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Canadian Building Digest

Division of Building Research, National Research Council Canada

CBD 159

Thermosetting Plastics

Originally published 1974

A. Blaga

Please note

This publication is a part of a discontinued series and is archived here as an historical reference. Readers should consult design and regulatory experts for guidance on the applicability of the information to current construction practice.

Thermosetting plastics (thermosets) constitute one of two classes of organic polymer-based materials. The other, thermoplastics, is described in **CBD 158**. Like thermoplastics, thermosets are used in a variety of applications, including construction, where they are generally preferred because of their greater strength and better resistance to creep. This Digest will discuss the general nature of thermosets and outline the major families.

General Characteristics

Once shaped into a permanent form, usually with heat and pressure, a thermosetting plastic cannot be remelted or reshaped because the basic polymeric component has undergone an irreversible chemical change. The operation by which the raw material is converted to a hard, insoluble and infusible product is referred to as cure (or curing) and corresponds to the final step of the polymerization reaction.

A thermosetting material may be cured by the use of heat, radiation, catalysts or a combination of these. The polymer component consists of molecules with permanent cross-links between linear chains that form a rigid three-dimensional network structure which cannot flow. The tightly cross-linked structure of thermosetting polymers immobilizes the molecules, providing hardness, strength at relatively high temperature, insolubility, good heat and chemical resistance, and resistance to creep.

Table I. Typical Range of Mechanical Properties of Thermosetting Plastics (Filled or Reinforced)¹

Thermosetting Materials	Tensile Strength, psi (ASTM D-638)	Elongation, % (ASTM D-638)	Tensile Modulus, 10 ⁵ psi (ASTM D-638)	Compressive Strength, psi, (ASTM D-695)	Flexural Yield Strength, psi, (ASTM D-790)	Hardness**
Epoxy (moulding compounds)*	10,000-30,000	4.0	30.4	25,000-40,000	10,000-60,000	M100-M110
Unsat'd Polyester	4,000-	0.5-5.0	8.0-45	15,000-50,000	10,000-	M70-M120,

Phenolics (cast-resin)	50,000 4,000-9,000	-	18.8	10,500-34,000	80,000 5,000-12,000	60-80 M85-M120, R110
Urea-formadlehyde (moulding compounds)	5,500-13,000	0.5-1.0	10.0-15.0	25,000-45,000	10,000-18,000	M110-M120
Melamine-formaldehyde (moulding compounds)	5,000-13,000	0.3-0.9	11.0-24.0	20,000-45,000	9,000-23,000	M110-M125
Alkyds	3,000-9,500	-	5.0-30.0	12,000-38,000	6,000-20,000	55-80 M95- M99, E76- E98

* Glass fibre filled

** Figures preceded by E,M or R (hardness scale symbols) represent values obtained by a Rockwell tester (ASTM D-785); the figures without letters were obtained with a Barcol tester (ASTM D-2583)

Thermosetting materials are usually preferred for structural applications because their strength is generally higher than that of thermoplastics and they do not have a tendency to cold flow (creep) at room temperature. The major families are epoxies, unsaturated polyesters, phenolics, amino resins (urea- and melamine-formaldehyde) and alkyds. Typical properties are given in Table I and Table II. (The ranges of these properties are also given for comparison, and may represent only a fraction of the values attainable.) As thermosetting plastics are generally used with fillers or reinforcements, the properties given are for materials containing such ingredients. Other thermosetting plastics include polyurethanes (used in foams and coatings), allyls, and furane resins.

Table II. General Properties of Commercial Thermosetting Plastics (Filled or Reinforced)¹

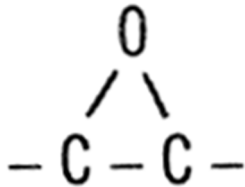
Thermosetting Material	Burning Rate (Flammability), in./min., (ASTM D-635)	Coeff of Therm Exp. 10 ⁰⁵ /°F	Resistance to Heat (continuous), °F	Water Absorption, % (ASTM D-570)	Chemical Resistance* (room temperature)
Epoxy (moulding compounds)	Self-ext	0.6-2.8	300-500	0.05-.020	Resistant to weak acid and in general to weak alkalis, attacked by some strong acids, and slightly by strong alkalis.
Polyester	0.7-2.0	0.7-2.8	300-350	0.01-1.00	Resistant to some weak acids, but attacked by strong acids, alkalis, and by oxidizing agents.
Phenolics (cast resins)	Negotiable	1.8-4.2	160-300	0.12-0.36	May resist or undergo slight attack by weak acids; are attacked by strong agents oxidizing agents and strong

Urea-formaldehyde (mould compounds)	Self-text	1.2-2.0	170	0.40-0.80	alkalis, undergoing decomposition. Fairly resistant to weak acids, but may undergo surface attack and decomposition in strong acids. Moderately attacked by weak alkalis, decomposes in strong alkalis.
Melamine-formaldehyde	Very slow burning, self-ext or nonburning	0.8-2.5	210-400	0.08-0.80	May resist or undergo slight attack by weak acids and alkalis but decomposes in strong acids and alkalis.
Alkyds	Slow burning, self-ext to nonburning	0.8-3.1	300-450	0.05-0.50	May undergo slight attack by weak acids and weak alkalis and more severe attack by strong acids and strong alkalis (with decomposition).

* Thermosetting materials do not dissolve, and only swell if they interact with solvents. Many thermosetting materials do not swell appreciably in contact with any solvent, but some of the compounding ingredients may be leached out.

Epoxies

This family of thermosetting plastics derives its name from the epoxy group,



which is present in the monomer as well as in the intermediate polymer before cross-linking. To produce thermosetting plastic articles the intermediate epoxy polymer is compounded with one or more ingredients that may include fillers, reinforcements, pigments, or plasticizers. Curing is effected by adding either hardeners or catalysts, usually in conjunction with heating. Thermoset epoxy plastics can be formulated for almost any application.

Reinforced plastics based on epoxy resins have better mechanical strength, chemical resistance, electrical insulating properties and environmental stability than those made with conventional unsaturated polyesters. Epoxy glass-fibre-reinforced materials are mainly used in printed electrical circuits and in wing and fuselage structural members of jet aircraft where they must maintain their strength over a wide range of temperatures. Other structures fabricated from reinforced epoxy thermosets are pipes, tanks, pressure vessels and tooling jigs and fixtures. Reinforcements and fillers include glass, asbestos, cotton, paper, metal foils, and synthetic fibres. Glass-filament-wound epoxy composites are used in the manufacture of casings of rocket motors for missiles.

Because of their excellent adhesion and good chemical resistance, epoxies are used in protective coatings and adhesives. Epoxy-based adhesives are compatible with most materials,

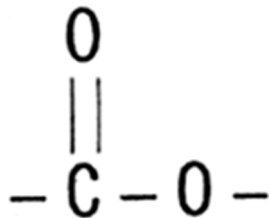
and some can withstand temperatures as high as 204°C (400°F) without weakening. Epoxy-resin-based materials used as surface coatings combine good chemical resistance, toughness, flexibility and adhesion. Epoxy coatings are used primarily in corrosion- and abrasion-resistant applications, for example, in maintenance paints and finishes; container, pipe and tank linings; heavy-duty floor and wall coatings for masonry, steel, and wood surfaces.

Because of their combination of properties epoxy resins are used in a number of heavy-duty applications in building and construction; for mar and wear-resistant terrazzo, industrial flooring, and for filling potholes and repairing cracks on highways and bridges. Owing to good bonding properties and low shrinkage during curing, epoxies are used in the fabrication of interior and exterior wall panels made with exposed aggregate (for example, with glass chips, marble).

Epoxies are used for making electrical parts by casting, for potting and encapsulating electrical components. Epoxy moulding compounds are also available and may be processed by injection, transfer moulding, etc; applications include packaging of electronic components and pipe fittings.

Unsaturated Polyesters

Polyesters are polymers that contain ester groups,



in the main chain. Conventional, general-purpose, unsaturated polyesters are produced by reaction of polypropylene glycol with a mixture of maleic and phthalic anhydrides. The molecule of the resulting polymer contains double bonds, (C=C), also called unsaturated bonds, from which the name unsaturated polyester has been derived. Various unsaturated vinyl-type monomers can be added as cross-linking agents to convert the unsaturated polyester to a thermosetting material. Styrene is most frequently used because of its low cost, availability, and the physical properties of the resulting product; and methyl methacrylate (acrylic modified polyester) used in conjunction with styrene will improve weatherability.

The most important advantages of unsaturated polyester resin systems include ease of handling, rapid curing with no volatile by-products, light colour, dimensional stability, and generally good physical and electrical properties. Applications of unsaturated polyester-based thermosetting plastics are many and include building and construction components, transportation applications, fabrication of electrical parts, consumer products and anti-corrosive materials.

In building construction, corrugated and flat sheets made from glass-fibre-reinforced polyester (GRP) are used for roofs, awnings, skylight domes, partitions, wall siding, decorative fixtures, fences, bathroom accessories, surfacing of concrete floors. Transportation applications include passenger car parts and bodies, truck cabs, and tank trucks.

Unsaturated polyester thermosets are, in general, good insulating materials for electrical applications and are often used with glass fibre as reinforcement. Consumer products include diverse articles such as luggage, chairs, fishing rods, cafeteria trays, pipes and ducts, and boat hulls. GRP is also used in fabricating pipes, tanks, ducts, grids and baffles for corrosive environments.

Articles and structures based on general-purpose unsaturated polyester resin have only limited resistance to chemical degradation. By modification of the basic resin and proper formulation, chemical resistance can be dramatically improved. Unsaturated polyester resin can also be

successfully formulated to yield good fire-retardant materials. The performance of articles (or structures) made for outdoor application from general-purpose GRP by present-day technology is fair. Compounds, formulations and techniques are available for making materials with better, even excellent, weathering resistance, but these materials are very expensive.

Phenolics

Most important among the phenolic plastics are those based on polymers produced by the reaction of phenol with formaldehyde. Basically, phenolic plastics are compositions of resol or novolac resins, various fillers, colouring agents, lubricants and plasticizers designed either for general use or for specific applications. The general purpose grades are usually filled with wood flour and other low-priced fillers to reduce cost and provide a balance of good insulation and strength. The finished article can have high gloss, but colours are limited by the tendency of phenolics to darken with age and exposure. Applications include appliance parts, wiring devices, switchboards and automotive parts.

Heat-resistant phenolic compounds contain mineral fillers such as diatomaceous earth, mica and asbestos. Some can withstand intermittent exposure to temperatures up to 260°C (500°F) without impairment of the finish or physical properties. Typical applications include handles on kitchen utensils, parts for appliances and ovens, and electrical switch gear. Impact-resistant compounds contain fibrous reinforcing materials such as cotton, glass, synthetic flock, and special grades of asbestos.

Phenolics are particularly suitable for electrical applications because of their good dielectric properties, dimensional stability and resistance to moisture. Phenolic-based compounds are used in laminating applications, for example, for decorative laminates for counter tops and wall coverings. A number of industrial applications, including heat setting adhesives, abrasive wheels, and sandpaper, are possible owing to their good adhesive properties and bonding strength. Phenolics are also used in varnishes and protective coatings.

Urea-Formaldehydes (Ureas) and Melamine-Formaldehydes (Melamines)

These thermosetting plastics, also called amino resins because they are produced by the reaction of amines, or compounds bearing the amino group ($-NH_2$), with formaldehyde, are clear and colourless, a distinct advantage over the phenolics. They also have better hardness and tensile strength than phenolics, but their impact strength and moisture resistance are lower. Ureas have lower hardness, heat resistance and moisture resistance than melamines.

Amino resins are used in the fabrication of industrial and decorative laminates, adhesives, protective coatings, paper manufacture, and moulding compounds. Melamine is one of the thermosetting plastics that can be made in unlimited colours. Articles fabricated from melamines are rigid and have one of the hardest surface finishes of any plastic material. Because of this they are widely used for the production of decorative laminates, which are usually assembled from a core of phenolic resin-impregnated paper and a melamine impregnated overlay sheet. The system is cured with hot pressing to produce such items as counter, cabinet or table tops.

Alkyds

The name of this family of thermosets is derived somewhat freely from the monomers used to produce the basic resin, the "al" from alcohol and the "cid" from acid. Currently, there are many commercial alkyd resins modified with epoxy resin, phenolic resin, rosin, fatty acids derived from mineral and vegetable oils, etc. A combination of interesting properties and moderate cost makes alkyd thermosetting resins and their modifications very attractive for certain applications, especially in coatings and moulding applications (in the automotive, electrical and electronic industries, for example). Their properties include durability, flexibility, gloss retention, reasonable heat resistance, good colourability and dimensional stability and good electrical properties.

Reference

1. Guide to Plastics, by the Editors of Modern Plastics Encyclopedia, McGraw Hill, Inc., New York, 1970.