable for use in hot-water circuits. It is for this reason that PVC is expected to dominate this area of building activities in the immediate future, and in the U.K. for example, the consumption is assessed at 280,000 tons for 1975, compared with the 92,00 tons consumed in 1965. Currently much of the PVC goes into flooring products, but by 1975 this is likely to be dwarfed by the demands for pipe and ducting fittings of one type or another, including of course the ever-extending use in electrical circuits and fittings. The advent of plastics on a large scale in the general plumbing area, will have a marked and progressively revolutionary effect on the design of domestic fittings, a field in which for many years the United Kingdom has with justification been criticised by competitors in Europe and the United States. As these modern materials become more established, inevitably the traditional methods and designs will disappear, and we shall graduate towards better living standards, and brighter and more hygienic housing generally. Quite naturally the developing nations will be able to benefit by these changes which are rapidly taking place, and will indeed be encouraged to apply plastics more widely and with greater confidence.

It is not only in these more traditional areas that we can expect considerable growth, but also in directions for which traditional materials could hitherto offer little service, or in which small public demand had hitherto made developments less economical. Outstanding in this connexion is the use of plastics as insulation materials, equally to conserve heat in the colder climates, and to protect from heat in tropical conditions. Again this is an area in which the United Kingdom has for decades been notably inadequate. With the advent of almost universal central heating, the house-holder in Britain has become aware not only of the cost of heating, but also of the fact that equable heating in the home through the various seasons can make a considerable contribution to what is generally termed better living conditions. These advances and quite radical changes pioneered in the developed countries, will be ready and waiting for adoption in developing countries, particularly in those where climatic conditions are such that tradtional building materials cannot compete.

Considerable growth can also be expected in the application of decorative plastics, in both the interior and exterior of buildings. This is fostered by the current trend throughout the world not only to better but also to brighten conditions of living. This extends of course into the field of surface coatings, an area in which plastics are increasingly applied in the provision of what have for decades been broadly classified as 'paints'. Not only do the plastics-based compositions make possible the application of plastics' number one attribute, colour, but they have a durability and general preservative quality far beyond that of traditional materials. This again is something which will appeal particularly to developing countries in the tropics, where the ravages of excessive sun have been hitherto difficult to combat.

C. PLANNING A FUTURE FOR PLASTICS IN BUILDING IN DEVELOPING COUNTRIES

Once the need and special potential for plastics in building, particularly in developing countries, is appreciated and accepted, and once it has been decided which materials are suitable for the purpose, the important question is how can the need be met, and what are likely to be the most rational lines of development. In all cases it can be assumed that many such development programmes will initially have to be financed on the proverbial shoe-string, which makes it the more essential that the right decisions will be taken from the start to avoid waste of capital and development time.

Accepting that in most cases the demands for structural plastics from developing countries will be ill-defined in the sense that they will be exploratory, at any rate initially, it will be advisable at the planning stage to include the equivalent of a market research exercise, to assess what the demands are likely to be both in relation to the physical needs of the people and the prevailing climatic and psychological conditions in the country involved. Such a survey should aim at selecting the major demands and concentrating and directing these along well defined manufacturing lines. This will be essential since the initial demands are likely to be for small quantities of a number of diverse types of end products.

1. The Logic of Step-wise Development

Quite obviously any developing country will have to be very critical and selective in its initial planning, since it cannot hope to commence the production of a number of plastics raw materials or end-products simultaneously. Having decided where the major demand is likely to fall, usually the most logical initial follow-up to this will be to import these manufactured end-products, or at least the bulk of them, so that actual user trials may be carried out to test their practical usefulness under the conditions obtaining, a decision which so frequently cannot be taken on the basis of experience gained in other countries. True user trials having established the demand for well defined products, the next logical step would be to import the necessary fabricating plant (injection machines, extrusion machines, etc.) to enable these or similar products to be manufactured, using of course imported plastics materials. Such a procedure offers the maximum economy of capital and gives the greatest possible flexibility of operation, without the necessity in the early stages of capital being locked up in costly plastics manufacturing plant, or as it would most likely have to be, plants. Though such fabricating plant would aim more particularly at the production of plastics units destined for building, this need not be exclusively so: once injection or extrusion plant is in operation it can meet many consumer needs, and indeed the broadening of the basis for production would have to be the constant aim of the early planners.

It may be argued that this step-wise plan is not helping the manpower and raw material problems of a country, and it leaves such a country vulnerable to crises of war or other economic upheaval, since supplies of the raw plastics might be cut off. This is a valid supposition but one less likely to eventuate in the future, since for some time to come alternative supplies for raw plastics are always likely to be forthcoming, so widely are established manufacturers (and exporters) of plastics materials, products and plant, distributed throughout the world. Such a plan would at any rate have the great advantage that it would enable a developing country to establish its industry with the minimum of initial capital outlay, and yet enjoy the advantage of the most competitive prices that world production can offer.

Assuming finally that proceeding by these perhaps slower and less spectacular but equally less speculative stages, a developing country has established a user demand and an end-product manufacturing industry, then the final and most ambitious step towards self sufficiency could be taken, namely the manufacture of raw plastics. In such a case it is rarely likely that any more than a few of the most widely used plastics would be considered, and most probably one or more of the three major 'polys' - PVC, the polyolefins and polystyrene. The attainment of this advanced stage of development would be accelerated by the availability of particularly favourable indigenous raw materials, or by the proximity of expanding export markets.

2. The Influence of Local Conditions on Planning

In deciding whether or not to establish a plastics industry in a developing country, many considerations other than the method of procedure outlined above have to be taken into account. This is true whether the plastics are destined for building or any other application, but certainly more true in the case of building. Two main points have to be satisfied; the proposed industry must meet the needs and improve the living conditions of the people, and possibly more important, it must work profitably.

Profitability in any industry is largely influenced by local conditions, and certainly it will be local conditions which will decided whether the entry into plastics will be through the three stages outlined above. The first demand is the basic home market and the ability of the country is to establish and sustain that market. The next point is the availability of raw materials (be those the raw plastics or basic chemicals), and of adequate labour of the necessary calibre.

On the question of raw materials, under the step-wise development plan outlined, these might well be imported from nearby established manufacturers, or indeed it frequently is quite competitive to transport material half way across the world from countries having surplus to their needs and prepared to offer cut-price sales rates. In some cases of course indigenous materials may be available in a country, but this is usually a matter for subsequent integration once basic manufacture is established. A natural resin, derived from a common wild nut, found in profusion in a tropical forest for example, could well be developed for application with plastics, but it is rarely a sound basis on which to found an industry. The best advice to the planners is usually to establish your demand, establish your industry to meet that demand, and then apply your innovating ability to use advantageous indigenous raw materials.

The question of the use of local labour is more easy to decide. Since the plant used in the fabrication of plastics is quite standard and not unduly complicated, local labour can with little doubt be applied. Indeed it has frequently been proved that the type of labour available in developing countries is admirably suited to the operation of repetitive processes. In the case of the operation of more complicated chemical process, it would usually be advisable to have a nucleus of trained staff, with the key personnel fully trained and experienced men. Here again it can be said that there are many routine chemical operations for which inexperienced personnel are perfectly satisfactory. With the increasing automation of many chemical and polychemical plants, this question of personnel may become less significant, but it can still be one valid argument for entry into plastics that adequate and cheap labour is available on location, despite the fact, as has been stressed elsewhere, that plastics is not a labour intensive industry.

VIII. GENERAL EPITOME

The foregoing brief chapters have given what can best be regarded as a 'snapshot' picture of what plastics are, what they are doing in building construction, and what their future might expectably be in the developing areas of the world. Though much of the latter is speculative, it will be abundantly clear that plastics as a family with their remarkable versatility and world wide availability, have much to offer. From what has recently been done, and from the schemes which are known to be under consideration, it is quite obvious that within the next decade plastics will have what is possibly a unique opportunity to assist in upgrading both the living conditions and standards of less advanced countries.

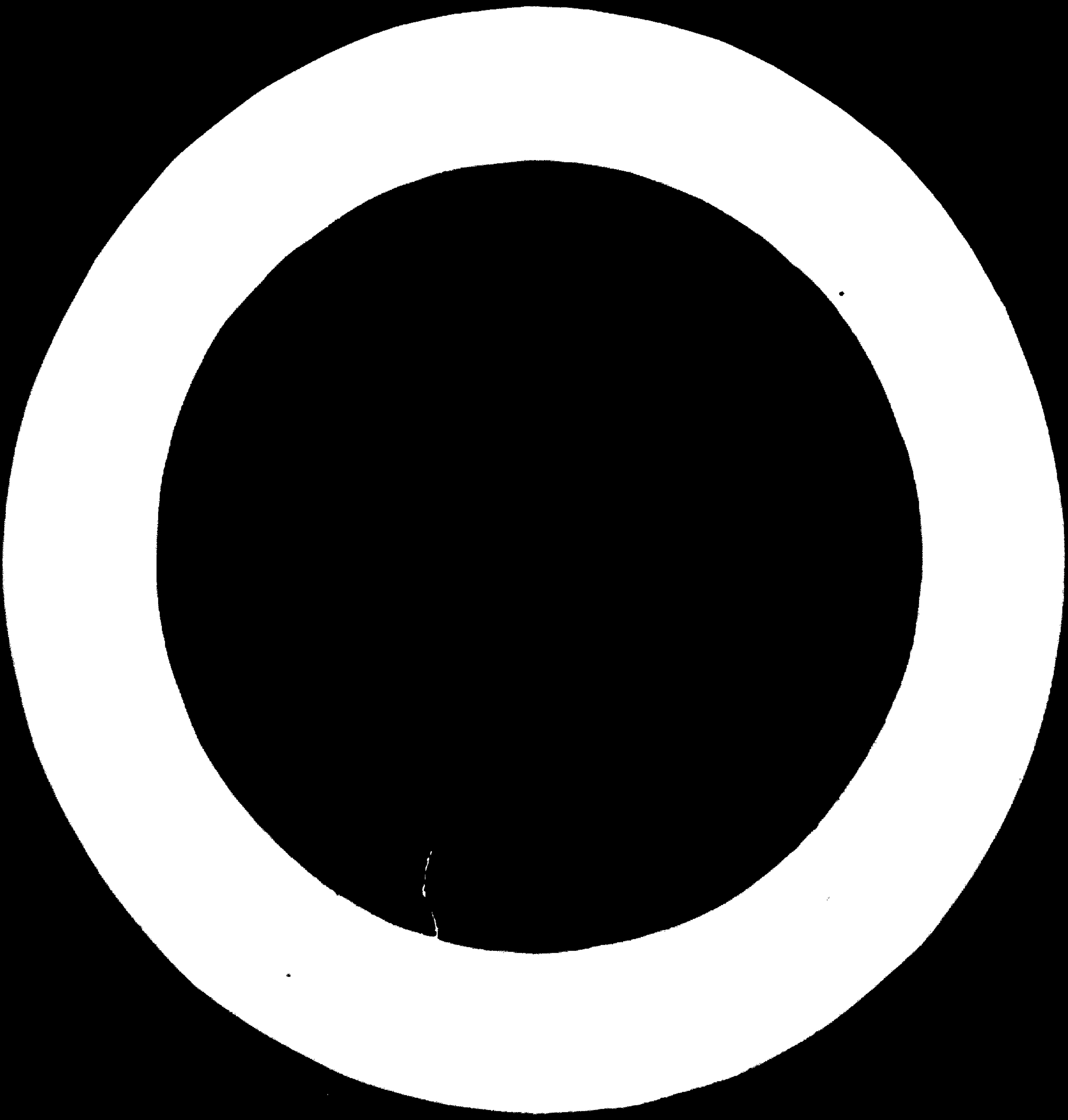
From what has been said however it will be equally evident that the process of exploring and exploiting these possibilities will not be an easy one, and the problems facing the planners will be many. Plastics have much to offer, but they can only exert their advantageous influence if they are applied in the right way, and under conditions which enable them to capitalise to the full their quite remarkable physical properties. The approach to the problem must be imaginative and selective, and any attempt to produce what would in effect be a blue-print to apply generally to any developing country would be foredoomed to failure. As has been stated, plans must be laid after due examination of all the factors involved in the respective countries, as much attention being paid to those stemming from climate and the psychology of the people, as to the more obvious economic and technological considerations. If plans are made having due regard to these points, and if the resulting development is carried out methodically and patiently, then the next decade could rank among the most exciting in the history of the development of plastics in building, and might have ultimate impact as much on the highly developed as on the developing areas of the world.

IX. ENVOI

To foretell the future in any sector of the plastics industry is no easy matter; particularly is this so in building construction in developing countries. The danger is that in making out the case one must alternately express optimism and pessimism, as may indeed be evident in this report. Quite clearly plastics will have a key role in building construction in the future throughout the world; already this is rated the best customer and best growth area for plastics in many countries, including the U.K. where it currently accounts for rather more than 25% of the total production of plastics. The difficulty is to substantiate optimism for the future by citing case histories from the past. Since these in many cases do not make too happy reading, any such optimism must frequently be based on recent experience of the growing application of plastics in building, supported by the most logical of all reasons, the onward progression of plastics if not in its own right, then as a significant part of the rapidly expanding oil and petrochemical industry.

Today petrochemical development is replacing iron and stell as the industrial status symbol which any developing nation in the process of achieving economic growth through industrialisation seeks to have. Oil is the obvious target toward which developing nations direct their aim, and once assured within this industrial area they could progress naturally to the sectors emerging therefrom, petrochemicals and plastics. Generally speaking international finance usually regards state interest in petrochemicals in developing countries less favourably than in oil itself, so that this is often an added reason for what may be termed 'going basic'. This is good and logical in its way; the difficulty arises when a number of neighbouring countries plan to do the same thing almost simultaneously. This danger was recently experience in Colombia, and it is one likely to face any developing country, namely that plans for a petrochemical and plastics industry may be ruined if they depend to any significant extent on exports to neighbouring countries. In the instance cited, what Colombia planned to producedand export could just as well be envisaged in neighbouring Mexico, Venezuela, Brazil, Argentine or Chile. The nations of Latin America avoided the difficulty by signing the Industrial Complementation Agreement within the framework of the Latin American Free Trade Association, as a preliminary to rationalising further expansion of productive capacity, particularly into more sophisticated fields.

What has been done in Latin America could be repeated in other parts of the world. Emergence of a nation towards a more advanced society and improved overall standard of living, may start with oil and progress through petrochemicals to plastics, and thence to a wide industrial field including building construction. In every case however technological advance must be safeguarded by what may be termed balancing arrangements between neighbouring nations.



APPENDIX 1: REPRESENTATIVE PHYSICAL PROPERTIES OF THE MAIN PLASTICS USED IN BUILDING, WITH AVERAGE U.S.A. AND U.K. PRICES, AND SOME TYPICAL APPLICATIONS

	POLYMER TYPE	CHEMICAL TYPE TS-thermo-setting TP-thermo-plastic	SPECIFIC GRAVITY	COMPRESSIVE STRENGTH p.s.i.	TENSILE STRENGTH p.s.i.	SPECIFIC STRENGTH Tensile strength / Sp.Gr. p.s.i.	FLEXURAL STRENGTH p.s.i.	YOUNG'S MODULUS OF ELASTICITY p.s.i.		THERMAL EXPANSION cm/cm/^{0}C	HDT (Heat distortion temperature) at 264p.s.i. ^{0}C (ASTM D.648)	BURNING RATE (Flammability)	WATER ABSORPTION % 24 hrs.	AVERAGE PRICE cents/lb U.S.A.	AVERAGE PRICE d/lb U.K.	SOME TYPICAL APPLICATIONS IN BUILDING CONSTRUCTION	
1	ABS	TP	0.99-1.15	2,500-11,000	2,400-8,000	2,422-7,830	3,000-13,500	$1.0\text{-}4.1 \times 10^{5}$	1	$6\text{-}13 \times 10^{-5}$	88-117	Slow	0.1-0.8	40	43	Pipes and fittings	1
2	ACETAL	TP	1.42	16,000-18,000	8,800-10,000	6,200-7,050	13,000-14,000	$4\text{-}4.1 \times 10^{5}$	2	$8.1\text{-}8.5 \times 10^{-5}$	110-124	Slow	0.22-0.25		69	Door and window furniture, extractor fans, W.C. fittings, ball valves, taps	2
3	ACRYLICS	TP	1.17-1.20	12,000-20,000	7,000-11,000	5,980-9,180	13,000-17,000	4.5×10^{5}	3	$5\text{-}9 \times 10^{-5}$	71-102	Slow	0.3-0.4	49.5	40	Suspended ceilings, door and wall panels, roof lights, baths, sink units, W.C. cisterns, light fittings, shower paints, roofing sheet and door furniture	3
4	AMINOPLASTICS 1. Melamine formaldehyde (MF) and 2. Urea formaldehyde (UF) moulding powders	TS	1.47-1.52 1.47-1.52	25,000-45,000 25,000-35,000	7,000-13,000 6,000-13,000	4,780-8,580 4,080-8,550	10,000-16,000 10,000-16,000	13×10^{5} 15×10^{5}	4	4.0×10^{-5} 2.7×10^{-5}	129-204 126-143	Self extinguishing Very low	0.1-1.0 0.4-0.8		33 23	Light fittings, door furniture, toilet seats chipboard binder, decorative laminates, paints and coatings	4
5	EPOXIDE RESINS (cast)	TS	1.11-1.40	15,000-28,000	4,000-13,000	3,610-9,280	8,800-21,000	3.5×10^{5}	5	$2.0\text{-}6.5 \times 10^{-5}$	47-288	Slow to self-extinguishing	0.08-0.15	58	78-84	Flooring and screeding compounds	5
6	GLASS REINFORCED PLASTICS	TS	1.35-2.3	15,000-50,000	25,000-50,000	18,500-21,800	10,000-80,000	$80\text{-}45.0 \times 10^{5}$	6	$1.5\text{-}3.3 \times 10^{-5}$	204	Slow to self-extinguishing	0.05-0.8		35-50	Glazing, cisterns, showers, baths, window frames, doors, external facing panels, sink units, roofing sheet, pipes concrete shuttering	6
7	NYLON	TP	1.13	7,000-16,000	7,000-12,000	6,200-10,630	8,000-16,000	$1.5\text{-}4.0 \times 10^{5}$	7	$8\text{-}15 \times 10^{-5}$	66-86	Self-extinguishing	0.4-3.3			Door and window furniture	7
8	PHENOLIC MOULDING POWDERS Phenol formaldehyde (PF)	TS	1.25-1.45	10,000-40,000	6,500-85,000	5,200-58,600	8,500-15,000	$7.5\text{-}10 \times 10^{5}$	8	$2.5\text{-}6 \times 10^{-5}$	110-315	Very low	[illegible]	27.5	15	Light fittings, door furniture, toilet seats laminating resin, foam insulation	8

APPENDIX 1 CONT.

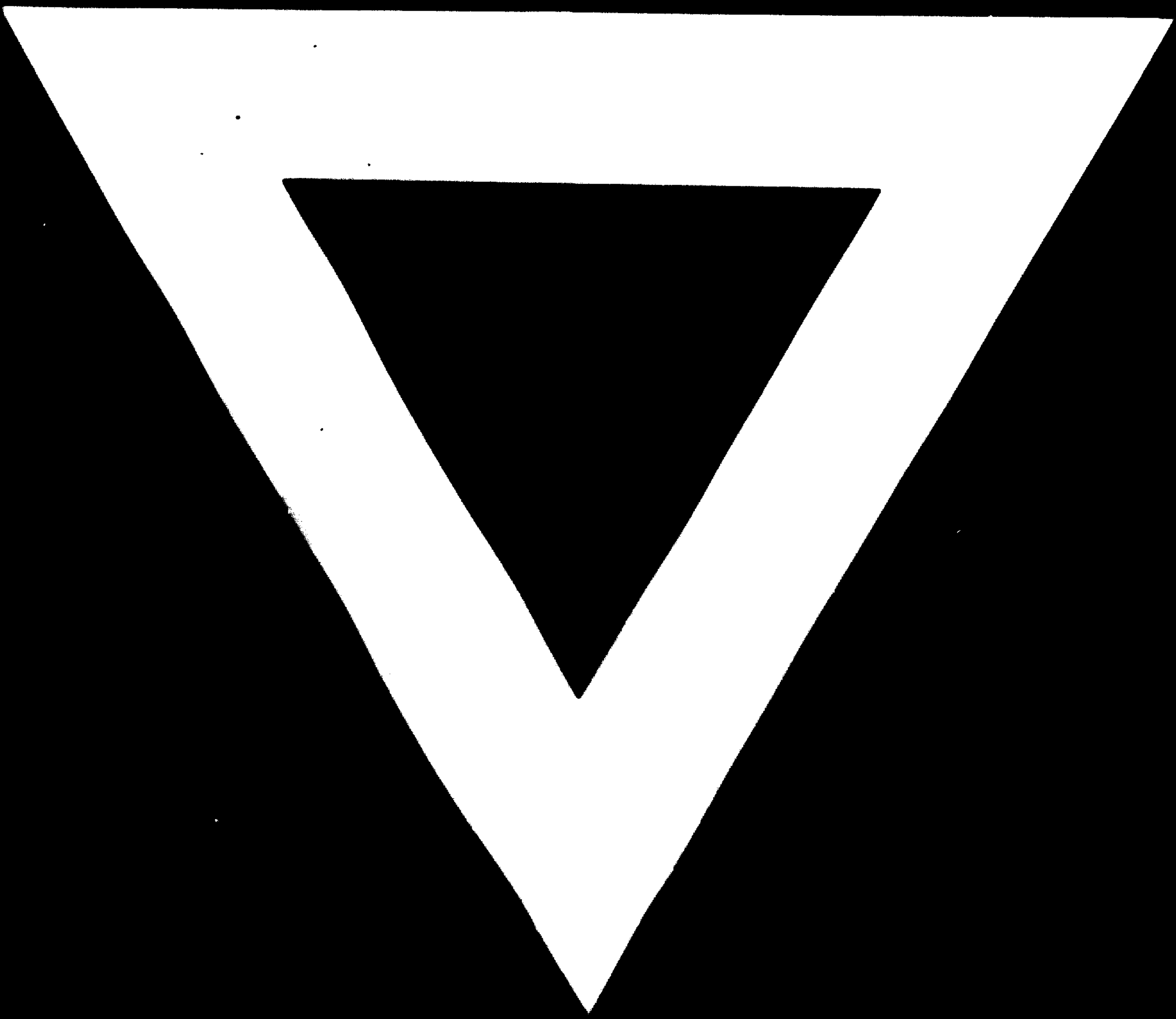
9	**POLYESTERS (Rigid)**	TS	1.10-1.46	13,000-30,000	6,000-10,000	5,400-8,000	8,500-10,300	$3.0-6.4 \times 10^5$	9	$5.5-10 \times 10^{-5}$ 80-204	Slow to self-extinguishing	0.15-0.80	32	30	Paints, flooring compounds, surfacing compounds (external) See also GLASS REINFORCED PLASTICS	9
10	**POLYETHYLENE** 1. Low density 2. High density	TP	0.9-0.96	1. - 2. 3,200	1,000-6,500	1,110-5,730	2,000-7,000	$0.17-0.8 \times 10^5$	10	$11-18 \times 10^{-5}$ 32-40	Very slow	0.1	17-19.25 18-20	16-21.5 21-23	Pipes and fittings, cisterns, damp courses, tanks, toilet seats	10
11	**POLYPROPYLENE**	TP	0.9	8,500-10,000	4,300-5,700	4,700-6,300	-	$1.3-2.0 \times 10^5$	11	11×10^{-5} 57-82	Slow	0 1	27	23 5	Hot and cold pipes and fittings, door and window furniture, W.C. cisterns, tanks, ducting, sink units, toilet seats	11
12	**POLYSTYRENE** (high impact)	TP	0.98-1.11	4,000-10,000	3,500-12,000	3,500-10,000	5,000-17,000	$3-6 \times 10^5$	12	$3.4-21 \times 10^{-5}$ 86	Slow	0.03-0 04	14.5-20 (20.0)	13.5-19.5 (19.5)	Wall tiles, acoustic tiles (cellular), foam insulation, bricks (cellular)	12
13	P.T.F.E.	TP	2.10-2.30	1,700	2,000-4,500	982-1,000	-	0.50×10^5	13	10×10^{-5} -	None	0.00	890	432	Pipe, thread, sealing tape	13
14	P.V.C. Unplasticised (rigid)	TP	1.30-1.40	8,000-13,000	6,500	6,120	13,500	3.5×10^5	14	5×10^{-5} 55-74	Self-extinguishing	0.5	15-24	13.5-14.75	Pressure and non-pressure pipes and fittings, rain-water systems, glazing, handrails, skirtings, ducting, roofing sheet, conduit, concrete shuttering, tiles, suspended ceilings, window frames, table covering	14

<u>Source</u>: This table is based on information collected from Modern Plastics Encyclopaedia data Sheet Issue 1965 and "Properties of Plastics" issued by Shell Chemical Co. Ltd. (Plastics and Rubbers Division)

<u>Notes</u>: (1) Having regard to the fact that some of the materials listed actually vary widely in their composition, a fairly wide range is quoted in a number of cases, e.g. ABS.

(2) Some plastics (notably polyurethanes and polyvinyl acetate) have been omitted from this table since they are mainly applied in building in combination with other plastics in paints and surface coatings: polyurethanes are used as such in expanded forms for thermal and sound insulation.

(3) <u>Specific strength</u> of common structural materials for comparative reference: aluminium 8,150; phosphor bronze 13,020; copper 5,200; steel 10,830; zinc 2,450; tin 816; lead 230.



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