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Distr.
LIMITED

ID/WG.96/9
20 August 1971

Original: ENGLISH

United Nations Industrial Development Organization

Expert Group Meeting on the Use of Plastics in the Building Industry

Vienna, 20 - 24 September 1971

SCOPE FOR PLASTICS IN BUILDING 1/

by

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id.71-6659

SUMMARY

There is a universal demand for more housing than ever before; the need is greatest in the developing countries. It is considered that plastics have a part to play in solving this problem. This note discusses the nature and properties of plastics and their limitations in relation to any contribution they might make to the housing stock and to improvements in house construction and performance.

The functions of the different elements in house construction are discussed with a critical appraisal of the contribution to be made by materials with the range of properties that plastics offer. Cost and other economic considerations, traditional attitudes and building legislation all exert a restraining influence on the use of plastics in building. Recommendations are made for further study of the materials and education of designers and users, to permit plastics to play a more effective part in solutions of housing problems in the developing countries.

The basic problem that prompts this paper need hardly be elaborated: there is a universal demand for more housing than ever before. Growth in populations and scattering of families, opening up of new areas, development of new industries and migration from rural to urban surroundings all create a need for more housing. Much of it must necessarily be built at low cost, to the minimum tolerable standard. In contrast wider educational opportunities and knowledge of technological advances have increased the demand for higher standards in housing.

Governments, international organisations and other large groups with housing responsibilities are all faced with a similar problem: how to obtain the best value in terms of adequate living standards for the maximum number of persons, within the inevitable budgetary restrictions and with the available labour force? Traditional approaches to building may in the past have provided acceptable houses, built of local materials, but the techniques are often slow and not sufficiently adaptable to change in circumstances. The necessary skills may be lost as able craftsmen move to more lucrative work, or to work in factories where standards of comfort are higher, or these craftsmen may be faced with a demand that exceeds their capacity and restricted by the growth of trades unionism from achieving their maximum productivity.

As this situation has arisen, effort has been devoted to the development of new building techniques; means have been sought to employ traditional materials more effectively; new materials have been developed for building and outlets have been sought in the building process for the developments in other fields of modern technology. It is in this situation that opportunities arise to employ plastics. All available techniques and materials must be considered as providing possible solutions to the problems, both of providing structures, and of furnishing them with appropriate services and fitments. Plastics, as much as most new materials offer possible progress from traditional approaches, and means to augment existing house-building capacity and improve standards.

Other papers before the meeting refer to possible applications of plastics in building and to the specific ways in which their introduction may lead to progress. The purpose of this paper is to make a critical appraisal of the scope for plastics, with particular reference to developing countries, suggesting where future development efforts might be applied.

The various environmental elements that make up the complete dwelling house are examined and the properties of plastics considered as they relate to both functional and economic aspects of the use or possible use of the materials in house-building. This leads to some suggestions for extending their use and also brings to light some of the deficiencies and problems that arise. In some fields of application the development of improved plastics materials or techniques of use might be rewarded by the satisfactory introduction of plastics. In other fields, the effort necessary is not justified by the probable cost or performance of the resulting product, particularly in relation to the availability of alternatives.

The attitude must be strongly resisted that plastics alone are likely to provide the best solutions to the many problems, although this might be the outcome in some instances. There is too often a danger that excessive pressure from manufacturers and fabricators to use their materials and promote sales will result in inept design, inferior quality and insufficient regard for the physical and mechanical properties of plastics. It is more effective to consider how, in conjunction with and in complement to other new and existing materials and, by development of new designs, they may augment rather than replace traditional building products.

FUNCTION OF HOUSING

The primary function of housing is to provide shelter from the elements and a degree of environmental comfort, adequate in terms of heat and humidity, ventilation, light and sound, for the daily living needs of the occupants. Safety in fire, either by the use of fire-resistant materials, or by restriction of the rate of spread of fire to a degree compatible with means of escape and appropriate to the occupants, is an important consideration. Satisfaction of these basic requirements to the minimum standard may suffice for temporary housing as used by migratory people or in disaster relief work, but more permanent schemes call for higher standards and also the provision of services - water, drainage and power.

For the purposes of this paper, low-cost, permanent housing only is considered. Plastics have a part to play in producing such dwellings - for climates that range from arctic to tropical. Satisfactory extension of their use in the different environments calls for an appreciation of the ways in which the properties of traditional materials have enabled them to give satisfactory service while their weaknesses have been overcome. In this context it is then possible to consider how far plastics have appropriate qualities to perform, and improve on, the same functions.

NATURE OF PLASTICS

Before considering in detail any specific building elements it is necessary to review in general terms the properties of plastics as they relate to building applications and to appreciate how these properties differ from those of traditional materials. It is of value as an introduction to the discussion of their properties to be aware of their basic nature which, as well as determining their advantages also indicates their limitations.

As organic materials, ie mainly or wholly composed of carbon compounds they owe their existence to the ability of carbon atoms in certain simple molecules (monomers) to link together to form the long-chain molecules called polymers. These carbon-based chains are the basis of plastics and also rubbers, and though they may be as much as tens of thousands of units long, they are still sub-microscopic in size. In some plastics the chains may be chemically joined by numerous cross-links.

If they are not so linked the chains are held together by relatively weak molecular forces which are readily overcome by rise in temperature. The materials softens at comparatively low temperatures and may be shaped under the influence of heat and pressure. This process may be repeated an indefinite number of times, and materials of this type are known as 'thermoplastics'. If chemical cross-links can be formed between the chains at the moulding stage, these enable the material to retain the form in which cross-linking occurs. These materials, are known as 'thermosetting plastics' or 'duroplastics'.

The lengths of polymer chains affect the material properties - shorter chains have greater molecular mobility; as an example the paraffins, a group of materials of similar chemical constitution, range from gases and volatile liquids of small molecular weight, through low-melting waxy solids, to the polyolefines - one of the groups of plastics. Arrangements of molecular chains also have a profound effect in determining properties. Often polymerisation produces chains with a kinked or curly inherent conformation. Within limits stress applied to these materials causes recoverable deformation and the polymers have rubbery properties. If the deforming force is large enough, there is a tendency for the chains to undergo more permanent straightening out; eventually the chains may slide over one another and permanent "plastic" deformation occurs. This tendency of most plastics to undergo irreversible deformation under continuous stress is recognised as 'creep'. It is most noticeable in thermoplastics, under certain conditions of stress, and must be taken into account in the design of plastics components to perform any mechanical function.

As the temperature is raised, chemical bonds become more mobile and thermoplastic chains move about more freely, so that the materials soften and become mouldable. Plasticisers can be regarded as lubricants which enable chains to move relative to one another and even to slide over one another. This accounts for differences between flexible plasticised PVC and its more rigid unplasticised equivalent.

The relatively large thermal expansion of plastics can be explained in terms of the bonds holding polymer chains together. These are weaker than the bonds in inorganic matter; heating permits the chains to move farther apart than the ultimate particles of inorganic materials and coefficients of thermal expansion are higher, often by an order of 10 or more, than those of minerals, metals or cements.

In thermosetting plastics, cross-linking produces a three-dimensional network structure at the moulding stage and this 'curing' restricts subsequent movement of the chains. Re-moulding is not possible, deformation at elevated temperatures is restricted and creep is considerably less than with thermoplastics.

The basic properties of plastics, as determined by their molecular arrangements, can be considerably modified by the incorporation of a wide range of additives. Plasticisers increase flexibility but may reduce strength; fillers may improve hardness and other mechanical properties while reinforcements greatly increase strength or rigidity. Pigments and dyes permit a range of colours. Stabilisers, anti-oxidants, ultraviolet radiation absorbers and other additives also affect durability. Appropriate compounding and processing of plastics is quite an involved art, which plays a large part in determining their properties.

PROPERTIES OF PLASTICS

It is clear from the preceding section that "plastics" must be regarded not as a single material but as a class of materials. Their properties depend on the basic monomer, on the lengths and configuration of polymer chains, on the degree of cross-linking and the nature and proportions of additives, as well as on the processing techniques. The properties of any individual plastics, eg polyethylene, or polyester or especially PVC, can be varied over a considerable range by these variations in material and processing, and the properties of all the plastics available cover a very wide spectrum. Like metals, plastics share common properties, but the differences between them are just as important in determining their versatility and the handling techniques for particular applications. Thus this review of the properties of plastics as they relate to building use can present only a general indication of their advantages and limitations. More detailed discussion follows in later sections of the paper with reference to particular materials in specific applications.

The properties of plastics may be considered under a number of principal headings without any clear attempt to distinguish individual properties as advantages or limitations from the building point of view. For the purpose of this paper, the following headings are chosen:

- i Formability
- ii Colourability
- iii Variability in terms of basic properties
- iv Density
- v Fire Behaviour
- vi Mechanical Properties
- vii Thermal Properties
- viii Insulating Characteristics
- ix Durability

i Formability

It is almost axiomatic, from the name, that 'plastics' may be formed into useful shapes. Numerous techniques are used in fabrication. Some of the principal ones are extrusion, injection moulding, post-forming, compression and low-pressure moulding, calendering and foaming. Most of these techniques are admirably suited to mass-production and the volume of demand often determines the viability of a product. Initial expenditure on machinery and moulds or dies is relatively large and can only be offset by large production runs.

However their formability does permit design in plastics to suit particular applications and the incorporation of integral detail at the design stage - often leading to significant reduction in numbers of components. The mass production techniques permit factory manufacture to closer tolerances than with traditional materials and in turn lead to economy in installation. At fixing points, or where additional stiffness or strength are required, it is often possible to incorporate metallic inserts during the forming process, to provide the requisite improvement.

Nevertheless there are limitations in the formability of plastics. The mass production techniques are most suited to thermoplastics, which in general are not used for structural purposes. Technical limitations in the size of extrusions and mouldings might be overcome - very large thermoplastics components have been produced, eg an all-plastics bathroom thermoformed from acrylic sheet, or very large diameter pipes produced by a spiral-winding technique; but the cost of overcoming the size limitation is likely to be jutified only if very large markets can be assured. The larger the component the more difficult it is to ensure adequate quality throughout and to avoid local stresses associated with the moulding technique and also the creep tendencies of thermoplastics limit their structural suitability. As a consequence, most large components are produced by low-pressure moulding of reinforced plastics which, while they are the most suitable for structures in terms of mechanical properties, are not so readily formed by mass production techniques and in any case are more expensive than most of the commonly used thermoplastics. For large production runs, a degree of mechanisation has been achieved, ranging from machine 'spray-up' of the material, to "hot-press" moulding of large panels, but for the majority of products for building "hand lay-up" methods are used. The possibility of using this technique is one of the main advantages of reinforced plastics in permitting short runs of large components, using relatively inexpensive moulds. Additional stiffeners and fixing points can easily be incorporated so that given suitable basic design there is seldom any technical problem in producing reinforced plastics components having adequate mechanical properties. Product costs are likely to be the main factor controlling this.

ii Colourability

One of the features of plastics products that makes them so attractive to the user is that most plastics can be coloured integrally with a wide choice of hue. Choice of colourant or pigment is not always a simple matter however - compatibility with the resin system particularly during processing, and inherent stability under processing conditions are essential as well as stability during exposure to the conditions of use. Both PVC and polyesters - both materials commonly used in building products - present problems in choice of pigment. One by-product of the degradation of PVC, that may be produced in processing or on weathering, is hydrogen chloride which has a powerful catalytic effect in causing deterioration of pigments and colourants. The action of peroxides, curing agents for polyesters, may be drastically affected by pigments that are unsuitable either chemically or because of their physical form.

Inevitably the most suitable and most effective colourants tend to be the most expensive ones and economics are likely in many instances to dictate the selection of colours which are not the ideal ones for particular applications. Nevertheless the choice of colours is still often very large and does constitute a major *advantage. Building components may be so pigmented as to require a minimum of attention in order to maintain the original appearance, intended by the designer.*

Many plastics may also be produced in translucent or transparent forms and in providing lighting for buildings can offer unique advantages. This applies both for artificial light fittings and in external panelling to control the level of daylight within the building. Translucency can readily be controlled at any desired level and even structural members, particularly in reinforced plastics can contribute so that it may be possible to integrate all the necessary lighting facility in the basic structural design. Performance when exposed to the weather must be borne in mind, however: there may be a slight increase in transparency on first exposure of some products, but the long-term effect of weather on all translucent plastics is to reduce light transmission, and excessive loss of transmission may sometimes be the criterion of failure.

iii Variability in terms of basic properties

It is a major advantage of plastics as a class of materials that by varying the size and shape of their molecular chains and by incorporating additives of various kinds, they can be produced with a considerable range of properties. With skill in compounding, appropriate materials can be produced to meet the requirements of particular applications.

Polyethylene with straight molecular chains has higher density, higher softening point and is harder than polyethylene with branched chains, which do not pack so well together, but this improvement may also be associated with reduced toughness and greater difficulty in moulding in stress-free forms. Plasticisation of a material, by compounding it with suitable low-molecular weight additives, may increase its flexibility and toughness, but at the same time cause loss in strength and poorer performance at elevated temperatures. The effects of pigments and colourants have already been discussed. Incorporation of flame-retardant additives in combustible plastics may produce a very significant improvement in the fire behaviour but have a deleterious effect on the weathering and mechanical properties of some plastics. Incorporating a range of lubricants, anti-oxidants and stabilisers may permit considerable modification of processing conditions and extend the range of sizes into which materials can be formed - eg, without effective processing aids of this type for PVC, it would be impossible to extrude or mould it into pipes and fittings in the large diameters currently used for water supply and drainage.

It is by the use of reinforcements that the most significant improvements may be obtained in the properties of plastics. Cellulosic and asbestos filters have been used for many years to improve the properties of moulded phenolic resins. The introduction and availability of glass fibres, in forms suited for the reinforcement of cold-setting resins, particularly polyester and epoxy resins have brought about a revolution in the use of these materials. They can be produced with greatly enhanced tensile strength, stiffness and resistance to impact, and can be moulded into components large enough to be considered for major parts of dwelling units rather than solely for fitments and ancillary parts. The performance of these materials is particularly dependent on the moulding conditions and the skill of the moulder. Though it is possible to choose completely appropriate resins, hardeners and reinforcements for particular applications, it is also possible to produce a product giving poor performance simply because of inadequate moulding control. In the nature of the process also it is particularly difficult to assess the quality of the composite, in particular its long-term properties, by tests carried out after moulding. This is one of the more striking examples of the difficulty of choosing and ensuring the optimum quality of the material for a particular plastics application.

It is an unfortunate feature of plastics that, as products of the chemical industry, they have names that convey little to the unaccustomed ear, and are not easily distinguished one from another. The names may not even be easily pronounced:- acrylonitrile-butadiene-styrene copolymer (ABS) polyurethane made from a hydroxyl polyester and a di-isocyanate; polyisocyanurate foam; these are all materials of potential value for building. Yet if plastics are to be used satisfactorily, it is essential that persons responsible for their use should be aware of the differences between materials and the variations that are possible in their properties by changing compounding ingredients and proportions, or processing conditions. Even the most erudite of users, however, cannot hope to be familiar with all relevant aspects of a material that might be used in a particular building product; he must depend very largely on the plastics manufacturer to ensure that a suitable choice of material and formulation is made for a particular application, and that proper control is exercised in the forming process. This can be achieved, however, only if the user or his agent, having some knowledge of different plastics and their properties, is sufficiently familiar with the building requirements to be sure that the manufacturer has all the necessary information to make a satisfactory product.

iv Density

In many industries, particularly in the field of transport, lightness in weight can confer major advantages on components. For some building products this same lightness, made possible by the low density of plastics, is an advantage; for some purposes it may also be a drawback. Carbon-based materials in general have lower density than other building materials except timber which is itself organic. The first column in table I, which compares plastics with other building materials illustrates the magnitude of this advantage. In consequence of their lower density, plastics building components are likely to be lighter in weight than alternatives in other materials. In cellular forms, as used for thermal insulation, the reduction in weight is even more striking.

Lightness in weight often leads to advantages in ease of installation, and handling on site; it may reduce the cost of transportation of building components to the site; in some instances, reductions in foundations and supporting structures may be possible, although such reductions may be little greater than those achieved with components of other materials, and depend as much on the style of construction as on the materials used.

Lightness in weight brings its own problems, in both cladding and structural components. The possible effects of wind require that additional anchorage and more careful fixing be provided for plastics components particularly in roofs than for their heavier traditional counterparts - it is notable that the weight of slates, or concrete or clay tiles or heavy layers of asphalt play a part both in keeping them in position in roofs and in improving the stability of the building. Lightweight components may have to be secured on site and there are problems in handling such components either manually or by crane in even moderate winds. A problem 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 is a district disadvantage where sound insulation is required.

v Fire Behaviour

Because of their carbon-based polymeric structure, all plastics are combustible. In all countries improved standards of fire resistance of building elements are thought necessary, inevitably restricting the use of plastics for many structural applications. Although they differ in the ease with which they are 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 - combustibility - cannot be overcome, so that allowance must be made for it in design. This usually calls for inclusion of supplementary elements to increase the fire-resistance, but also adds to weight and cost. Plastics are not, of course, unique in displaying weakness in fire and the final column in Table I compares briefly their performance with some conventional building structural materials.

Some plastics unfortunately produce noxious fumes and more smoke than traditional materials in the event of a fire. This naturally raises reservations about their use where these combustion products may affect escape from a building, and also from fire-fighting authorities. The problem of control of combustion products is at present under active investigation.

vi Mechanical Properties

It is often pointed out that plastics have a high strength-to-weight ratio but as weightiness is not usually a major restriction in building applications, this advantage of plastics is less important in building than in aircraft structures. It is total strength that is important, and it is an unfortunate limitation that, in the mechanical properties which are important for load-bearing members, plastics are inferior to the traditional materials in present use. The designer must be aware of the following features in which the engineering properties of plastics differ markedly from those of traditional materials: stress-strain curves are not usually linear up to the point of failure and their moduli of elasticity and rigidity are very low; plastics often exhibit anisotropic behaviour; the mechanical performance of plastics is affected by the rate of straining of the material, and also by the temperature and other environmental conditions to which it is subjected; plastics 'creep' under load with time, and may show a reduction in ultimate strength with time even under static loading. These properties in general can be ascribed to the structure of molecular chains which can, under stress, move relative to one another and which are not restrained in the more rigid crystalline lattice structure associated with inorganic materials.

The consequence is that, in the design of plastics structures, in order to obtain rigidity and ensure a minimum of change with time, components must be subjected to stress levels very much lower than the ultimate failure stress as determined by short-term tests. Plastics structures are frequently 'over-designed' to provide the necessary rigidity at low stress levels; alternatively structures are designed which differ radically from those of traditional building, eg 'stressed skin' and 'folded plate' structures which form enclosures with odd shaped internal surfaces. This 'over-design' is also partly accounted for by lack of suitable mechanical design data. As a direct consequence of these design problems, plastics may well be unacceptable either for economic or aesthetic reasons in simple functional structures, although they are undoubtedly have a place in unusual applications such as exhibtition buildings. There are further problems in the shape of such structures - curved surfaces produce awkwardly shaped speaces, destroying the useful rectangular shape of rooms, and present problems in requiring specially-made fitments - pipes, glazing, furniture to match the original designed shape and style. Furthermore, such shapes are not at all economical in the use of ground, where land prices or availability are at a premium.

vii Thermal Properties

With rise in temperature, the polymer chains in thermoplastics become more mobile and at temperatures in the region of that of boiling water quite small applied stresses may cause relative movement. This increase in mobility is a gradual process as the temperature rises and plastics do not as a rule show a clearly defined melting point, but the consequent decline in mechanical properties is greater for plastics than for traditional building materials. The recommended maximum working temperatures - some are shown in Table I - for most of the thermo-plastics are well under 100°C, though some of the normally available thermosetting plastics may be used continuously above this temperature. So-called 'high-temperature' plastics with softening points as high as 800°C have been produced but are so expensive and difficult to process as to be of no interest for major building applications.

TABLE I

TYPICAL PROPERTIES OF SOME BUILDING MATERIALS

Material	Density kg/m^3	Tensile Strength MN/m^2	Young's Modulus MN/m^2	Coefficient of linear expansion Per ^{o}C	Maximum temperature for continuous operation	Behaviour in fire
(Low Density) Polythene	910	10	1.8×10^{2}	20×10^{-5}	$80^{o}C$	Melts, burns like wax
Rigid PVC	1400	55	2.4×10^{3}	5×10^{-5}	$65^{o}C$	Melts, burns only with difficulty
GRP	1600	140	0.7×10^{4}	2×10^{-5}	$90 - 175^{o}C$	Combustible, may be flame retardant
Steel	7700	400	2.1×10^{5}	1.2×10^{-5}	$400^{o}C$	Softens eventually melts
Aluminium	2700	250	7.0×10^{4}	2.5×10^{-5}	$200^{o}C$	Softens and melts
Softwood	480	-	1.0×10^{4}	0.3×10^{-5} (along grain)	-	Burns Slowly
Concrete	2200	-	1.4×10^{4}	1.0×10^{-5}	$120^{o}C$	May spall and crack
Brick	1900	-	2.0×10^{4}	0.5×10^{-5}	$250^{o}C$	Generally resistant

The temperature limitation imposes some restrictions, eg in components and systems for hot water supply and for internal drainage or thermal insulation of hot surfaces. In some applications the temperature limitation is obviously more significant in hot countries than in temperate regions - this applies particularly to roof coverings but also in other dark-coloured components, eg pipework, exposed directly to solar heating. For most internal building components, however, there are no problems in terms of temperature resistance though thermal cycling and relatively large movements may lead to problems of a different type.

One of the most striking differences between plastics and traditional building materials, exemplified by the fourth column of figures in Table I, is in their large coefficients of thermal expansion relative to most other building materials. This property is too often ignored and in fact is responsible for many of the problems that arise with the introduction of plastics in building. For example incorrectly fitted plastics pipework installed in cold weather can become badly distorted as the temperature rises, or pipes fitted in warm weather may contract out of fittings as cold water passes through them. The large differential movement when plastics are used in conjunction with traditional materials, calls for careful attention to the design of joints, specially where thermal cycling is likely, as it is on the exterior of buildings. When plastics panels are fitted in a metal or timber framework, allowance must be made for movement either in the shaping of panels or in the design of expansion joints. Movement is usually too large to expect problems of leaking joints to be overcome by the simple tradition[al] building expedient of inserting mastics or other sealants. Differential heating of the front and rear skins of composite panels may also lead to bowing and distortion unless allowance is made for movement.

viii Insulating characteristics

Because electrons do not move easily across organic materials of the type incorporated in polymeric chains, plastics are usually poor electrical conductors. This is used to advantage in almost all electrical applications - most electric cable insulation nowadays is of plastics and thermosetting plastics are almost exclusively used in plugs and fittings. An occasional building problem arises because static electricity is not easily dissipated on insulating plastics surfaces which may collect dust, espeically in dry atmospheres. Readily-available anti-static treatments can reduce this problem to insignificance in housing applications.

Plastics in themselves are also good thermal insulators and when they are produced in cellular forms, with a gas, usually air, trapped in the cells, they are remarkably effective for thermal insulation. Air-filled cells, even when these are interconnecting, give insulating qualities adequate for most building applications, but the closed-cell structure of some plastics may be induced by foaming with fluorinated hydrocarbons to give materials with uniquely high thermal insulating characteristics. If component surfaces are sealed to prevent diffusion out of the fluro-carbon and ingress of air, these thermal insulants will retain their effectiveness over long periods; however although this degree of thermal insulation may be necessary for cold stores, it is seldom so vital for building purposes.

It must also be borne in mind that plastics components, solid or cellular, with their relatively light weight have also relatively low thermal capacity. This may be suitable for structures in hot humid regions where, also, high ventilation rates are required. It is less effective than the more massive construction used in hot dry regions to maintain equable conditions within buildings.

ix Durability

One requirement for any new material, before it can be used with confidence in building, is information on its durability. It is a corollary of the newness of plastics that many of the questions on their durability still remain unanswered. Durability relates to performance in a particular environment and can never be known completely before use, but nevertheless a good deal of evidence of the durability of plastics in specific applications does exist and provides a sufficient background for reasonable assessment to be made of probable performance.

Broadly, plastics are resistant to the corrosive influences that affect metals, an important advantage in many of the applications where they are used as metal replacements; eg in plumbing applications where corrosion is a problem, they may have considerably better durability than the metals they replace.

Biological attack could be a serious limitation on the use of plastics, particularly in tropical countries, but in general the materials are not subject to biological deterioration. Although they may be disfigured by organic growth, only in rare instances, eg with some plasticisers in PVC, can they in any way contribute nutriment for such growth. They have an important advantage over timber in the respect that they do not sustain fungal growth and in hot countries the advantage is even more striking in their resistance to termite action. Although termites will make persistent efforts to puncture protective plastics sheathing, or tunnel through the softer and cellular types of plastics in the search for food, because they obtain no nourishment from plastics they have never proved as serious a problem as they would with timber in a termite-infested region. Plastics can be stated with assurance to have better durability, in terms of their resistance to organic action, than does timber. Rodent attack is an ever-present hazard in many areas and there have been occasional instances of plastics water supply pipes being gnawed through by rats, but in most regions the problem is not a serious one; the harder the plastics, the less is the problem and incorporation of hard fillers in soft plastics achieves some improvement though extermination of the rodents is the only really effective control.

In the minds of most users, the most important question over the durability of plastics is their weathering behaviour. In this property, they are at a disadvantage when compared with other materials. However, although only a limited number of plastics materials have been in use for more than a decade and to that extent prediction of durability must be based on restricted data, there is evidence that when properly formulated and manufactured, the life of some plastics components could be as long as that of the buildings on which they are installed.

Sunlight, particularly its ultra-violet component, is the most significant factor in outdoor 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 include many of the 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 for products designed for use in temperate regions. Factors of acceleration of three or four times are usually obtained. Nevertheless, there are several plastics materials capable of good and continuous service out of doors for considerable periods of years, even in tropical exposure. In many cases, in fact, plastics would be expected to behave satisfactorily out of doors but performance does depend considerably on the control exercised by the manufacturer and there is need for broader evidence of performance in particular climatic conditions before users can acquire the necessary confidence. Some of the evidence may be obtained from laboratory trials, but much of it must come from natural weathering trials and, best of all, when it is available, from the evidence of performance in actual use.

Maintenance

The possibility of effective maintenance must be considered if confidence in durability is to be achieved. It is often important to the user to know if, in the event of damage to or deterioration of a component, it is capable of repair or can be replaced. It is unfortunate for plastics that, in most cases of mehchanical failure there is no alternative to replacement. An exception is in the case of reinforced cold-setting resins, which can be patched by further resin/fibre application, but this calls for very careful site control of both temperature and humidity. The same technique has been used for the repair of thermoplastics, or even of metal or masonry components; its effectiveness depends largely on the bond achieved between the resin and the substrate. Normally plastics failures require complete replacement of the appropriate units and techniques have been evolved similar to those for conventional materials - eg in replacement of pipe sections - but this does require that the replacement parts continue to be available. This may be a problem where each manufacturer has his own system of matching parts; it may be improved by standardisation.

In terms of the requirements for maintenance to restore appearance, the situation is rather better and plastics can in fact be treated or painted with little more difficulty than conventional surfaces. One of the aims in using plastics, however, is to avoid the need for such maintenance. Although it may take longer after initial installation until maintenance is required, once it has been started regular repainting becomes necessary, to maintain appearance. Contrary to the requirement for metals though, painting is not necessary to prevent corrosion, and in this respect the use of plastics may effect considerable improvement.

Techniques of painting are as many as the number of plastics used but except for polyolefine surfaces which do not easily hold paint, well washed plastics surfaces provide a reasonable key for oil-based paints although even light sanding to improve adhesion may have a deleterious effect on mechanical properties. A measure of ability to recognise the different plastics is of value in this, as in other aspects of the use of plastics in building.

Restoration of translucency in roof or wall-lights may be possible if its loss is due to surface deterioration - scrubbing away the degraded surface and application of a lacquer will often effect improvement - but once started, a regular cycle of maintenance will be required to keep up the improvement. Such restoration is more difficult if the degradation is effective in any depth, eg as with the darkening of transparent PVC.

In the light of the foregoing discussion of the properties of plastics, their suitability for application in different constructional elements is now considered.

ELEMENTS IN HOUSE CONSTRUCTION

Building elements must be related to the design of the building structure, and to the erection technique used. For any particular region these are likely to have evolved on the basis of requirements of the inhabitants and on local materials available for building. In consequence building shapes differ in different parts of the world and, in line with different climatic and social needs, may perform different functions. If plastics are used, although the basic requirement is unchanged, a partial or complete departure from traditional shapes and designs may follow and the function of the building be achieved in other ways. Nevertheless the elements for building may still be considered within the same classifications:- basic structure; secondary structural elements; means of achieving environmental control; services. Although distinctions become blurred by differences in constructional technique, these groups of elements of house construction are considered in turn, with a critical examination of the scope for plastics from both functional and economic viewpoints. The only distinction to be suggested between "self-help" and professionally constructed housing is that the former probably marginally favours the use of plastics because they are more adaptable to the design of prefabricated components. Because most of the developing countries are in hot regions, the emphasis in this discussion is on building for tropical conditions.

(i) Basic structure

Because of the importance of the roof structure in excluding the elements and, in warm climates, because of the over-riding need to reduce solar heat gain, the roof is considered first, than the walls followed by floor and foundations. This sequence, contrary to that followed in actual construction, is logical in the light of the importance of the roof and its effect on the design, construction, suitability, cost and durability of the whole structure. In this as in the other applications, the question must always be asked "Why plastics?", if traditional materials do the job equally well and are available for it.

a. Roofs

In all hot countries, roofs should preferably be of lightweight construction and the external surfaces should absorb as little solar energy as possible. In humid areas, the minimum of insulation should be used; the less solar energy absorbed, the less insulation is required for the provision of comfortable conditions within the building. In arid regions also it is necessary to reduce to a minimum the absorption of solar energy by the roof but if cool nights predominate then it is necessary to reduce radiation and other heat losses at night by the provision of insulating material or reflecting foil. The provision of ceilings is also an advantage, both for aesthetic reasons and to provide by means of the resulting space an additional measure of insulation. Not unsimilar considerations apply in cold regions, though provision of vapour barriers is usually necessary to minimise condensation. Double-pitched or dome roofs are suitable where high wind speeds can be experienced; mono-pitch roofs suffice where wind speeds are not excessive; flat roofs should only be specified if there is a special need, as they can cause a lot of trouble unless carefully designed, constructed and maintained. All roofs must have a satisfactory degree of fire resistance.

The lightness of plastics is a useful advantage in roofing and light-coloured solar reflecting plastics sheets have been used as alternatives to metals, which may corrode, or to asbestos cement which becomes brittle with use. Lack of rigidity even in corrugated sheeting may call for additional support - usually provided by timber or metal girders, either of which might have to be imported, so in some regions where these materials are expensive, all-plastics roof structures might be considered, but as a rule only for small units. "Orange-segment" domes have been designed and made in reinforced plastics - thermoplastics would not be satisfactory because of their tendency to creep - and when pigmented opaque white, to reflect solar radiation, perform satisfactorily, though their durability in tropical climates may leave something to be desired. Joints in such roofs should be kept to a minimum and confined to radial lines to control thermal movement. These roofs resemble in shape many of those made in tropical areas from traditional materials and could be used with similar basic wall structures - possibly in single mouldings for single unit dwellings. To provide sufficient stability against wind loading and especially in hurricane areas, such roofs would have to be well anchored, possibly directly to the ground via the walls. Lightweight plastics thermal insulation could be used where required, though transportation of this may not be economical. Such structures would resist termites better than traditional alternatives but the weather resistance of the material would have to be good and very economical design would be necessary in order to justify increases in cost over traditional roofs, except in emergency housing situations. A further consideration in most situations is that such housing is very uneconomical in its use of ground space.

If flat roof construction is used, the mechanical properties of plastics are not suitable for the structural framework but they might be used for covering membranes. In this application, although more durable than bituminous papers and felts, they are normally so much more expensive as to require to be used in single layers, and much more skill is necessary to obtain a satisfactory application. One possibly useful technique is the insertion of a plastics film membrane between layers of mud in a mud-shell roof to prevent ingress of water. Protected from the elements, polyethylene, the material suggested would not deteriorate on weathering, but might tear in the event of shrinkage movements in the structure. A similar form of construction for flat roofs has recently been proposed employing a flexible PVC membrane covered with a layer of gravel to protect it from the action of the weather. In this type of construction, protection of the plastics from weathering is a major consideration. Degradation would lead to loss of extensibility and, in the event of movement of the structure, would be followed by cracking of the membrane and failure to keep out water.

b. Walls

The primary structural function of the walls of a dwelling is to support the roof. In addition, depending on the climate of the region, it will have further performance requirements in order to maintain internal comfort within the building.

In hot humid regions, the principal need is for a light-weight structure coupled with high ventilation rates, as it is impracticable to achieve a satisfactory internal climate in complete isolation from external conditions. This normally necessitates large open areas, possibly windows, with the walls shaded as far as possible by broad eaves, and painted externally in light colours to reduce the solar gain.

This type of structure may be achieved with composite construction using plastics, and sandwich panels of various types have been used in prefabricated dwelling units of this kind. It is not however a wise starting point to ask "how can an all-plastics panel be produced to meet the given specification?" Rather, the decision should be made to which material, new or traditional, will give the best performance at each stage. Plastics may provide the most effective external skin in terms of durability, colour, and resistance to water penetration, but cellular plastics may not necessarily provide the best core for the sandwich in terms of stiffness, fire-resistance, or compatibility with the skins. The inner skin may be more satisfactorily made of plaster board, or of glass-fibre reinforced gypsum than of plastics to contribute a certain amount of mass and fire-resistance to the unit. In some situations it may be advantageous to pre-assemble such panels in the factory, if they are to be installed by unskilled labour on site or if site-erection would be likely to result in the leaving of cavities which might harbour insects and rodents. If sufficiently skilled labour is available on the building site, it will often be more economical to assemble panels or to make up walls from the component parts, even if these have to be imported, as part of the process of erection. It will certainly permit greater adaptability and reduce the need for close tolerances in all aspects of the construction process.

These concepts are likely to produce a variety of different answers when applied in different countries where different materials are available; it may be that for some regions, where other lightweight building materials are virtually unobtainable, the "all-plastics" solution will be the best one although because of the very high basic cost of plastics, this situation will occur only rarely, even allowing for transportation and fabricating costs. If the "sandwich panel" approach to design is effective there may be need for a framework to take the panels, and this is unlikely to be made from plastics whose low modulus would not contribute to structural stability. Problems in providing effective waterproof jointing would result from differential thermal movement and would not be easily solved.

One of the major practical barriers to this composite form of construction is in marrying together the technology and experience of the plastics industry with those of the other materials industries. Until builders can acquire the same familiarity with plastics as they have with traditional building materials, so that they know how to use them to the best advantage, composite construction using plastics is likely both to be expensive and to generate expensive problems.

An alternative to the use of panel wall systems for lightweight construction is in the stressed-skin approach to plastics structures. Folded-plate systems, domes, barrel vaults and arc shapes may permit enclosure of appropriate spaces for dwelling units, comparable in shape to the native houses in many of the developing countries. On this count they might be acceptable in many parts of the world although for better standards of housing and in the developed countries, rectangular enclosures with eaves to protect the walls are normally preferred. However, a stressed-skin form of wall structure is usually integral with the roof and the possibility of providing ventilation which would be absolutely essential, is greatly reduced if continuous transfer of stress across the surface is not to be lost. Because of this restriction on ventilation, the internal conditions in such structures tend to suffer from high solar heat gain. A further technical consideration with such shapes is that they have very poor acoustic properties resulting from the angled unabsorbent sound-reflecting surfaces. It is always possible to reduce the sound reverberation within such a structure by covering the surfaces with an open-textured material - open-cell plastics foam may serve this purpose - although this would require an additional expensive building operation on a structure already made by a relatively expensive technique from expensive materials. Cost will normally render this form of construction impracticable.

In arid regions, unlike the humid ones, there is usually a fairly large diurnal temperature range and to provide internal conditions that are as nearly equable as possible, the structure of a building must be used as a heat reservoir to absorb excess heat during the day and to warm the interior at night. A requirement for this type of construction is structural material with high thermal capacity. This plastics, or lightweight structural units incorporating them, can not provide even with additional provision of a moderate amount of thermal insulation. In fact, there is no doubt that the best structural wall materials for such regions are those based on mud or clay, fired clay, stone or portland cement with aggregates, if they can be obtained from the ground at minimal expence and with very low transportation costs. A light-coloured weather resistant plastics external finish, eg in the form of imitation timber weatherboarding, may be a useful means of upgrading this form of construction.

c. Joints

Despite the sophistication of joint details apparently possible with plastics, it must be borne in mind that not all plastics shaping processes produce complete accuracy in components everytime. If the joints are to perform even their obvious function of connecting structural units with exclusion of wind and water, they must be reasonably tolerant of inaccuracies in dimensions. In addition they must accomodate structural movements.

In structures which are made up from large units of plastics or other impervious materials, stresses and movements are concentrated at a relatively small number of lines instead of being distributed at insignificant points throughout the building surfaces. Movement may be due to shrinkage of the underlying soil or of the building components, or to thermal or moisture effects. With any of these causes, if the building is to provide a barrier to the external environment - wind, rain, dust, etc, the joints must provide an effective seal and still permit movement to occur. Very often a two-stage joint may be the most suitable means of providing this, with an external baffle that keeps out most of the weather and an inner seal, which is shielded from the elements, in particular the degrading action of sunlight. Plastics membranes or fillets may be suitable for the baffle provided the material is dimensionally stable and has a degree of resilience; but the inner component of the joint is more demanding and durable synthetic rubber or mastics must be used to maintain a satisfactory seal.

If the joint has also to perform a structural function, holding together components of the structure, the additional requirements of maintaining adequate stress levels and having an appropriate standard of fire resistance as well as providing resistance to fire penetration, are likely to call for metallic or other components with better properties than plastics.

d. Floors

For single storey construction, the initial advance from a trampled mud floor is the use of a slightly raised stone or concrete raft. The most effective contribution that plastics can make to this type of construction is in excluding rising damp by incorporation of a polyethylene film as a water and vapour barrier in the floor construction. This function plastics can perform very satisfactorily provided that there is not sufficient structural movement to tear the film being used. Where bituminous materials are not readily available or would have to be transported long distances, polyethylene film is probably the cheapest and most easily transported means of providing a damp-proof membrane. Even an all-plastics structure is likely to require a concrete raft although in some instances timber floor construction may be desirable to raise the building above the level of the surrounding soil and out of reach of rodents etc. There is no satisfactory economical means of achieving this form of construction at present in plastics although some of the newer composite materials such as glass-fibre reinforced cement may offer possibilities in this area. These new materials can provide advantages in resistance to termites, to which timber is susceptible.

As is also the case for walls, in hot dry regions the most effective floors are solid ones with high thermal capacity; in hot humid regions lightweight suspended floor construction is normally advantageous. In either case it may be desirable to apply some form of membrane to improve either the feel or the appearance of the floor finish. In this application plastics tiles and sheeting are very widely used, and generally are cleaner and more attractive in appearance than the traditional materials, mostly made from natural products that they replace. In colder climates an even later development is the use of synthetic based carpet to improve comfort and thermal insulation. Most of the plastics finishes have better resistance to abrasion than the materials they replace and if manufactured to a reasonable quality can be remarkably durable.

e. Foundations

Massive and stable footings are required only when they support heavy structures with cement or clay-type components; because they can usually be provided quite satisfactorily with locally available materials, there are no useful plastics substitutes. For lighter types of constructions minimal footings are normally required but there is no particular advantage in importing relatively expensive plastics to perform this function. At present none of the polymeric materials suggested for pouring on to soil to stabilise it is good enough to avoid the need for preparing any foundations.

PVC water stops have been for many years on acceptable means of barring ingress of water between separate castings of concrete in building foundations.

(ii) Secondary elements

a. Doors

Doors provide a barrier and they are used to complete the enclosure of compartments. They have to be moved regularly in performing their normal function so are required to be massive only when their protecting function is the major purpose in using them. Timber is the traditional material for doors; lightweight hollow construction with timber framework has been developed from this in the course of time; in many parts of the world, however, timber of satisfactory quality is not readily available or alternatively if timber is used it is susceptible to termite attack so it is worthwhile seeking alternatives and these may in some instances be found in plastics. Elegant all-plastics doors, sometimes translucent, have been made from a combination of extruded plastics sections, although attention might be given to designing much simpler functional doors. One difficulty with these, as with many instances where timber is replaced by plastics, is that final adjustment to fit the frame by cutting or planing down is less easy than it is with the traditional timber. The same may be said of door frames and all the surrounding sections which, however if made in plastics, can be made to perform an additional function in carrying electrical services. This may also be extended to skirtings. In very low cost housing however these refinements may be unnecessary and particularly in hot humid conditions may be omitted as they constitute additional barriers to natural ventilation.

b. Lighting

In temperate climates, plastics are used for corrugated roof-lighting. The materials most used are PVC and glass-fibre reinforced polyesters. There are problems in the use of these materials even in European climates but the one that gives most concern is their weathering behaviour; this would be more of a problem in hot climates where the degradation reactions responsible for break-down proceed three or more times as fast as in temperate climates. It is possible to manufacture products with very good weather resistance but even these will only pefrform well in the tropics for a limited time if directly exposed to the maximum of sunlight (Ref 1). However because roof lighting normally contributes to high solar heat gain and is therefore an undesirable structural feature in tropical conditions, these sheets are more likely to find application in wall-lighting: provided they are installed under the eaves of a broad-roofed structure, properly manufactured sheets particularly of GRP are likely to be acceptably durable in terms of light transmission. As with other lightweight sheeting, good fixing is necessary in hurricane areas, though they may do less damage than metal sheets if torn loose.

In humid tropical areas, the requirement for maximum ventilation may call for complete omission of any barrier to air flow in wall-lighting areas. However in hot dry climates where protection against the external environment requires a restricted air flow, such sheets need no elaborate framework and may provide a cheap means of glazing.

All-plastics window frames have been manufactured but because of lack of rigidity in the materials they are not so far very widely used. Plastics in combination with metal or timber may have the necessary stiffness but without very good jointing are not proof against corrosion or rotting of the reinforcement. Without such stiffeners heavy plastics sections are required. The chief problem in window-frame design where plastics are used is in accommodating the high thermal movements; and performance of joints is likely to be paramount in determining the durability of the product and it is principally because plastics frames may be more durable and require less maintenance than traditional window frames that their use may be economical. They are mostly more expensive in initial cost. Plastics are seldom used for window glazing; the major application seems to be in vandal-resistant glazing in cool or temperate countries. The effective factor here in determining use is the cost of multiple replacement rather than the initial cost.

Plastics have been used as foils for venetian blinds, to assist in controlling illumination levels, although aluminium, with slightly greater rigidity is probably used to more advantage. Plastics are also widely used in sunny countries as external shutters and roller blinds for windows. Durability, of appearance and mechanical properties, is a major consideration in this application.

c. Partitions

Partitions may provide a barrier to the free circulation of inhabitants or air within a building. For this purpose they need only be light in weight and plastics may be used as components of sandwich-based partitions. However these provide only very poor sound insulation and little barrier to fire both of which are useful attributes of partitions made of materials like glass-fibre reinforce gypsum or plaster board. Where site erection by unskilled labour is required, local materials are scarce and transportation is expensive, such light weight plastics sandwich units may be acceptable. Cost effectiveness becomes the major consideration, in determining which material should be used.

d. Internal finishes

Plastics can provide very effective hygienic internal surfaces either applied as rigid laminates or as flexible films. These are readily cleaned and likely to be more durable than the alternative traditional finishes. Nevertheless, many of these traditional finishes are so remarkably cheap and easily applied, eg whitewash, that it may well be cheaper and equally effective to apply each year a new coat of this finish particularly when labour is cheap. Using plastics, finishing may be possible at the prefabrication stage, but this calls for careful handling of components on delivery and installation and it is often just as convenient to finish on site a factory-prefabricated structure.

e. External finishes

Similar considerations to the above apply to external finishes in plastics although because these are likely to have much better resistance to the action of water than traditional finishes, they may give very good service in protecting structures made of water-sensitive materials, and excluding rainwater. They can be decorative and light coloured to improve solar reflectance. The problem of impervious surfaces, that of providing effective seals at any joints, may cause difficulties.

Traditional alternatives in hot countries are such cheap applied finishes as whitewash or limewash and it may not always be a disadvantage to renew these finishes annually and thereby freshen up the appearance of the whole building and improve its solar reflectivity. Certainly the newer plastics-based liquid applied finishes are likely to be more durable than the traditional materials, provided they can be applied in appropriate conditions, but because these must be more carefully controlled, the advantages over traditional finishes may be lost.

(iii) Environmental controls

Several aspects of the part that plastics may play in achieving the necessary control of the internal environment have been referred to in the preceding sections. With their relatively low thermal capacity plastics provide little advantage in the massive structures required in hot arid regions with temperature cycling although they may, in the form of cellular plastics which have excellent thermal insulation, be able to assist in the reduction of temperature fluctuation in such structures. In hot humid regions there is little thermal advantage to be gained in using plastics, except as part of a lightweight system of construction. In cooler regions there is no doubt that their very effective thermal insulating characteristics are an appreciable advantage. Because only a small amount of insulation may be required except in the coldest climates to obtain the necessary degree of thermal comfort, cheaper and more fire-resistant insulating materials may prove equally effective.

Lightweight plastics components provide little barrier to sound transmission and impervious plastics surfaces offer no advantage in reducing sound reverberation within compartments. Resilient layers of cellular plastics, in particular expanded polystyrene and foamed polyurethane are sometimes used to absorb impact sound in floor construction although this is more an advantage in multi-storey than in single-storey constructions. The most effective acoustic application of plastics is in the form of open-cell flexible urethane foam which is very effective as acoustic lining for noisy compartments. Unfortunately it has poor performance in fire and also has a tendency to trap dust and particularly in tropical regions might be expected to become unhygienic and to harbour vermin of various types.

The role of plastics in lighting has been mentioned. The durability of the plastics used, in terms of their retention of light transmission, may leave a good deal to be desired, although if they are used on sheltered parts of the building, away from direct exposure to the sun they are likely to give adequate performance. In both hot and cold countries the size of windows should be kept to a minimum in order to permit better control of thermal comfort within the building.

(iv) Services

The traditional materials used for the provision of services are for the most part metals which are relatively expensive and which suffer from corrosion. Alternatives may be used in some areas depending on their local availability; salt-glazed pipe-ware, pitch-fibre pipes, asbestos cement or concrete products have all been used. The introduction of plastics, light in weight and so easily transported, resistant to corrosion, and capable of manufacture in suitable shapes for many of the applications in the field of services are playing an increasingly important part in this area of building materials usage in all parts of the world. Without doubt, this is the field in which plastics have their most important role to play in housing for developing countries.

a. Water supply

Because of their greater strength metals have better resistance to internal pressures and require simpler joints than plastics. Nevertheless metal pipes have to be jointed at much more frequent intervals and are much heavier to transport so that for cold water supply in many areas flexible plastics pipes, in particular polyethylene, have been used with considerable advantage. Even PVC, although it has to be transported in straight lengths which require regular jointing, has a degree of flexibility which permits this jointing to be carried out above ground before placing pipes in a trench so that for carrying water any distance plastic pipes have advantages, particularly in highly corrosive soils such as occur in many tropical areas. Durability of these materials when used underground is very good although rodent attack on some of the softer polyethylene pipes has been noted. Above ground, where they are subject to weathering degradation and thermal cycling, their performance may be less effective.

In the developed countries standards have been established for water pipes made of both polyethylene and PVC, in different ranges of diameters from about 10 up to 600 millimetres. Short-term and long-term hydraulic and external loading tests have been used to obtain data for pipes that give assurance that pipes made to standard specification will have a life of 50 years or more. Joints also are available to match the requirements met by pipes.

Plastics for hot water services have also been widely discussed but problems of design of joints and allowance for thermal movement have retarded this development which is further complicated by the desire to use a single material for both hot and cold water services. This will not normally be a major consideration in any developing country where the basic requirement is usually only for a hygienic cold water supply. By the time that developing countries come to regard hot water services as a necessity it is not unlikely that shortages of suitable metals in the rest of the world will have encouraged investment in the design of suitable plastics hot water systems; at present some of the plastics available have sufficiently good performance at the temperatures of domestic hot water supplies to be used in this application. Cold water storage cisterns of polyethylene and glass-fibre reinforced plastics are widely available at prices competitive with metal alternatives although if used for roof rainwater storage, as is the practice in many tropical countries, such cisterns would require to have a good weather resistance or alternatively be surrounded by a protective casing; the latter is probably the better alternative in permitting water temperatures to be more effectively controlled. The mechanical strength of plastics is not regarded as sufficient for them to be used as an alternative to glazed ceramic ware in sanitary applications although with suitable external cradling they are used in baths and basins and with reasonable treatment give good service for many years. Lightness in weight permits reduction in transportation costs. Users have had to learn to handle them more carefully than their metal counterparts but seem well satisfied with their performance. One other interesting development in this field is the manufacture of water taps from plastics as an alternative to the more expensive non-ferrous metals. Not only may these be more economical than their metallic counterparts; they may also be very elegant in design. Relatively cheap but simple functional versions are also available.

b. Drainage

As for water supply the materials used in drainage applications are required to be formable in pipe or channel sections, and in fittings and connections for jointing. Lightness in weight is more of an advantage for above-ground use than below. Resistance to impact is also required and these are one of the reasons that metals have traditionally been used above ground in preference to claywore. The lightness in weight of the plastics products that are available on the market also makes for ease of transportation and installation and as it offers a satisfactory alternative in many cases to metals, plastics drainage for soil and waste water and, where required for rain water are likely to be increasingly used in the future. The relatively large thermal movements of plastics must be accommodated even if such movements are only produced by changes in ambient temperature and if hot water is occasionally poured into drains the movement to be accommodated is larger and there is need also to use plastics with satisfactorily high softening points. Problems have arisen because inadequate plastics materials were used in the past in insufficient thicknesses; these have now been satisfactorily overcome; a significant and growing proportion of drainage products in the developed countries is now made in plastics and with the potential saving in metals by the introduction of these products it is expected that in the developing countries also, plastics will provide a very satisfactory means of meeting domestic drainage requirements.

Underground drainage is another growing development but external soil loading must also be considered in this case. As drains, unlike water supply pipes, are normally run at only a fraction of their capacity the pipe walls receive no internal support. Programmes of external loading tests have led to the development of suitable designs for this application. In the past claywares or salt-glazed ceramic pipes have been used for small diameter underground drainage. Concrete has been introduced more recently for larger diameter drains and sewers and asbestos cement products are also used. One of the principle advantages of plastics pipe is that it is available in longer lengths than any of these materials and permits a considerable saving of labour in installation. This is no particular advantage in many of the developing countries but the saving in transportation of longer and lighter weight components may be considerable. In this application for drainage, plastics may contribute to considerable and rapid improvements in standards.

For both water supply and drainage application the normal requirements will be for pipes and fittings that will either be buried or concealed within the walls of dwellings. Because this may not always be the case, good protection against weather action is necessary and in this, some plastics are better than others. There is great need to ensure that satisfactory standards of weathering performance can be achieved by the materials used for these applications, although standard procedures for assessing weatherability leave much to be desired.

It will have been noticed that, for many applications of plastics in the building elements referred to above, the plastics products are likely to be used because they lead to improved standards in existing forms of construction, rather than to meet basic structural requirements. This is regarded as a desirable objective - there is as much need to improve standards of existing types of housing as to produce new houses.

OBSTACLES TO THE WIDER USE OF PLASTICS

Plastics have their limitations but they also offer many technical advantages and the fact that they 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.

(i) Economic Factors

Economic considerations are perhaps the most important: the basic prices of plastics materials are high relative to those of most traditional materials. Although because of comparability of costs they may often be considered for direct replacement of metals, in most other applications they can be considered only where they offer very considerable technical advantages, particularly in leading to saving of other materials or saving in costs of transportation, erection, or installation. This is seldom an important factor in the developing countries and because the use of plastics components may require new techniques and additional training in the properties of plastics, any reduction in costs may have to be balanced against this. Otherwise they are likely to be used principally because of local shortages of other traditional building materials or because such materials just do not exist. The availability of plastics materials is an important consideration and although attempts through UNIDO to encourage the development of plastics industries in developing countries (Ref 8) are bearing some fruit, the raw materials are still produced mainly, and consequently available most cheaply, in the developed countries which can offer large markets for them. The scale of production of most plastics materials in the developing countries is not sufficiently large for them to be considered as major building materials and it will be a considerable time before such indigenous plastics producing capacity exists.

The fact that some of the developing countries have ample supplies of petroleum, the raw material for most plastics, does not necessarily mean that the most effective way of developing the usage of plastics is to set up polymer producing industries although it is clear that a petrochemical industry is a most effective status symbol. In most countries plastics manufacturing industry is likely to be developed more through the importation of moulding materials and other intermediates and fabrication from these of necessary products. However in this form of development, foreign exchange is involved and this creates great problems for developing countries, especially when they themselves do not have strong export businesses.

(ii) Psychological and traditional attitudes

Psychological and traditional attitudes play a strong part in determining the acceptance of new products in most countries. Naturally those areas that are most technically developed will find new innovations more acceptable than those countries which until recently have been backward. In an affluent society the older traditional styles and materials may be a status symbol, but in the richer countries much of the initial resistance to plastics, which were formerly regarded as inferior substitutes, has been overcome and they are generally acceptable as building materials, provided always that they function efficiently. Some of the so-called "developing countries" are indeed very old countries with long histories and established traditions. These find it difficult to adapt to new ideas quickly and have yet to become accustomed to the rapid changing of attitudes which is now taken for granted in the older industrialized countries. In the larger developing countries, particularly where the population is large and scattered, the communication of any evolving change in attitudes is very slow and the introduction of new techniques and materials shares this slowness.

One factor that probably creates greater resistance to the use of plastics in building than in consumer goods is the requirement for permanence normally associated with a home. It is important that there should be no disastrous failures, no patently obvious short-comings in their early use. Any new plastics development, when it is introduced to a developing country, must be as nearly complete as possible; the performance must be ensured for the relevant climate and attuned to the needs and customs of the inhabitants. Living with plastics will give a very good opportunity for their appraisal; if the experience obtained is marked by failures, there will be no benefit to anybody.

(iii) Building Legislation

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 a 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 of the standards that are long established and used elsewhere, though these may not always be relevant. Building regulations must be framed within the context of national and personal income levels and must not unduly restrict economic progress. Ideally, they should be independent of materials and related only to performance requirements, but in practice, regulations are usually equated only with satisfactory traditional products, rather than based on function. Inevitably some restraints are imposed on plastics which perform differently from conventional products and, because of their combustibility, must necessarily be restricted in areas where fire may be a hazard. These restrictions must not be carried too far, however: for example because of the growing incidence of foam fires in furniture factories, there has been a growing blanket discrimination against the use of cellular plastics in building insulation, although the problems are entirely different. Insurance companies also, aware that plastics are combustible, may further restrict their use by requiring increased premiums for buildings where plastics are incorporated. This is probably not a major consideration for government-financed low-cost housing, which will not normally be insured, but it should be regarded as an indication of the expected hazard, and borne in mind in designing housing schemes. Education of both builders and building regulators in the properties and performance of these new materials is necessary to obtain satisfactory but non-restrictive control in the use of plastics.

One of the more effective means of ensuring the satisfactory introduction of plastics building components within the regulations is by the development of satisfactory performance standards for these materials. There are some thirty British Standards for plastics building products: other developed countries have similar numbers; they serve as a partial control to ensure that plastics building products are likely to be suitable for their application. In many European countries also there are government-sponsored organisations, charged with the assessment of new building processes and products and collaborating in this through the European Union of Agrement. It is unlikely that most of the developing countries could afford such an organisation nor should they accept without question the findings of these Agrement authorities in the developed countries whose requirements are considerably different. Nevertheless because in this way a number of new building products, including many that incorporate plastics, have been proved adequate for introduction to building, there may be a case for UNIDO or some other international agency setting up an authority charged with this form of assessment.

Because also there is need that new products should be used in the correct manner, it is essential that any new standards or appraisals should take this into account. Recommendations should be made for codes of practice in the use of new products including plastics ones.

REQUIREMENTS FOR FUTURE DEVELOPMENTS

In practically every country in the past ten years there has been a growth in the use of plastics for building. This trend can be accounted for in several ways: there has been an impressive improvement in the characteristics of the materials and in the functional and aesthetic design of the plastics building products made from them: the price of plastics has remained more or less stable in the face of general increases of price for building commodities in other materials: plastics as a group are no longer new and untried so that there is now a better appreciation of their merits and more sober assessment of their *limitations. However in the author's opinion it remains necessary to caution the over - confident and temper with realism some of the enthusiasm for introduction of plastics for building; for this reason this paper has tended to concentrate on the problems associated with the use of plastics in building.*

However there is every reason to expect that in the future plastics will play a greater part in building in developing countries. It is important, however, to encourage systematic rather than haphazard development. Some of the limitations of plastics will not be overcome but considerable progress and satisfactory development will be achieved if encouragement can be given in certain particular areas associated with the development of plastics materials: there is a great need for satisfactory design data to permit the production of economical designs for plastics building components; further study is necessary to achieve a better understanding of the fire properties of plastics but at the same time there must be acceptance of their limitations; research in plastics materials to achieve improvements in performance, particularly in terms of long-term behaviour and weathering characteristics should be encouraged; perhaps the most important requirement of all is for education of the designer and user of plastics to ensure that maximum advantage is taken of their potential but that their limitations are fully considered.

In the preparation of this paper, it has not been found possible to accept in entirety the premise that new constructional concepts are necessary in order to use plastics to the best advantage in housing. The basic requirements for housing remain unchanged; it is the magnitude of the problem that is different. Suitable techniques to meet the requirements have been developed by trial and error over the ages; plastics, as the materials of a new age, have a major part to play in this development. However it seems that plastics will be used best by modification of existing approaches to design rather than by any radically new approach and even to achieve this development, broadly-based education in their properties and performance, and awareness of their limitations is necessary.

If the developments in plastics that emanate from the UNIDO Working Group are to make a significant impact on the world's housing problem it will be necessary to acquire practical experience of them in the true context of the developing countries and by wide-ranging trials. Without evaluation of such experience, there may be introduction of interesting and even spectacular structures; there will not be the major contribution there ought to be to the total solution of the problem.

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