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THE BEHAVIOUR OF POLYMERS USED IN BUILDING CONSTRUCTION

by

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SUMMARY

The note examines the use of different types of polymeric materials in the construction of buildings, for structural as well as non-structural purposes, and indicates increasing applications in the future in most areas. After a brief look at general fire behaviour the use of various standard fire tests is considered and the characteristics of a range of materials under a selected 'reaction to fire' headings are tabulated. The behaviour of polymeric materials under natural fire conditions has been of concern and various 'full scale' studies have been carried out which are summarized at the end of the note.

Department of the Environment Fire Research Station of the Building Research Establishment

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INTRODUCTION

Rapid growth in the use of polymeric materials, particularly their introduction into construction dates from 1945 when polyethylene (PE) and polymethyl methacrylate (PMMA) came into general use followed soon afterwards by polyester compounds. For the next ten years the main emphasis was in domestic equipment and fittings, electrical insulation and flooring materials using PVC. From 1960 onwards great inroads were made into the building field with rainwater goods, rooflights and GRP (glass reinforced polyester) structures for kiosks, cabins and domes of various kinds. Expanded polystyrene (EPS) and polyurethane foams (PUR) were first used for sound insulation and led to composites made of the so-called structural foams, ie a foam core with a dense skin of the same material allowing rigid components to be fabricated. The introduction of acrylonitrile butadiene styrene (ABS) was beneficial to the plumbing industry and clear polycarbonate (PC) as a substitute for glass helped overcome some of the problems due to vandalism. Prefabrication of buildings started with sandwich core panels for industrial buildings, external wall panels with built-in windows and has now progressed to complete mobile homes and to leisure centres clad completely or nearly completely with translucent materials.

A number of significant fires, in recent years (eg at the St Laurent-du-Pont dance hall and at the Summerland leisure centre) have drawn attention to some of the fire problems which might be created knowingly or unknowingly with the increasing use of plastics in buildings.

A continuing debate on possible fire hazards associated with polymeric materials began and it is important to have a knowledge of their behaviour under fire conditions so that rational judgements can be made. A review of the major uses of polymeric materials was made jointly by the Fire Research Station and the Building Regulations Professional Division of the Department of the Environment. Their fire behaviour and the current and projected research was outlined. The present paper concentrates on the use of polymeric materials in the construction or finishing of buildings and provides information on their behaviour in small and large-scale laboratory investigations.

CONSUMPTION OF PLASTICS

In 1973 over 200,000 tons of various plastics materials were used in building (Table 1) [2] representing just over 10 per cent of the total production of polymeric materials.

TABLE 1 - UK PLASTICS CONSUMPTION IN 1973 (100^3 tons)

	PVC	PS	EPS	ABS	EPOXY	POLYESTER	PUR	TOTAL*
Materials used in buildings	130.0	3.5	18.0	3.7	0.5	12.6	1.1	212.3
Percentage of total produced	31.3	2.0	78.3	9.3	3.8	22.9	1.9	11.6

*The total includes a number of other products not listed.
PVC - Polyvinyl chloride; PS - Polystyrene, dense; EPS - Expanded polystyrene, ABS - Acrylonitrile butadiene styrene; PUR - Polyurethane.

It is noticeable from the table that PVC is the most common material to be found in buildings and that most of EPS is intended for building purposes. It was estimated [3] in 1973 that up to 1980 the annual rate of growth is likely to be 8.5 per cent. The down turn in the industrial and construction industry last year has probably led to some reduction in the UK rate of growth.

However the situation in other countries is indicative of continuing growth. An American study [4] shows that the use of plastics in domestic buildings, contents as well as construction, in the countries of Western Europe was 3×10^6 tons in 1975 and is expected to increase at 8.5 per cent to 6.5×10^6 tons in 1985. This represents one-fifth of the total plastics market and 30 per cent of this is destined for furniture and soft furnishings. The most common use of plastics in building construction is in keeping water away from where it is unwanted ie for weatherproofing, sealants, pipes and rainwater goods. Nearly 8 per cent of the current plastics consumption in buildings can be related to this use. The most impressive future growth is likely to be in the lightweight rigid foam field, the growth rate of 15 per cent between 1950 and 1973 is likely to increase to 20 per cent in the future. The 1976 forecast [5] for the urethane foam in the USA was 975×10^6 board ft ($\simeq 4 \times 10^8$ m^2) a 19 per cent increase over 1975. 95×10^6 kg of cellular foam was expected to be poured in place, sprayed in situ, used in factory made boards, for tank and pipe insulation, for roof insulation, as cavity infill and as a core material for panels. It is obvious from these few statistics that plastics is a growth industry and in future there is likely to be more rather than less material in each building situation.

Plastics offer numerous advantages over conventional materials, the main ones being their formability or mouldability, colourability, translucency, lightness and resistance to corrosion. In some areas they have completely taken over from traditional materials eg PVC rainwater goods, pipes and cisterns are now standard components, PVC flooring and underlay are commonly accepted. The use of PMMA, PVC or PC as glazing to clad large areas in panels or domes offers advantages of lightness and maintenance free coverings. The low thermal conductivity of foam is making them increasingly attractive for insulation purposes, hence the popularity of EPS tiles and PU boards. The thermal conductivity of PU foam is half that of glass fibre, a quarter of fibre insulating board and about a tenth that of aerated concrete.

The main disadvantages of plastics are creep under stress, temperature sensitivity, large thermal movement and some unusual fire problems. Temperature sensitivity has been mainly responsible for the lack of progress in the structural use of plastics Even thermosetting materials such as polyester weaken at temperatures in excess of 200°C. Whilst the combustible nature of plastics is recognised, there are some special problems posed by thermoplastics and concern has also been growing on their contribution to the level of smoke and toxic products in the fire gases.

BUILDING FIRES

Most fires have small beginnings and differ in their rate of growth, severity, damaging effects and problems they create for occupants as well as the firefighters. In order to understand the role of building materials and constructions it is possible to idealize important parts of a fire into three or four separate phases (Figure 1).

The primary ignition phase represents the start of a fire incident when an individual material becomes involved and its ease of ignition determines the continuation of combustion. It is possible for the flames to involve another item in the next phase provided it is close enough, the conditions are favourable for heat conservation and the flammability characteristics of the materials are appropriate. Hot gases including smoke and other products begin filling the room leading to a rise in the ambient temperature conditions. Progressively the conditions reach a critical stage, with the atmosphere becoming hazardous for the occupants because of heat, smoke and toxic products.

Provided the ventilation ie the supply of oxygen is adequate the fire grows rapidly into the third phase, increasing ambient temperatures facilitate the ignition of uninvolved materials and radiation from flames and hot gases along the ceiling becomes important. Fire progression is influenced by the rate of heat release on the decomposition of various materials and the conservation of heat within the room. Ambient air temperature rises to 600°C and above leading to the 'flashover' conditions when all of the exposed combustible materials are evolving flammable gases and total involvement occurs. Usually there is not sufficient oxygen for all combustion to take place within the room as a result the unburnt gases ignite and burn outside the windows. The gases are also forced to other parts of the building.

After 'flashover' the fire reaches its maximum intensity and continues to burn at a rate determined by the nature of the fuel, ventilation conditions and heat conservation by the boundaries. Air temperatures may exceed 1000°C in this phase and the construction is severely punished if its fire resistance characteristics are inadequate.

Customarily the likely behaviour of materials, products and constructions is considered under a number of headings such as ignitability, flammability, flame spread, rate of heat release, smoke production, toxicity and fire resistance. These are not necessarily unique characteristics of a given material or a product under some precisely defined conditions but represent a range covering situations related to different phases, use conditions and inter-action between products. For example, ignitability characteristics depend upon the size and nature of the igniting source, the ambient temperature and moisture conditions, the orientation of the material, its association with other products, its method of retention and its protection by other materials. Obviously no single test or measurement could conceivably provide information related to all these factors.

SAFETY REQUIREMENTS

The main objectives of various safety requirements can be summarized as:

a) Protection of the occupants of a building on fire.
b) Protection of contents/construction in parts away from the fire.
c) Prevention of fire spread from building to building, and
d) Prevention of conflagrations.

The building regulations and codes usually concern themselves with the life safety aspects whilst the protection of contents is the main concern of the insurance requirements. Nevertheless each influences the other and some of the life safety considerations require a control on the spread of fire and measures to contain it. The safety objectives are achieved by a number of measures such as:

a) Controlling the nature of materials used in construction.
b) Controlling the contribution of exposed surfaces to fire spread.
c) Controlling the size of fire by compartmentation.

d) Controlling fire spread from storey to storey and from building to building.

e) Providing means for the safe evacuation of occupants.

f) Providing means for the detection and extinction of fires, and

g) Providing facilities for firefighting.

At present not all of these provisions are included in a single set of codes or regulations but they occur in a number of different statutory and non-statutory documents.

The current controls do not usually extend to the normal contents of a building such as furniture and furnishings, however, recent studies [6] have highlighted some of the problems and shown the need for codes of good practice in the selection of materials and the design of furniture.

Very few of the safety requirements are designed to deal specifically with plastics materials, most are functionally based and discriminate against all organic products if their behaviour is not considered to be satisfactory. Most requirements make use of fire tests for control purposes, most but not all of which are able to deal with the range of products likely to be used in a given situation. However an unsatisfactory situation has developed in one or two specialized areas either because the existing tests do not seem to be able to handle certain types of thermoplastic materials or some special tests particularly designed to assess the performance of a specific material are used for all situations. In both cases meaningful comparisons between different organic products become difficult.

The whole field of fire tests, their concept, design and application is under examination by a special committee of the BSI [7]; this activity is also being pursued in other countries as well as internationally. In future more guidance should be available on the design and utilization of tests in an overall safety scheme.

TYPES OF PLASTICS

The most common types of plastics to be used in building construction [8] are listed in Table 2 with an indication of the shape or form in which they are likely to be found. The materials can be grouped into thermosetting or thermoplastic categories, as indicated, the latter exhibit the well known tendency to soften when their temperature is raised to a range between 90 and 150°C. Some of these materials have a sharp transformation from the rigid to the softened stage whilst others go through a pronounced plastic phase. The ability to soften allows these materials to be formed to a variety of shapes, eg corrugated rooflights, domes, pipes and ducts.

TABLE 2 - LIST OF COMMON PLASTICS MATERIALS

NAME	ABB.	TYPE	SHAPE/FORM
Acrylonitrile butadiene styrene	ABS	TP	Rigid sheet, pipes
Polycarbonate	PC	TP	Clear sheet
Polyethylene	PE	TP	Sheet, pipe, film
Polymethylmethacrylate (Acrylics)	PMMA	TP	Clear sheet, domes fibre
Polypropylene	PP	TP	Sheet, mouldings, fibre
Polystyrene	PS	TP	Sheet, mouldings
Polyvinylchloride	PVC	TP	Sheet, pipes, ducts, tiles film
Chlorinated PVC	CPVC	TP	Pipes, ducts
Polyester/glass reinforced	GRP	TS	Rigid sheets, domes, framework, wall panels, ducts.
Expanded polystyrene	EPS	TP/F	Panels, tiles, core material
Phenol formaldehyde	PF	TS/F	Panels, laminates
Polyisocyanurate	PUI	TS/F	Laminates, core material
Polyurethane	PUR	TS/F	Laminates, core material, spray.
Ureaformaldehyde	UF	TS/F	Cavity fill

ABB. - Abbreviation; TP - Thermoplastic; TS - Thermo-setting; /F - Foam.

Polyester is perhaps the best known thermosetting material with a great deal of versatility when reinforced with glass fibres or cloth. It can be cast into panels, sheets, domes and many types of intricate shapes and forms. Mechanised processes allow products of great rigidity and strength to be formed and with a suitable gel coat an acceptable weather resistance is possible.

Of the foamed products EPS is the sole thermoplastic product which softens quickly at about 100°C and reverts to the dense polystyrene. The others are of thermosetting type, and may shrink to some extent after decomposition but do not melt away. Urea formaldehyde is the lightest material and its main application is as in situ fill in cavity walls.

Table 3 shows various uses under four different headings to which the main plastics materials are put in buildings. The constructional field covers wall and roof panels of preformed sheets, composites, cladding of GRP and PVC, light transmitting inserts, rooflights, domes and glazing panels in place of glass. Most uses represent a new product replacing a non-polymeric material but the trend towards the fabrication of a complete component of plastics is increasing. The initial concept of making an all plastics building has been replaced by a more practical approach of combining plastics with other materials to obtain not only pleasing visual effects but also a satisfactory level of fire performance. GRP facia panels with a natural aggregate finish and wall units with a foam core and a plywood or plasterboard internal surface represent some typical examples. Plastic components such as pipes, door and window frames, ceiling panels, curtain walling units represent another important usage.

The translucency of plastics, their lightweight and mouldability has made them the ideal choice for complete cladding of large areas to provide a pleasant environment for recreational purposes. A number of leisure centres have gone up in the country in which PMMA or PVC has been used to advantage as a weather barrier without some of the shortcomings of traditional materials. The most novel application is the use of films for air supported structures in which a slight positive pressure is able to provide a light, shaped covering for areas as big as a stadium without the necessity of structural framework.

In the decorative category are materials to line the internal surfaces of a building or provide finishes which fulfil a number of functions. Thin sheet materials of phenolic laminate type, wall papers with smooth, embossed or fibre finish, floor tiles and carpeting squares, translucent films for false ceilings are a number of the typical usages. There are very few paints available on the market which do not have a large polymeric content.

The versatility of plastics and the ability to provide any desired finish has enabled these materials to virtually take over the decorative side.

Most insulating materials are foamed products, which may be sprayed on in situ on surfaces, poured into cavities for a cavity fill or as a core material in a composite product, faced with paper, plastic film, fabric to provide boards or even used as tiles for direct adhesian to a substrate. Duct and pipe insulation and lagging for tanks with preformed sections of EPS or PU is another application of foamed materials. They have been used inside concrete panels and floors and proposed as a permanent form work.

One of the most dramatic inroads in the services field has been the use of PVC for rainwater goods where it has virtually taken over from sheet metal and cast iron materials. Pipes for fluids of various types can be made in PVC, ABS, PE or PP but most are restricted to normal or low temperature usage only. Ducts for ventilation systems can be made from PVC or GRP and have proved useful for domestic occupancies. GRP flues have been used, although rarely, for the upper parts of chimneys attached to appliances which do not release gases above 60°C.

GENERAL FIRE BEHAVIOUR

All plastics materials because of their organic nature are combustible, can ignite, decompose, produce heat, smoke and other products some of which may be more harmful than expected from cellulosic materials. Unlike other groups such as cellulosics, plastics cover a wide range of products with differing chemical compositions, ignition temperatures and reactions to high temperature conditions. Consequently it is not possible to generalize on their ignitability, flammability or other fire characteristics. Their nature and method of production permit changes to be made in their composition which can significantly alter their fire behaviour, as a consequence virtually all types of plastics are available in a standard formulation and a number of flame or fire retarded formulations.

Table 4 lists a range of plastics materials with their flash ignition temperatures and in the case of thermoplastics their softening temperature as determined by method 102C of BS 2582.

TABLE 4 - IGNITION AND SOFTENING TEMPERATURES

MATERIAL	SOFTENING* TEMPERATURE	FLASH IGNITION⫽ TEMPERATURE
ABS	90°C	365°C
PC	145	500
PE	110	340
PMMA	105	290
PP	110	-
PS	90	350
PVC	75	390
GRP	Thermosetting	350
PUR/F	"	310
PUI/F	"	330

(*As measured by method 102C of BS 2782 or similar)

(⫽From Flammability Handbook for Plastics - Hilado C J. Technomic Publishing Co.)

A large number of plastics products to be found in building are of a thermoplastic nature with the softening temperature in the range of 75 to 150°C. One of the major differences between the fire characteristics of cellulosic materials and plastics is the significance of softening on burning behaviour. Most thermoplastics commence to soften before ignition can take place but the extent of softening and its effects depend upon the rate of heating, the mass of the material and its method of attachment. A thin film stretched across a ceiling will soften and tear itself into ribbons, a panel retained along the edges ineffectively could completely fall down, a pipe or a duct could become detached and suffer collapse before ignition takes place. In general such a behaviour would not be regarded as hazardous in itself except that it has assisted in the exposure of another surface to heating or allowed an opening to become available to fire. It is possible to use collapse as a design feature as with the "stretched" PMMA sheets used in the cladding of the Olympic Structure at Munich in 1972, which had unidirectional molecular orientation so that on heating a sudden contraction occurred at a specified temperature above 100°C leading to the fall of the sheets. Another example of softening leading to a less hazardous situation was noted in an investigation on EPS tiles which when adhered over the whole surface to a noncombustible substrate without any surface finish, shrank back to the substrate as a thin film without suffering ignition until exposed to a fully developed fire.

In practice with many types of heat sources and different rates of heating as well as methods of fixing for such materials a range of performances is likely. At one end of the scale the softened material may collapse or fall without any ignition having taken place and at the other it can soften, ignite and cause burning molten drops to fall down on contents capable of causing their ignition. The use of translucent thermoplastics as rooflights for purposes of fire ventilation has been suggested so that the collapse of sheets allows ventilation of smoke and hot gases. However the time of failure is dependent not only upon the thickness, size and shape of the sheets but also on their method of retention and is less predictable than with the purpose built ventilators. Furthermore a ventilation system needs to be designed for a given situation taking account of the provision of high level smoke reservoirs.

Thermosetting materials on exposure to heat behave in a similar way to timber and wood products. Local charring takes place with flaming combustion on the surface if the flammable vapours are given off in a suitable quantity. The charred mess may shrink and fall away but if it stays in place it can provide an insulating barrier controlling the flow of heat to the undecomposed mass and the flow of vapours from it. GRP is a good example of the assitance given by one part of the system in improving performance. As polyester begins to decompose, char and burn the glass reinforcement retains the charred mass in place and protects the unburnt material thereby slowing down the rate of charring and in many cases preventing fire penetration. One of the new developments taking place in the field of polymeric materials is the introduction of thermosetting products, of dense and foamed variety capable of producing a stable char layer.

REACTION TO FIRE CHARACTERISTICS

A number of standardized laboratory procedures are available to determine burning or decomposition characteristics of individual materials and composite products. Most commercially available products have been subjected to one or more of these tests and data published by the manufacturers and in some cases by the testing bodies. The most commonly used procedures are listed in Table 5 with some of their main features.

The main characteristics which are of interest for different plastics materials are ignitability, flammability, rate of heat release, smoke evolution and toxicity. These are listed for a range of products in Tables 6, 7 and 8, using a generalized method of assessment rather than the grading classification or other methods of expressing results proposed in different standards. Ignitability implies the possibility of ignition in the primary phase from a small source and is indicated as a yes/no type of condition for various materials listed in the tables. Flammability is a measure of the ability of flames to be propagated on the surface and is a contributory factor to the rate of growth of fire. An arbitrary scale L, M and R is used which indicates good, medium and poor performance for the range of conditions examined. The rate of heat release is also expressed similarly on an arbitrary scale but using the information from the BS 476 : Part 6 test. Smoke density is indicated figuratively in the absence of a suitable test procedure as an indication by expressions representing low, medium and dense outputs. No judgment is made on the toxicity potential at all, only the type of toxic product of any significance likely to be encountered on the decomposition of the materials is indicated.

The data given in Tables 6 to 8 are primarily on individual materials, their actual fire behaviour will depend on the other materials in combination with them and the precise method of use. The combined product can behave in a significantly different manner than the individual material. The nature of the substrate, the method of attachment or retention, the nature of the finish can all be important factors in the overall performance. Foam materials with noncombustible facings, insulation in cavity brick or block walls are rarely at risk at the beginning of a fire. The failure of the finish or the adhesive can lead to a poorer performance from a material because this may increase the surface/mass ratio allowing more heat transfer. Finishes on foam substrates are liable to show more rapid flaming than on solid materials.

Table 9 shows the behaviour of some individual materials and composite products [2] in a heat release type of test to show the effect of the substrate on the surface finish. If the index of performance is taken to represent the relative hazard this is considerably reduced by the presence of a facing material, particularly if it is of an inert type.

TABLE 9 - PERFORMANCE OF SOME COMPOSITE PRODUCTS

Description		Index of performance Initial	Total
PUR/F Std grade	25 mm	44	29
PUR/F FR grade	25 mm	20	26
PUI/F Std grade	25 mm	10	19
PUR/F core, plasterboard facing	25 mm	4	9
PUR/F core, aluminium facing	25 mm	1	4
PUR/F core, FR plywood facing	31 mm	6	25
PUI/F core, FR hardboard facing	28 mm	6	27

STRUCTURAL FIRE PERFORMANCE

Constructions relying upon plastics components to provide structural stability have an inherent difficulty in providing adequate fire resistance. Most materials suffer damage at high temperatures but this is usually progressive and the critical temperatures are above 400°C. Thermoplastics by softening above 100°C will lose their structural properties rapidly in case of a fire and thermosetting materials do so less rapidly by decomposition above 200°C. The behaviour of the latter would by and large be similar to that of wood products of an equivalent density. However most plastics components are used in smaller sections than corresponding wood sections consequently their usefulness may be considerably reduced compared with products they replace.

GRP has been used in the fabrication of mobile cabins and accommodation units and the constructional techniques allow a skin thickness of 5 mm to provide the structural stability expected from a framed construction having

12 – 15 mm facing materials. Under severe fire conditions the 5 mm facing is likely to be severely damaged in less than 10 minutes with the consequential loss in stability. One form of GRP wall [9] in which a number of other materials were combined has been successfully tested for 90 min. The 200 mm wall comprising plasterboard internal facings, and a reinforcement of 6 mm asbestos panels to the external facing of GRP was subjected to heating on the internal face.

PUR foam filling for sandwich panels is capable of providing a great deal of rigidity. A partition with steel facings and a core of foam 25 – 60 mm in thickness has been subjected to a fire resistance test. The whole construction retained its integrity for nearly 30 minutes but most of the foam core was destroyed in 6 to 7 minutes after which it was not capable of providing much insulation. Experiments with phenolic foam have illustrated their ability to provide a superior performance in comparison with other foams.

EPS sections to fill voids in concrete slabs or floors and even as permanent shuttering has many attractions over the traditional techniques of removable cores or shuttering. As a core material it can be used in walls as well as floors and experiments have shown that with 25 mm concrete facings the rate of rise of temperature is quite slow. When 100°C is reached EPS cores begin to soften and the molten particles attach themselves to the nearest surface which in case of the floor would be the lowest internal face. The quantities are small and volatalization at higher temperatures does not lead to either significant core pressures or the emission of flammable vapours. The use of EPS permanent shuttering places the material in a more vulnerable position with respect to the fire, and if it is protected on the soffit by a board or a finish its disintegration is delayed by a few minutes. As soon as the finish is damaged the shuttering material becomes involved quickly in the fire with a resultant increase in flaming which may not last for more than a few minutes. After its disappearance the floor behaviour depends upon its design and in experiments constructions have been able to provide a fire resistance of just over 60 minutes [9] representing the inherent capability of the floor itself. UF has also been used successfully as a core material.

The use of plastics components has been restricted to materials for fittings, handles, spacers, trim etc. One particularly advantageous application is to either cover a wooden door frame with a PVC moulding or even to make a reinforced PVC framing section for a door. One such design has been shown to be capable of providing a door assembly for 30 minutes' fire resistance.

The successful use of plastics weathering materials for roof constructions has been well illustrated in numerous tests and GRP rooflights have been examined for their ability to prevent fire penetration from an external source [10]. The need for sealing the edges as a possible source of weakness has been well illustrated. PVC rooflights soften and collapse under similar conditions and whilst not representing a hazard by themselves leave an opening in the roof without resistance to the penetration of burning brands. Reinforcement with a fine wire mesh has enabled such materials to provide an effective barrier. PMMA can be ignited from a small source particularly if it attacks a bare edge and the softening of the material and the fall of burning drops can be a hazard. PC is expected to give much improved performance in comparison with PMMA.

FULL-SCALE INVESTIGATIONS

There are a number of problems concerning fire spread in buildings and the behaviour of composite products which cannot be resolved without a full knowledge of all the factors affecting the complex reactions which take place in a fire. Comprehensive and detailed studies are needed before solutions can be found to all such problems but often it is necessary to resolve some immediate issue. One method used for this purpose is to undertake a series of full-scale examinations, attempting to reproduce as many of the important factors as possible. A single experiment can give misleading information as it may not simulate the range of conditions under which fire behaviour has to be studied. A number of such investigations have been undertaken in connection with plastics products, some have been fully reported and the reports on others are under preparation. Some of these are briefly described particularly where they illustrate some special behaviour pattern.

a) Expanded polystyrene tiles. The use of EPS tiles in domestic situations has been examined [11] in detail in full-scale as well as small-scale representations under a variety of fire situations including the simulation of a typical kitchen fire. The investigation showed the lack of correlation between the small-scale flammability tests and the behaviour of such tiles in use. The small-scale tests distinguished between material samples with and without flame retardant additives, in use there was little difference in their response. Without any surface treatment, in thicknesses up to 12 mm tiles on exposure softened and if not properly attached to the substrate became detached and fell down sometimes after ignition had taken place. However when they were adhered fully to the substrate shrinking occurred and they were transformed into a thin film whose behaviour was similar to that of wall paper. A marked change in the behaviour pattern occurred when a surface finish was applied to the tiles, a film of gloss paint usually detached itself on exposure and burnt furiously causing a rapid progression of flames along the surface. Matt emulsion or flame retardant paints were found to be less likely to cause flame spread but the unpainted materials were found to be least hazardous. Most small tests of the type listed in Table 5 were unable to predict the findings of the large-scale investigation.

b) Air supported structures. The fabric of an air supported structure has to be light and strong, preferably translucent so that it can make use of the daylight. At first sight the hazard would appear to be the flammability of the fabric which on ignition could lead to rapid flame spread of the entire enclosure. Full-scale tests have shown [12] again the inadequacy of the small tests to predict the behaviour of a complete structure and the special problems which may be created in some situations. A fire in an air supported structure results in some unexpected features, contrary to conventional expectations. The structure depends upon the presence of an impermeable membrane to retain its stability and consequently an orifice caused by a fire should lead to instability and collapse. Experiments have shown that this can happen if the orifice is large and central but a small opening in the wall section may not cause collapse and collapse can be much delayed due to the additional buoyancy provided by the hot fire gases.

When a small opening is formed as a consequence of small flames attacking the fabric, before flame spread can occur the escaping air forces the flames out of the opening and has a cooling effect along the edges. This restricts the amount of damage to the fabric. A good example of the restricted damage was given in a full-scale test on a polythene structure where with a crib fire a hole nearly 2 m^2 was formed but the structure did not collapse or completely burn out. However deflation can cause some other problems such as forcing the smoke down to the ground level and out of openings and doorways when open. With very large structures where great numbers of occupants are concerned, some low level support system may need to be provided to enable safe evacuation. It is a type of construction where the nature of the material is less relevant than other safety features and where the main effort should be to providing the occupants with an easy escape route.

c) Roof insulation. The use of foamed plastics, EPS, PUR, PIR or PF, as an insulating layer above an industrial deck roof offers many heat conservation benefits. There have been some fires [13], including one or two large incidents [14], in which the roof insulation was allegedly responsible for extensive fire damage. A number of full size investigations have been carried out which have highlighted some important issues. It has been shown that the problem is not due to the presence of foamed plastics but the combination of materials particularly the bituminous vapour barrier and the bituminous binder. Transmitted heat through the deck causes the tibuminous products to melt and decompose, the molten materials and gases can enter the building through the openings in the deck some of which are caused by buckling due to heat. EPS will also soften and melt and allow the felt weathering to become involved. PUR and PF will char progressively and delay the involvement of felt weathering. Fluted or troughed metal decking can allow the gases produced by decomposition to be transferred to other areas, without dilution the concentration may be too high for ignition to occur but when mixing with air has taken place flaming can occur remote from the fire. Some of the leaked gases can enter below deck area, eg the ceiling space, and burn inside the building. Some of the molten material can fall on top of the ceiling or on the floor and burn. Materials with a durable char and without much bituminous content offer the best combination on top of the roof deck. Closure of the troughs with a metallic or some other suitable material should minimize the transfer of flammable vapours.

d) Foamed plastic ceiling boards. Ceiling boards 12 or 19 mm in thickness comprising a core of PUR or PIR foam and 0.8 mm paper facings, as in plasterboard, offer much better thermal insulaticn than many other materials of an equal thickness. Their use had been criticized following a few fire incidents and led to some full-scale investigations [15]. In these experiments the possibility of fire penetration into the ceiling void and re-penetration into other parts of the building was studied. Ceilings of foamed plastic material cannot withstand direct exposure to fire conditions without being penetrated quickly, the time depending upon the severity of fire. Once the fire enters the ceiling space other contents such as roofing felt and stored contents can become involved increasing the severity of fire and facilitating its downward entry into other parts of the building.

The precise hazard created by such materials should take into account the use situation, in some cases there are obvious benefits due to early penetration of the ceilings. It can release the pressure, provide an outlet for the fire gases and prevent the lateral spread of smoke and fire. If the roof construction was perforate a considerable quantity of the combustion products would escape to the outside.

FIRE EXPERIENCES

As more and more plastics are used in buildings, their involvement in fires increases and knowledge is gradually being accumulated on their performance and contribution to fires. A few incidents have occurred which have been highlighted due to the tragic consequences and plastics have been associated with the fire's behaviour. Perhaps the most outstanding incident was the Summerland fire [16] in the Isle of Man in 1973 in the leisure centre which was clad on the roof and the upper parts of the side walls with PMMA pyramidal panels mounted on metal framework.

The fire started by the burning of a kiosk against the outside metal clad wall and penetrated into the cavity spreading rapidly on the inside face of the combustible lining. Products of combustion spread to the undivided inside areas of the building causing panic and deaths and the acrylic panels were involved when the fire had gained a firm foothold. At this advanced stage it spread rapidly to the top and the roof panels collapsed quickly venting the fire. The plastics cladding was quickly destroyed without causing much damage to the steel framework. The public enquiry report traces the history of the building and the fire and does not blame any single material or cause for the tragic consequences.

An earlier fire in France in 1970 at St Laurent du Pont involved a night club and dance hall and again caused much tragic loss of life. The inside surfaces had been given a grotto-like appearance by spraying foamed plastic, probably PUR, on wire netting suspended from the roof. The fire started in a stool and involved the ceiling causing emission of smoke and other fire gases - unfortunately for security reasons the exit doors were locked, barred or inaccessible and many of the deaths could be attributed to the fact that no adequate escape routes were available. This does not condone the hazardous use to which the foamed plastics material had been put.

A multi-million pound fire in a large brewery building near Liverpool [14] in 1973 gutted half of a nearly complete but unoccupied building. This fire was unique in having started outside in a builder's hut, been noticed at a fairly early stage, reached the roof level and spread without any assistance from the contents as the inside was empty at the fire end. The metal roof deck was provided with EPS insulation, bituminous vapour barrier and felt roofing and the supporting structure of light tubular metal was unprotected and supported on reinforced concrete columns. The progressive failure of the roof was due to the combined effect of the burning of the bituminous materials, buckling of the deck, early softening of EPS and progressive collapse of the supporting structure.

Some of the smaller fires which only occasionally make news can sometimes provide information of great practical use. One such incident [17] occurred 18 months ago in an extension to a dental surgery built from GRP sandwich panels containing 50 mm PUR foam. Various treatment rooms were provided with a suspended ceiling with aluminium supports and the space was used for central communication services including a PVC duct for the instrument despatch system. The fire in the plant room though separated from the surgeries by a brick wall was able to bypass it through the PVC duct, damage the aluminium supports to the ceiling causing its collapse, cause destruction of the timber roof members and damage the GRP panels. The problem in this fire did not seem to be the use of plastics materials as such but the weaknesses introduced inadvertently by the provision of features which the fire could exploit.

CONCLUSION

This note has attempted to show the increasing uses of plastics in building construction, the variety of functions they can perform and their likely fire behaviour. Plastics represent a whole family of products ranging in their performance from easily ignitable to those requiring a consistently high heat source before ignition can take place. One of the main differences between plastics and other organic products is the behaviour of thermoplastics which soften and melt at high temperatures.

It is necessary to take into account not only the nature of the material, but also its method of use, its association with other materials and the fire conditions to which it is expected to be exposed. The aim of the safety engineering should be to understand the nature of the materials and to design the products and systems in such a way that the fire hazard is minimized. The solution does not lie in banning plastics from buildings but by understanding their behaviour to use them safely.

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TABLE 3 - MAJOR USES OF DIFFERENT PLASTICS MATERIALS

MATERIAL	CONSTRUCTIONAL	DECORATIVE	INSULATION	SERVICES
ABS	-	Sheets	-	Pipe for waste systems
PC	Glazing panels	-	-	-
PE	Film and fabric for air supported structures	Film	-	Waste pipes
PMMA	Glazing panels, domes, rooflights	Sheets, carpeting	-	Bath & shower units
PP	Sheet, mouldings	Carpeting	-	Waste pipes
PS	Clear panels	Sheets	-	Insulation
PVC	Panels, cladding, rooflights, domes, frames, ceilings, components	Sheets, film, floor tiles	-	Pipes for waste systems, water, etc
GRP	Panels, cladding, rooflights, domes, frames, components	Sheets	-	Ducts, bath units
EPS	Core material, structural laminate	Tiles	Tiles, core material, cavity filling, tank and pipe insulation	-
PF	Sheets, laminates	Laminates	Core material	-
PUI	Sandwich boards	Laminates	Laminates, core material	-
PUR	Sandwich board	Laminates	Laminates, core material, spray coatings	-
UF	-	-	Cavity fill	-

TABLE 5 - STANDARD FIRE TESTS USED FOR PLASTICS

NAME	STANDARD REFERENCE	TYPE	APPLICABILITY	SPECIMEN SIZE mm	MAIN TEST FEATURE
Ignitability test for materials	BS 476 : Part 5	Ignitability	Individual materials	228 x 228	Application of a small flame
Fire propagation test for materials	BS 476 : Part 6: 1968	Heat release	Individual materials or composite products	228 x 228	Rate of heat release of linings and cladding
Surface spread of flame test for materials	BS 476 : Part 7: 1971	Flammability	- do -	230 x 900	Flame spread along vertical surfaces
Methods for testing plastics Rate of burning	BS 2782 : Part 5 1970 Method 508A	Flammability	Individual materials	150 x 13 x 1.6	Flammability of a horizontal strip of rigid materials
Degree of flammability of thin PVC sheeting	Method 508C	Flammability	- do -	550 x 35	Flammability of a film
Flammability	Method 508D	Flammability	- do -	150 x 150	Flammability of an inclined sheet with flame underneath
Test for flameproof materials	BS 3119 : 1959	Flammability	- do -	51 x 318	Flammability of a vertical strip of fabric
External fire exposure roof test	BS 476 : Part 3: 1975	Fire penetration	Construction	840 x 840	Resistance of a roof construction to resist fire penetration
Fire resistance test for elements of building construction	BS 476 : Part 8: 1972	Fire resistance	Full size construction	-	Resistance of a construction to resist a fully developed fire
Horizontal rate of burning of cellular plastics	BS 4735 : 1974	Flammability	Foamed plastics	150 x 50 x 13	Flammability of a horizontal strip

TABLE 6 – REACTION TO FIRE CHARACTERISTICS OF SHEET MATERIALS

MATERIAL	TYPE	THICKNESS mm	IGNITABILITY[1]	FLAMMABILITY[2]	HEAT RELEASE[3]	SMOKE [4]	MAIN TOXIC PRODUCT
ABS	Std	3.2	I	R	R	M	CO
PC	Std	3.0	NI	L	L	M	CO
	Std	6.0	NI	L/M	L	M	CO
PMMA	Std	1.6	I	R	H	L/M	CO
	Std	3.2	I	R	H	L/M	CO
	FR	5.0	NI	L	M	M	CO*
PS	Std	1.6	I	R	H	D	CO
PE	Std	1.6	I	M	M	L/M	CO
	Std	3.0	I	L	M	L/M	CO
PP	Std	3.0	I	R	H	L/M	CO
	FR	3.0	NI	M	M	M	CO*
PVC	Std	1.5/3.0	NI	L	L	D	HCL/CO
GRP	Std	1.2/3.0	I	R	M	D	CO
	FR	1.2/3.0	NI	L/M	L/M	D	CO*

Std – Standard Formulation; FR – Flame retardant Grade

L – Low; M – Medium; D – Dense or R – Rapid or H – High

I – Easily Ignitable. NI – Not Easily Ignitable

* – FR additive can also release toxic products

1 – BS 476 : Part 5, 2 – BS ~~746~~ 476 : Part 7, 3 – BS ~~746~~ 476 : Part 6,
4 – DD 36.

TABLE 7 - REACTION TO FIRE CHARACTERISTICS OF FOAM MATERIALS

MATERIAL	TYPE	THICKNESS mm	IGNITABILITY	FLAMMABILITY	HEAT RELEASE	SMOKE	TOXIC PRODUCTS
PUI	Board	25.0	NI	L	M	D	(CO, HCN NO_x
	Board with A1 facing	25.0	NI	L	L	D	CO
PUR	Board	25.0	I	R	H	D	CO, HCN, NO_x
	FR	25.0	NI	L/M	M	D	CO, HCN, NO_x
PF	Board	32.0	NI	L	M	L	CO, phenol
	Board with A1 facing	50.0	NI	L	L	L	CO
	FR	12.5	NI	L	L	L	CO
EPS	Board	9-12	NA	NA	M	D	CO
	Board/NC*	9-12	NA	M	L	D	CO
	Board with gloss paint	9.0	I	R	H	D	CO
	FR/NC*	9-12	NI	M	L	D	CO
UF	Board	51.0	NI	R	M	L	CO, NH_3

*Board attached to a non-combustible substrate.

NA - Not Applicable.

TABLE 8 - REACTION TO FIRE CHARACTERISTICS OF FILMS

MATERIAL	FINISH	THICKNESS mm	IGNITABILITY	FLAMMABILITY	HEAT RELEASE	SMOKE	MAIN TOXIC PRODUCT
Polyester	PVC coated	0.6	NI	M	-	M	CO
PE	-	0.12	I	M	-	M	CO
	-	0.26	I	M	-	M	CO
	FR	0.27	NI	L	-	M	CO
PVC	Nylon reinforced	0.6	NI+	L	-	M	HCL/CO
	"	0.8	NI+	L	-	M	HCL/CO
PVC	Polyester reinforced	0.7	NI+	M	-	M	HCL/CO
	"	1.0	NI+	L	-	M	HCL/CO

+Easily ignitable when highly plasticized.

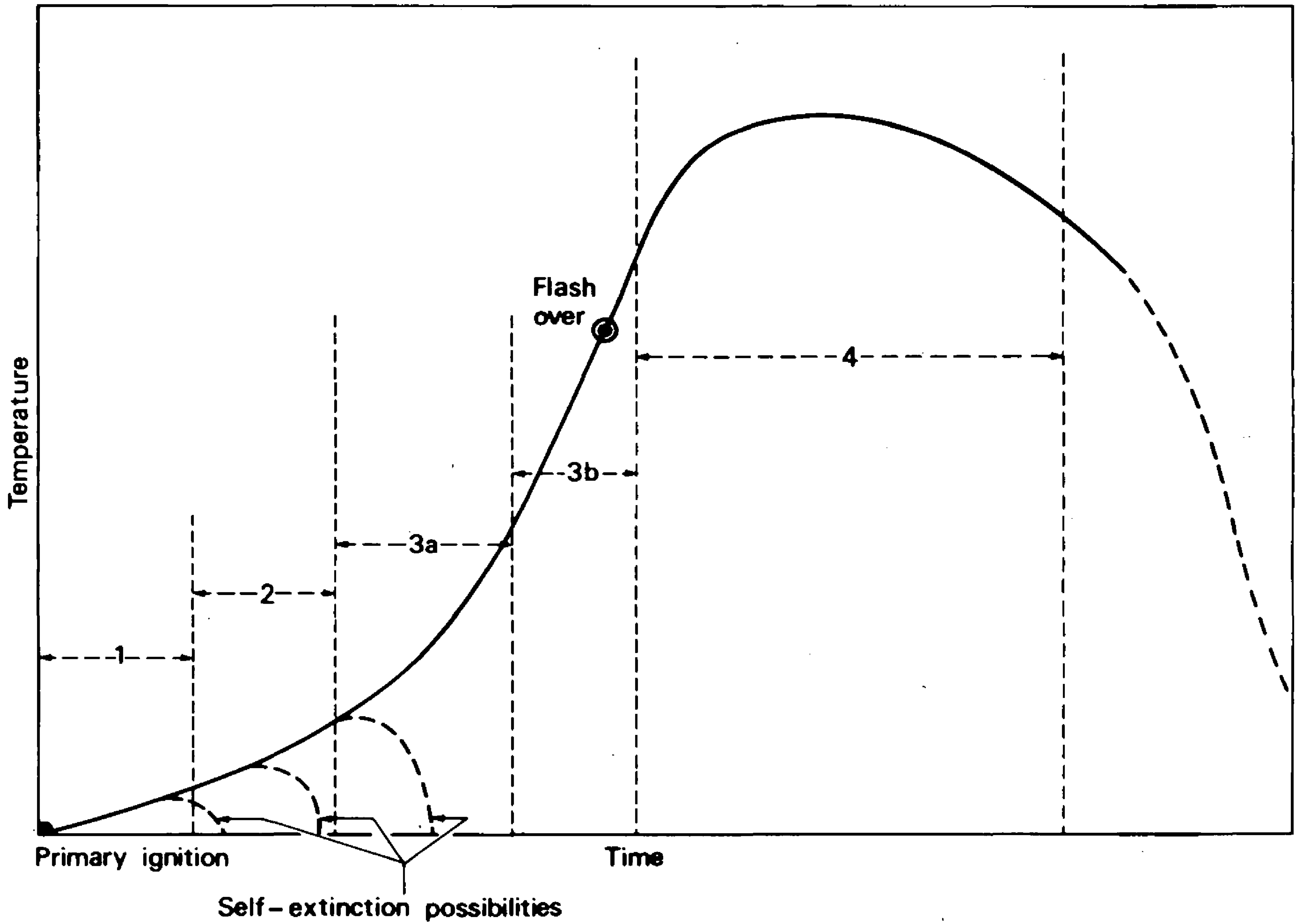
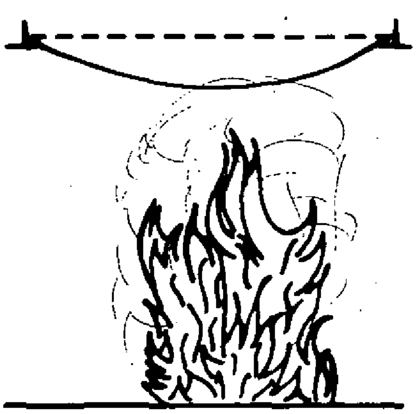
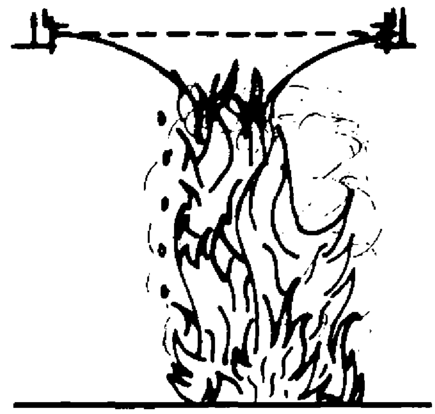


Figure 1 Different phases in the development of a fire

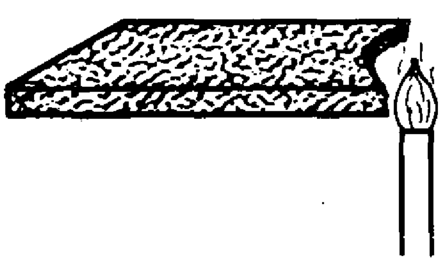


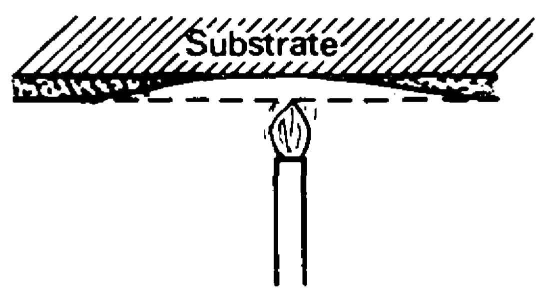


Collapse before ignition

Ignition before collapse

Rigid thermoplastic sheet



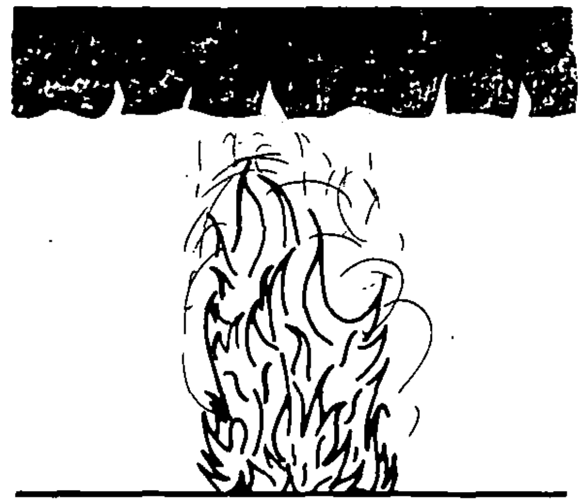


Receding from a heat source

Receding to a substrate

Foamed materials

Figure 2 Thermoplastic materials — some patterns of behaviour



Unstable char

Stable char

Figure 3 Thermosetting materials