

SYMPOSIUM*
PLASTICS IN PHARMACY

NATURE AND PROPERTIES OF PLASTICS

BY C. L. CHILD, B.Sc., Ph.D.

*Plastics Division, Imperial Chemical Industries Ltd.,
Welwyn Garden City, Herts.*

The group of materials known as "plastics" is hard to define unambiguously and yet comprehensively, but easier to describe. It is a group of new materials of construction, numbering several hundreds described in the literature and in patents, but of which only about a score are as yet of commercial importance.

A member of this group may have some properties which differ, not only in degree, but in kind from those of another, but in certain respects each member differs from the others only in a small degree. It is this essential similarity which enables us to group them together under the description "Plastics."

These are their important similarities; 1. Plastics are synthetic, of high molecular weight and with complex molecules; 2. Plastics are usually organic chemicals. There is the important exception of the silicone family of plastics which essentially is based on the inorganic element silicon; 3. Plastics are sensitive to temperature, and at some period in their history there is a temperature at which they can be made to flow in a controlled manner under applied pressure. Some retain this property throughout their history, others, having reached this temperature, undergo a chemical change and become infusible; 4. Plastics have limited temperature ranges of usefulness, becoming more brittle as the temperature decreases, softer as it rises. The lower limit may be -100° C. or even much lower; the upper limit never exceeds 350° C. and generally lies in the range 70 to 90° C.; 5. Plastics are of low specific gravity—generally in the range sp.gr. 0.9 to 2.5; 6. Plastics have mechanical strengths approaching those of metals measured on a strength to weight basis, but much lower stiffness; 7. Plastics are electrical insulators; 8. Plastics have low thermal conductivity; 9. Plastics are generally resistant to inorganic chemicals, but in general are attacked or dissolved by organic chemicals.

It will be seen from 1 and 2 that there are no clear cut dividing lines between plastics on the one hand, and fibres and textiles, or rubbers, or paints and varnishes on the other. It is this overlap that is responsible for the difficulties in defining the term "Plastics."

THE NATURE OF PLASTICS

It is sometimes said that plastics can now be "tailor-made" by the chemist to meet a particular application. This is an over-statement. It

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is true that modern physico-chemical theories enable us to correlate some of the properties of a plastic material and specific features of its molecular "make-up" and from this knowledge we can forecast to some extent the kind of molecule and molecular arrangements which must be obtained in order to give a product with certain properties. To this extent the plastics chemist can "build-in" desirable properties in a new material, but our ability to do this is still limited by the complexity of the molecules and their arrangements. This can be illustrated by a consideration of the problems encountered with the (chemically) simplest plastic, polythene.

This plastic is made by polymerising ethylene of high purity at high temperature and pressure. The chemical process is often illustrated thus: $m(\text{CH}_2 = \text{CH}_2) \rightarrow \text{---CH}_2\text{---CH}_2\text{---CH}_2\text{....CH}_2\text{---CH}_2\text{---}$. The polymer chains so formed can be of any desired length—hundreds or thousands of ethylene units long. By assuming this kind of picture for a polythene molecule, we can account for some of the properties of the polymer. For example, it is a simple straight chain hydrocarbon, therefore we may expect a material which is chemically rather inert, electrically highly insulating, with a crystalline structure and a sharp melting point, and which is rather brittle—in short, resembling any other paraffin. In fact the material behaves chemically as we expect, and it is an outstandingly good electrical insulator. It does have a crystalline structure—but only in part; partly it is amorphous. It therefore has a sharp melting point, and also a wide softening temperature range. Furthermore, it is flexible and remarkably tough, becoming brittle only at low temperatures, sometimes lower than -100°C .

It is apparent that our simple picture of a molecule, $\text{---}(\text{CH}_2)_m\text{---}$, is incomplete. Some of the factors which we have not considered—but must—are (1) the value of "m," that is, the length of the chain, (2) the terminal groups of each chain, (3) the possibility of chain-branching, its frequency and the lengths of any side chains, and (4) the presence of groups, even in minute quantities, such as >C=O , ---CH_3 , $\text{---C}\begin{matrix} \text{H} \\ \diagup \\ \text{O} \end{matrix}$, $\text{---C}\begin{matrix} \text{O} \\ \diagup \\ \text{OH} \end{matrix}$, and so on, arising from the presence of the catalyst or traces of impurities. And, of course, even if all the molecules were simple straight chains, we would not expect "m" (the molecular weight, in effect) to be constant for every molecule in a given sample. We should, on the contrary, expect to find a normal frequency distribution curve applying, so that we have to replace factor (1) above by, (1a) average chain length (or molecular weight), and (1b) chain length spread, (or molecular weight spread). It is unnecessary here to pursue these complexities further, so long as their existence is remembered, and it is appreciated that these and many related difficulties severely limit our ability to forecast, or fully understand, the properties of plastics.

With this qualification we can make some generalisations. Thus we can safely say that plastics owe their importance to the fact that they consist of macro-molecules—long chains which are entangled with one another. If the chains are flexible and have little attraction for one

another, then, under the influence of heat the chains can easily slide over one another, and this is manifested in a low softening point. If we want to raise the softening point, we can (i) increase the interchain attractions, for example, by introducing polar groups into the molecules; or (ii) we can stiffen the chains, for example, by introducing large groups which impede free rotation about C — C links in the molecule, or (iii), we can do both. Finally, we can modify the properties of the material drastically by chemical substitution and by linking chains together by strong "chemical" bonds, so giving a vast irregular network which is in effect a super giant molecule, weighing perhaps several pounds. If the links are numerous as well as strong, and the chains stiff, we can raise the softening point to such an extent that the material becomes infusible, decomposing before it can soften.

On the other hand, it is possible to lower the softening temperature of a given polymer by what may be called "external chemical means." This is the process of "plasticisation," in which polymer molecules are partly "solvated" by a poor solvent for the material. The effect of the solvation is to reduce interchain attraction directly, and also (indirectly) by increasing interchain distances. As a result, the polymer molecules can more easily slide over one another, and this is shown by increased flexibility, lower strength, lower softening temperature and retention of flexibility to much lower temperatures. Most polymers can be plasticised, and the choice of plasticiser in any instance is governed primarily by the chemical nature of the polymer. The application of these general principles will be illustrated in the consideration of individual materials later.

THE PROCESSING OF PLASTICS

Much of the importance of plastics lies in the fact that their behaviour towards heat makes possible mass production to close tolerances at relatively low cost. Thus, with plastics such as polythene, consisting essentially of long entangled chains with no strong forces between them, heating to a moderate temperature produces a soft mass which flows very easily under pressure and which hardens again on cooling. If the material is cooled while it is held in an impressed shape, then that shape is retained when the plastic is cold. Materials behaving in this way are "thermoplastic." There is a second group of plastics which behave differently when heated, in that again they first soften and flow under pressure, but they then undergo a chemical reaction which leads to the linking of one molecular chain to another giving a rigid infusible material. Such materials are "thermohardening" or "thermosetting."

In commercial practice, thermoplastics are handled in the following basic ways; 1. Extrusion, in which the cold material is fed into a heated barrel, along which it is forced by an Archimedean screw. The material heats by friction and by contact with the hot cylinder, softens and squirts out of an orifice (die) at the end of the barrel, taking the shape of the orifice as its cross-section. The extrudate is quickly cooled in air or in water before it can deform; 2. Injection moulding, in which again the plastic is fed into a heated cylinder through which, this time, it is forced by a ram.

On emerging from the nozzle at the end of the cylinder, the material fills a cavity in a relatively cold mould, and takes the shape of the cavity; 3. Blow moulding, in which a tube of softened plastic made by extrusion or injection, is blown by internal air pressure against the walls of a cold mould cavity to produce hollow articles, such as containers; 4. Rolling and calendering, in which the material is squeezed through heated metal rollers until it is soft, when it forms a homogeneous skin round one of the rollers, and can be cut and pulled off, cooling in air or in water to give a sheet or film of determined thickness and width; 5. Spreading, in which rollers or scraper blades spread the softened material over the surface of a "base," such as paper or fabric; 6. Bending and stretching, in which sheets of heat softened thermoplastic material are shaped over formers or by pressing with male tools or by applying different air pressures on opposite faces, and then allowed to cool while held in the desired shape. There are many variations and combinations of these, and also some other methods used in special problems.

Thermosetting materials, however, can be heated in a hot metal mould, pressed and as soon as the chemical reaction (cross-linking) is completed the mould can be opened and the hot mouldings extracted and allowed to cool. Sometimes catalysts (usually in this connection called "hardeners") can be used to promote the cross-linking at lower temperatures, even down to room temperature.

SOME PLASTIC MATERIALS

18 major types of plastics have been selected for further discussion and it will be most convenient to make a somewhat arbitrary division of these into the following 5 classes.

1. *Semi-synthetic Thermoplastics*

Cellulose nitrate, cellulose acetate, cellulose acetobutyrate, ethyl cellulose, and regenerated cellulose.

2. *Synthetic Thermoplastics*

Polythene, P.V.C. and copolymers, polymethyl methacrylate, nylon, polytetrafluoroethylene, polystyrene, and polyvinylpyrrolidone.

3. *Synthetic Thermosets*

Phenol formaldehyde, aniline formaldehyde, urea formaldehyde, and melamine formaldehyde.

4. *Polyesters*

5. *Silicones*

SEMI-SYNTHETIC THERMOPLASTICS

The important members of this class are all based upon cellulose which is chemically modified to form either esters or ethers.

Cellulose nitrate. Cellulose nitrate, conventionally plasticised with camphor and castor oil, is the oldest of the plastics of present-day industry, having been discovered independently in England and America in the middle of the 19th century. It is best known under one of its trade

names, "Celluloid," and is variously described as "cellulose nitrate," "nitro-cellulose," "N.C." and "pyroxylin." Its uses for dress ornaments and toilet accessories, such as combs, brush backs, spectacle frames, etc. are well known, and it is probably the most widely used material for knife handles. Another very important, but perhaps less known use, has been the covering of base fabrics for the production of leathercloth. In all these applications the toughness of the material is outstanding, but because of its very high inflammability it has been replaced in most of these applications in recent years. There remains one application which no other material has yet succeeded in capturing from cellulose nitrate, and that is in the manufacture of table-tennis balls, where the toughness and resilience are quite outstanding. In the form of cast film it provides an excellent base for photographic film and in solution form has been used for colloids.

Cellulose acetate. The first attempt to overcome the inflammability hazard of cellulose nitrate was to modify the cellulose with acetic acid instead of nitric acid. The product retains many of the advantages of cellulose nitrate, and overcomes its extreme inflammability, but cellulose acetate suffers from being much more sensitive to water and water vapour, so that its dimensional stability is inferior to that of cellulose nitrate. This is a disadvantage in such applications as manufacture of slide rules and other scales, where dimensional accuracy is required, and also in the manufacture of containers and components where screw threads or sliding fits are required. Cellulose acetate is plasticised with organic esters such as phthalates and because of its non-inflammability, its attractive colours, its stiffness and its toughness, it has found a major application in the manufacture of toys, and in transparent foil form for packaging. Cellulose acetate is used as the basis of "non-flam" photographic film.

Cellulose acetobutyrate. The mixed ester of acetic and butyric acids was prepared in an attempt to overcome the moisture sensitivity and consequent dimensional instability of cellulose acetate. While the product is in this respect superior to cellulose acetate it remains inferior to cellulose nitrate, but it is extremely tough and much less inflammable than cellulose nitrate, and has, therefore, been used for applications requiring dimensional stability, electrical insulation, toughness and non-inflammability—e.g. screw-driver handles. It suffers from the drawback that in certain circumstances the odour of butyric derivatives is perceptible.

Ethyl cellulose. As the various esters of cellulose were prepared, each in turn showing some advantages but some disadvantages compared with its forerunners, an attempt was made to overcome the disadvantages by forming cellulose ethers instead of esters. The only product of commercial importance in this group is the ethyl ester—ethyl cellulose—which is characterised by having a very high strength and general toughness. It is employed mainly in industrial applications, but has been used for the manufacture of hammer heads.

Regenerated cellulose. Regenerated cellulose is not perhaps, strictly speaking, included within the products of the plastics industry, but is

mentioned here as an illustration of yet another attempt to utilise the long chain molecules of cellulose. It has attained importance as the best known and one of the most useful of all transparent packaging films, particularly under the name of "Cellophane." It is made by converting the cellulose into cellulose xanthate, extruding this in the form of a flat ribbon, coagulating it and then decomposing it so as to reform the cellulose, which is now in the physical state of a flat film. Regenerated cellulose film can be used either unplasticised or plasticised with glycerine. Its resistance to water and water vapour can be improved by coating one surface of the film with a compound of wax, urea-formaldehyde resin and nitrocellulose. Its particular importance lies in its clarity, strength, stiffness and ease of printing.

SYNTHETIC THERMOPLASTICS

It is in this branch of the plastics industry that the greatest advance has been made in the last 25 years. In fact, it is only during this period that the synthetic thermoplastics have become of commercial importance. They are made either by polymerisation of compounds containing an ethylenic double bond, or by condensation of bi-functional molecules, e.g. the condensation of di-acids and di-amines, di-acids and di-alcohols, or the self-condensation of amino-carboxylic acids.

Polythene. Reference has been made earlier to the chemistry of this polymer. Its production is of interest not only because polythene is one of the few polymers made by the bulk polymerisation technique, but because the reaction is carried out at extremely high pressure, as high as 30,000 pounds per square inch and at high temperature, as high as 250° C. The polymer combines flexibility with toughness; low water absorption and low water vapour permeability with good resistance to inorganic chemicals; good electrical insulation characteristics at all frequencies with durability. It does not rust or corrode, and is of very low specific gravity—it floats on water. Its most important fields of use are in the insulation of low and medium voltage power cables (up to 11 kilovolts); in the insulation of high frequency communication cables (radar, television, submarine telegraph and submarine telephone); in sheathing underground cables operating in corrosive soils; in tubing for chemical plant and domestic, industrial and agricultural cold water supplies, and industrial effluent drains; in packaging films, for individual packs and drum liners; in surface coating papers for packaging; in domestic ware (bowls, baths, brush holders, racks, etc.); and in flexible and unbreakable containers, ranging from very small to 55 gallon capacity.

Polyvinyl chloride and vinyl chloride copolymers

Polyvinyl chloride (or P.V.C.) is chemically very closely akin to polythene, differing from it in having one hydrogen on every second carbon atom replaced by a chlorine atom. This modification, however, has profound effects on the properties, and hence the uses, of the polymer. The effects of the chlorine atoms in the molecule are to hinder regular packing of the

chains, thus preventing crystallite formation, to increase the stiffness of the chains, to increase the interchain attraction, to make the molecules electrically unsymmetrical, and to make the product non-inflammable. Thus P.V.C. is generally wholly amorphous, and it has a wide softening range with no sharp melting point. The product is hard, tough and horny, less flexible and "waxy" than polythene. The electrical unbalance of the molecules leads to a high electrical loss factor at high frequencies, and other factors reduce the insulation properties of P.V.C. considerably in comparison with those of polythene. Most commercial grades of polymer do not flow easily under pressure at temperatures less than about 160° C., and at this temperature it is difficult to prevent decomposition, with evolution of hydrochloric acid, discolouration and loss of strength. Grades of lower molecular weight are now available which, correctly stabilised, can be processed in sheet form by pressing, blowing or vacuum techniques at temperatures of 100° C. to 130° C., and these sheets are used for trays, refrigerator parts, drawer linings, signs and fluorescent lighting fitting reflectors. The higher molecular weight grades are used with plasticisers, so that their working temperature is reduced to a safe level below their decomposition temperature. Depending on the nature and quantity of plasticiser used, the products can vary from hard and horny to soft, flexible and rubbery. Although P.V.C. is unsuitable for high frequency insulation, at low frequencies it is comparable with rubber compounds, and indeed low voltage, low frequency cable insulation and sheathing are two of the major uses of plasticised P.V.C.

Its high loss characteristics at high frequencies allow it to be welded by the "high frequency" or "R.F." or "electronic" technique. Plasticised P.V.C. calendered sheets and films are welded in this way to make rain-coats, babies' pants, sponge bags, racquet covers, quilted card table tops, pouches and shampoo packs. Protective clothing is often made from textile fabric coated with P.V.C., either by calendering or by spreading a paste made by cold mixing polymer and plasticiser and which is subsequently gelled by heating. The pastes are also used to make toys, stethoscopes, etc. by moulding and dipping techniques. The plasticised compounds are used for a variety of extrusions—straps, belts, braces, draught excluders, upholstery beading, and so on. For certain purposes it is necessary to modify the flow properties of the polymer under heat and pressure, that is, during processing, without having recourse to the addition of extra plasticiser. This can be done by co-polymerisation of vinyl chloride with a minor proportion of, for example, vinyl acetate or vinylidene chloride. The resultant copolymers are generally easier to process, less chemically resistant and hence more easily soluble. Because of the effect of the second component on the flow properties of the polymer, it is sometimes called an "internal plasticiser." Copolymers of vinyl chloride/vinyl acetate are used, for example, in the making of long-playing gramophone records where the requirement is for a material with the desirable properties of P.V.C., but which can be used satisfactorily in existing equipment, originally developed for handling slate-dust filled shellac.

Polymethyl methacrylate. Chemically, methyl methacrylate can be regarded as derived from ethylene by substitution of both hydrogens on

one carbon atom, $\text{CH}_2=\text{C} \begin{array}{l} \text{CH}_3 \\ | \\ \text{CO-OCH}_3 \end{array}$. The polymers are remarkable for their

clarity and colourlessness, and for retaining these properties on exposure. They can be prepared in an unlimited range of colours, in the physical forms of powders, sheets, rods and tubes. They have a low specific gravity and are rigid and strong. Electrically, they are moderate insulators, and chemically are resistant to inorganic and some classes of organic materials. The sheets are used for glazing of aircraft, and, in corrugated forms, for glazing of buildings; for instrument panels, dials and scales; for lightweight crockery; for sinks, baths and wash basins; for lighting fittings (reflectors, refractors and diffusers) used with filament, fluorescent, mercury and sodium lamps; for signs, advertisements and display stands; for machine guards and goggles and visors. Polymethyl methacrylate moulding powder is used principally for motor car rear light covers and reflectors, where resistance to outdoor exposure, to oil and petrol and their fumes, and to impact shocks, combined with high light transmission and suitable refraction characteristics are the essential properties; for car horn buttons and insignia, refrigerator name plates, combs, brush-backs and other toilet accessories, where clarity and a sparkling appearance are required; for coloured telephones, where brightness, strength, electrical insulation and permanence are wanted. Fine powders of polymethyl methacrylate are used, either by injection moulding or by making a partial solution in catalysed methyl methacrylate monomer, for the manufacture of dental plates and false teeth and eyes.

Nylon. There are 4 basic grades of nylon in commercial production at the present time, and intermediate and special combinations of properties can be obtained by mixing polymers, co-condensing mixtures of primary reactants, and by plasticisation. Chemically, nylons can be regarded as polythene in which, at regular intervals in each molecular chain, the

peptide group $\begin{array}{c} \text{— C — N —} \\ || \quad | \\ \text{O} \quad \text{H} \end{array}$ has been inserted. As a consequence of the

regularity of the structure the molecules can easily pack into orderly arrangements, and the 4 basic nylon polymers are indeed highly crystalline. The most notable effect of the introduction of the peptide group is to increase the interchain attraction considerably (probably by hydrogen bonding), so that the melting point is considerably increased (nylon 66 melts at 264° C.), and the material is stiffer and stronger than polythene. In fact, if the orderliness of the molecules is increased by orientation, that is by making most of the crystallites lie in a given direction, tensile strengths of over 50,000 pounds per square inch can be obtained, compared with 2000 to 3000 pounds per square inch for polythene.

Nylon plastics resulted from a research designed to produce a protein-like fibre—an object triumphantly achieved. It followed, naturally, that the first use of nylon outside the textile industry was in the form of thicker

filaments. The success achieved by nylon monofil in domestic, toilet and industrial brushes is well known. It is perhaps not so well known that considerable progress has now been made in developing a tapered filament, with fibrillated ends, suitable for use in paint and distemper brushes. The outstanding property of nylon monofilament in these applications is its long life. Allied to this are the facts that the fibres are smooth surfaced solid rods, easily kept clean and aseptic, that the chemical resistance is good, and that the water absorption is low, so that the stiffness of the brush varies but little with humidity. Other uses of nylon monofil include fishing lines, sports racquet stringing and non-absorbable sutures.

The first development of nylon in forms other than monofils was as an injection moulding material, and in this form it is proving to be a competitor to light metals. In light engineering equipment, such as for example, calculating machines, meters, and textile machines, there are many bearings and gears now made from nylon. Nylon is silent in use, it generally requires no lubrication, and where a lubricant is necessary, water can be used, so that contamination of foods and textiles with oil can be eliminated, and it will outlast metal parts.

Whereas the 4 basic types of nylon have entered fields previously the preserve of light metals, the newer co-polymers and plasticised compositions have leathery characteristics, and one of the most recent applications for nylon is in moulding bicycle saddles. More recently, nylon grades suitable for extrusion have been produced. Tubing, such as for blood transfusion and car pressure lubrication, and sheathing, as on wire ropes and army communication cables, demand toughness, abrasion resistance and resistance to chemicals and temperatures above 100° C. and these are provided by nylon. Nylon type 66 can be chemically modified by methoxy methylation so as to render it soluble in mixtures of alcohol with water, and from the solutions water vapour permeable films can be cast. Nylon plastics, particularly type 66, are notable for their high melting points, rendering them more amenable to conventional sterilisation techniques. This is made use of in the surgeon's nailbrush, with a moulded nylon stock and nylon monofil tufts; in a light weight, unbreakable syringe; and in bottles and containers.

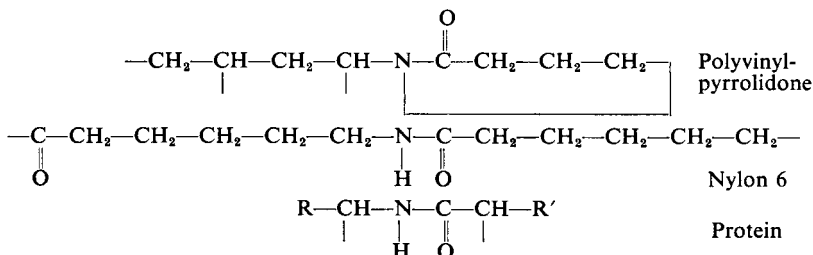
Polytetrafluoroethylene. This high-priced material is of great interest because of its unique properties which are unexpected in an organic compound, and it illustrates dramatically the effect of substituting all the hydrogen atoms in polythene by fluorine atoms.

First of all, it has the highest density of any organic polymer (2.2 cf. polythene 0.92). Secondly it is unaffected by any chemical at temperatures up to 280° C. except molten alkali metals and sometimes fluorine. Thirdly, it can be used continuously at temperatures of 280° C. for months, without decomposition, and, in fact, must be heated to above 327° C. in processing. Fourthly, it has the lowest reported coefficient of friction—less than that of wet ice on wet ice. The facts that it is in the same class as polythene as an electrical insulator, and that it exhibits remarkable non-sticking properties may be expected from, respectively, its chemical constitution and its chemical inertness.

The chief uses of P.T.F.E. are in high-frequency electrical insulation in situations where high temperatures and corrosive chemicals are met; in chemical plant (tank linings, gaskets); in bearings where low coefficient of friction is required, and loads and speeds of rotation are fairly low; and in food processing plant (bakeries) where surfaces to which doughs and other mixes will not stick are required.

Polystyrene. This material is again a hydrocarbon, and can be regarded as derived from polythene by substitution of one hydrogen atom in each ethylene unit by the phenyl radicle. Its electrical insulation properties are of the same order of magnitude as those of polythene, and again, as with polythene, the softening point is low, indicating low interchain attraction and low stiffness of the chains. The presence of the phenyl group in the molecule hinders crystallisation, and the polymer is glassy in type. It is colourless, rigid and brittle. Its important properties are, firstly its low cost, and secondly the ease with which it is injection moulded so that, although it has come into industrial production only recently, it has become the most important injection moulding material on a tonnage basis. It has been used for a great range of domestic, toilet and industrial mouldings, where rigidity and clarity or brightness of colour are of importance. One of its biggest uses has been in refrigerator components, such as crisper dishes. Copolymers, mixtures of polymers and plasticised polymers have been produced for special purposes, for example to give extra flexibility for such applications as battery boxes, or to reduce the accumulation of static electricity which leads to dust collection on display articles or dress hangers.

Polyvinylpyrrolidone. This material is of unusual interest because its major uses so far established lie in the field of medicine and surgery and not in the conventional fields of plastics applications. Its uses in medicine and pharmacy are dealt with elsewhere in this Symposium, and here it is sufficient to note the similarity in molecular structure of the polymer and a typical protein, as this doubtless accounts for its usefulness as, for example, a blood plasma substitute. Comparison of its molecular structure with that of a typical nylon is also interesting, and illustrates how molecular modification influences properties and uses.

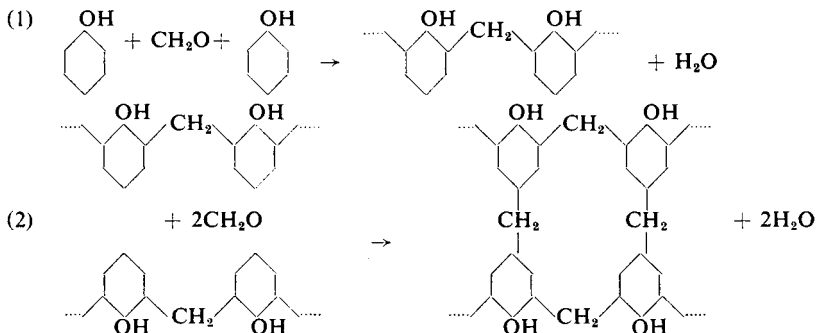


SYNTHETIC THERMOSETTING PRODUCTS

The important products of this group are made by the condensation reaction of formaldehyde with a compound which can react chemically in at least 2 places. Examples are, aniline, phenols, urea, and melamine.

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Phenol-formaldehyde. The term “phenol formaldehyde plastic” covers resins and moulding powders made not only with phenol, but also any cresol or mixture of them. The reaction can be typified in two stages as follows:—



The first stage produces moderately long thermoplastic chains which, in the second stage, react with further formaldehyde to form methylene links from one chain to another. As this process occurs in all directions a vast network is formed, rendering the product rigid and infusible.

The resins are dark coloured powders or liquids, and are used as adhesives for many purposes. They are unaffected by moulds or bacteria, or by moisture, and phenolic bonded plywood will withstand years of exposure even in the tropics. Because of their water resistance, phenolic glues are also used for marine work. Besides wood glues, phenolic resins are used to bond layers of paper or fabric together to make the so-called laminates for industrial and electrical work. These are employed in building as wall panels and corrugated corrosion-proof roofing sheets, and in special hollow forms and sandwich structures as partitions and bulk-heads on ships and where strength and insulation are required combined with light weight.

The best known use of the resins is as the binder for a variety of fillers to make moulding powders of the type generally referred to as “Bakelite” (a trade name derived from that of Dr. Baekeland, who first controlled the reaction of formaldehyde with phenols). The uses of these powders require no elaboration, being so widespread in the home and all branches of industry.

Phenolic powders of a special type can be prepared which are compatible with foodstuffs and beverages, but in general they are unsuitable for this purpose because they cause tainting of the taste of the food or drink. Their dimensional stability, however, makes them suitable for closures for many purposes.

Amino-plastics. This group includes the condensation products of formaldehyde with aniline, urea and melamine. Aniline formaldehyde resins are used to make paper and fabric laminates for the electrical industry. The laminates have very good insulation properties and high strength.

Urea resins are used in the same applications as phenolic resins, but

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differ in several ways from them. The urea resins are pale straw coloured to colourless, and hence permit laminates and powders to be produced in a complete range of colours, whereas phenolic products, because of the basic colour of the resins, are perforce restricted to dark colours such as black and brown. The urea resins are cheaper, but more sensitive to moisture than their phenolic counterparts. On the other hand, they are odourless and tasteless and can be used in contact with foodstuffs and drinks.

Urea moulding powders are used for lighting fittings, closures, domestic and toilet ware, electrical fittings and cosmetic containers, and the laminates are used for decorative purposes. In this last application advantage can be taken of the dimensional stability and resistance to humidity of phenolic resins, and the attractive appearance of clear urea resins by making laminates with phenolic bonded cores and urea bonded surfaces. These are finding wide use for table tops, and restaurant panelling, and cigarette proof grades are made by incorporating a layer of metal foil in the laminate to conduct away the heat of the burning cigarette end. Melamine plastics combine many of the merits of both phenolic and urea plastics, but they cost more. They are used in the same ways as phenolic and urea resins and powders wherever their special combination of properties justifies their extra cost.

POLYESTERS

Polyesters, derived in effect from polyhydric alcohols and polycarboxylic acids, are yielding a rich harvest of new polymers. Not all are plastics—indeed the most famous of them all is a textile, “Terylene,” but even this one, polyethyleneterephthalate, can be made into a film with unusual properties of electrical insulation, resistance to water and water vapour, and strength. Indeed, films as thin as .00025 in. thick are stronger than many films from other materials in thicknesses 10 times greater. It is a new product, and its possibilities remain largely unexplored, but it is certain that much will be heard of it in future years. Other classes of polyesters containing conjugated double bonds yield resins which cross-link—that is, thermoset—by polymerisation, and this process can be carried out often at pressures and temperatures near atmospheric. These resins have found particular application in making glass fibre laminates, which are gaining prominence as structural materials for small boats, yachts and motor car bodies. Some polyesters yield foams which are of value in insulation against heat and sound, and for upholstery and vibration damping. The chemistry of this class of resins is particularly adapted to the new techniques of “block” and “graft” polymerisation which have given the polymer chemist two new tools to use, and many new plastics, films, textiles and rubbers, each with special properties, can be expected from the polyesters.

SILICONES

In one sense, the silicones are “the odd man out” of the plastics family, in so far as their molecular chain is not composed of a carbon backbone,

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but of silicon and oxygen. The different members of the family are formed by attaching different organic radicles to the silicon atoms of the backbone. Although these organic pendant groups place some limitation on the thermal resistance of the silicones, the main silicon-oxygen chain proves to confer more heat resistance on the product than the carbon-carbon chain of other plastics except P.T.F.E., which may be regarded as so well protected by the fluorine atoms as to be "hors concours." The presence of the organic side groups adds water-repellency, flexibility and solubility in organic solvents to the mineral silicate—like chemical inertness, resistance to heat and resistance to oxidation of the siloxane backbone. An important property of the silicones is that their viscosity changes but little with temperature, so that their temperature range of usefulness is very wide—in some instances from -85°C. to $+285^{\circ}\text{C.}$

Their uses lie in water repellent finishes for masonry, textiles, etc.; in providing anti-sticking surfaces in the food and confectionery industries, and in organic plastics moulding; in chemical and heat resistant rubbery tubes and mouldings; in electrical insulation of wires; in foam suppressors; in polishes; and in medical and surgical applications.

They are available in the forms of oils, greases and rubber and can be either thermoplastic or thermosetting in type.