# Plastics
## edition 8

# Thermoplastics and Thermosets

**desk-top data bank®**

**D.A.T.A., INC.**
a Cordura Company

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Property values reported in this publication should be used as a guide to the performance of the materials, not as specification data upon which designs can be based. In all cases, we recommend that you consult with the manufacturer before final selection of the plastic is made.

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## Thermoplastics and Thermosets

## a desk-top data bank®

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**PUBLISHER'S FOREWORD**

I.P.S. has actively sought out, researched, and compiled technical data from leading U.S. producers of thermoplastics & thermosets. This information, currently residing in our data bank, is presented here in book form as a convenient reference source. By utilizing the appropriate index(es), or ranked listing, or principal property section you will be able to locate additional relevant information on the plastic you require.

Please read the "How to Get the Most Out of This Book" section. This will help you determine the best starting point for your search. We also suggest that you read the introductory paragraphs before each main section of the book to get a more complete understanding of how the information is presented.

All of the data in this publication is in our computer data base. Please call 619/578-3910 for information on leasing magnetic tapes of the data, or on how to access and search the file via an on-line computer system.

We invite all subscribers to this publication to contact us with any new or revised industry data that can be incorporated into the next edition of Plastics. Thank you.

# How to Get the Most Out of this Book

# Notes on Properties, Units, and How Data are Listed

| Property | Significance/Comments | Units: English | Units: Metric | ASTM Test |
|---|---|---|---|---|
| Processing Methods | The kind of processing (extruding, molding, casting, etc.) techniques recommended by the manufacturer. | | | |
| Processing Temperature | An average value is given rather than the temperature range often specified by the manufacturer. | °F | °C | |
| Injection Molding Pressure | The pressure applied to the cross-sectional area of the molding cylinder. | lb/in² | kg/cm² | |
| Linear Mold Shrinkage | The difference between the size of the part and the size of the mold cavity. Values given are often the average of a range. | in/in | in/in | D955 |
| Melt Flow | Rate of extrusion of molten resin through a die of a specified length and diameter. The conditions of the test (e.g. temperature and load) should be given. Frequently, however, the manufacturers' data lists only the value, not the condition as well. | g/10 min | g/10 min | D1238 |
| Density | The equivalent property to specific gravity; measured by displacement. | lb/ft³ | g/cm³ | D792 |
| Tensile Strength, Yield | The maximum stress that a material can withstand without yielding when subject to a stretching load. | lb/in² | kg/cm² | D638 |
| Tensile Strength, Break | The maximum stress that a material can withstand without breaking when subjected to a stretching load. | lb/in² | kg/cm² | D638 |
| Elongation, Yield | The increase in distance between two gauge marks at a yield point divided by the original distance between the marks. A zero value in the field indicates that it measured less than one. | % | % | D638 |
| Elongation, Break | The increase in distance between two gauge marks at the break point divided by the original distance between the marks. A zero value in the field indicates that it measured less than one. | % | % | D638 |

| Property | Significance/Comments | Units | | ASTM Test |
|---|---|---|---|---|
| | | English | Metric | |
| Tensile Modulus | (Also called modulus of elasticity). The ratio of nominal stress to the corresponding strain below the proportional limit of a material. | lb/in² | kg/cm² | D638 |
| Flexural Strength, Yield | The measure of resistance of the material to fracture during bending. | lb/in² | kg/cm² | D790 |
| Flexural Modulus | The ratio, within the elastic limit, of the applied stress on a test specimen in flexure to the corresponding strain in the outermost fibers of the specimen. | lb/in² | kg/cm² | D790 |
| Compressive Strength | The ability of a material to resist a force that tends to crush it. | lb/in² | kg/cm² | D695 |
| Izod, Notched, RT | The energy required to break specimens in which there is a v-notch to create an initial stress point (The value 999 in the tables indicates that the specimen did not break.) | ft lb/in | kg cm/cm | D256 |
| Izod, Notched, LT | The energy required to break specimens in which there is a v-notch to create an initial stress point but measured at low temperature (minus 40°C). (The value 999 in the tables indicates that the specimen did not break.) | ft lb/in | kg cm/cm | D256 |
| Hardness | The resistance of a material to compression, indentation and scratching. There are several scales, and the data in the book gives both the scale used and the value on it. | | | |
| Thermal Conductivity | The rate of heat flow under steady-state conditions through unit area per unit temperature gradient in a direction perpendicular to an isothermal surface. | BTU in/ hr ft² °F | cal cm/ sec cm²°C | C177 |
| Linear Thermal Expansion | The fractional change in length of a material for a unit change in temperature. | in/in °F | cm/cm °C | D696 |
| Vicat Softening Point | The temperature at which a flat ended needle will penetrate a specimen under a specified load using a uniform rate of temperature rise. | °F | °C | D1525 |
| Brittle Temperature | A measure for judging the relative merits of materials for low temperature flexing or impact - i.e., the temperature at which materials rupture by impact under specified conditions. | °F | °C | D746 |

| Property | Significance/Comments | Units English | Units Metric | ASTM Test |
|---|---|---|---|---|
| Continuous Service Temperature | The highest temperature at which a material can perform reliably in a long term application - long term being, however, inconsistently defined by the manufacturers. | °F | °C | |
| Deflection Temperature, 264 lb/in² | The measure of temperature at which a specimen deflects 0.01 inches under a load of 264 lb/in². | °F | °C | D648 |
| Deflection Temperature, 66 lb/in² | The measure of temperature at which a specimen deflects 0.01 inches under a load of 66 lb/in². | °F | °C | D648 |
| U.L. Temperature Index | The maximum temperature below which a material maintains its electrical and mechanical integrity over a reasonable period. | °C/mm | | |
| Volume Resistivity | The measure of ratio of the potential gradient parallel to the current in the material to the current density. | Ohm cm | | D257 |
| Surface Resistivity | The ratio of the potential gradient parallel to the current along its surface to the current per unit width of the surface. | Ohm | | D257 |
| Dielectric Strength | The voltage that an insulating material can withstand before dielectric breakdown occurs. | $V/10^{-3}in$ | V/mm | D149 |
| Dielectric Constant | The ratio of the capacity of a condenser made with a particular dielectric material to the capacity of the same condenser with air as the dielectric. Measured at a frequency of $10^6$ cycles per second. | Constant | | D150 |
| Dissipation Factor | The ratio of the power dissipated in watts in an insulating material to the product of the effective voltage and the current. Measured at a frequency of $10^6$ cycles per second. | Constant | | D150 |
| Refractive Index, Sodium D | The ratio of the velocity and light in a vacuum to its velocity in the material. | Constant | | D542 |
| Water Absorption, 24 hours | The percentage of water absorbed by a material when immersed in water for 24 hours; water absorbed in a material chiefly affects its electrical properties. | % | | D570 |
| Effect of Strong Acids | A descriptive notation to indicate the material's performance. | Text | | D543 |

Note 1 - Please see the fuller descriptions of ASTM tests for more information on test procedures (pages A113).

Note 2 - Please note that a given plastic in this publication will have data presented on only 23 of the above 30 properties.

Note 3 - We list average values rather than ranges in order to make comparisons more easy to make, both visually and in computer-based search systems. Frequently we take a manufacturer's range and give its average value.

Note 4 - Frequently it is clear from the property values of a plastic that a filler is present, even though the manufacturer does not list what it is. In these instances we have indicated that the material contains "Unspecified Filler".

# Common Acronyms

- **ABS** Acrylonitrile-butadiene-styrene
- **ACS** Acrylonitrile chlorinated polyethylene and styrene
- **API** Addition-reaction polyimides
- **ASA** Acrylic-styrene-acrylonitrile
- **BMC** Bulk-molding compound
- **CA** Cellulose acetate
- **CAB** Cellulose acetate-butyrate
- **CAP** Cellulose acetate-propionate
- **CPE** Chlorinated polyethylene
- **CPI** Condensation-reaction polyimides
- **CPVC** Chlorinated polyvinyl chloride
- **CTFE** Polymonochlorotrifluorethylene
- **DAP** Diallyl phthalate
- **EC** Ethyl cellulose
- **ECTFE** Ethylene-chlorotrifluorethylene
- **EMA** Ethylene-methyl acrylate
- **EP** Ethylene propylene
- **ESCR** Environmental stress crack resistance
- **ETFE** Ethylene-tetrafluorethylene
- **EVA** Ethylene-vinyl acetate
- **FDA** Food & Drug Administration
- **FEP** Fluorinated ethylene-propylene
- **FR** Fiber reinforced
- **FRP** Fiber-reinforced plastics
- **HDPE** High-density
- **HIP** High-impact polystyrene
- **HM** High-modulus
- **HMC** High-strength molding compound
- **HME** High-vinyl modified epoxy
- **HMW** High molecular weight
- **IPN** Interpenetrating polymer network
- **LCP** Liquid crystal polymer
- **LDPE** Low-density polyethylene
- **LIM** Liquid injection molding
- **LLDPE** Linear low-density polyethylene
- **LMC** Low-pressure molding compound
- **LMW** Low molecular weight
- **MA** Maleic anhydride
- **MBS** Methacrylate-butadiene-styrene
- **MDPE** Medium-density polyethylene
- **MMA** Methyl methacrylate monomer
- **MW** Molecular weight
- **PA** Polyamide (nylon)
- **PAI** Polyamide-imide
- **PAN** Polyacrylonitrile
- **PB** Polybutylene
- **PBT** Polybutylene terephthalate
- **PBTP** Polybutylene terephthalate
- **PC** Polycarbonate
- **PCTFE** Polychlorotrifluoroethylene
- **PE** Polyethylene
- **PEC** Polyphenylene ether copolymer
- **PEEK** Polyetherether ketone
- **PEH** Polyphenylene ether homopolymer
- **PEI** Polyetherimide
- **PEO** Polyethylene oxide
- **PES** Polyethersulphone
- **PET** Polyethylene terephthalate
- **PETP** Polyethylene terephthalate
- **PF** Phenyl-formaldehyde
- **PFA** Perfluoroalkoxy (resin)
- **PI** Polyimide
- **PIB** Polyisobutylene
- **PIE** Polysiobutylene
- **PMMA** Polymethyl methacrylate
- **PMS** Paramethylstyrene
- **PMT** Polymethylpentene
- **PP** Polypropylene
- **PPO** Polyphenylene oxide
- **PPS** Polyphenylene sulfide
- **PS** Polystyrene
- **PTFE** Polytetrafluoroethylene
- **PU** Polyurethane
- **PVC** Polyvinyl chloride
- **PVDF** Polyvinylidene fluoride
- **PVF** Polyvinyl fluoride
- **RH** Rockwell hardness
- **RH** Relative humidity
- **RIM** Reaction injection molding
- **RP** Reinforced plastics
- **RTM** Resin-transfer molding
- **SAN** Styrene-acrylonitrile
- **SMA** Styrene maleic anhydride
- **SMC** Sheet molding compound
- **TFE** Polytetra fluorethylene
- **TMC** Thick molding compound
- **TPE** Thermoplastic elastomers
- **TPU** Thermoplastic polyurethane
- **UF** Urea-formaldehyde
- **UHM** Ultrahigh-modulus
- **UHMW** Ultra-high molecular weight
- **UL** Underwriter's Laboratories
- **UV** Ultraviolet
- **VAE** Vinyl acetate-ethylene

# Table of Contents

# dexes

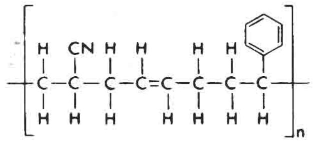
# Survey of Generic Types

This section presents brief descriptions of generic types of plastics that are commonly used in molding and extruding applications. Each description includes the history of the plastic's development, its chemical structure and a summary of the plastic's advantages and limitations.

The following generic types of plastics are described, or made reference to, in this section. There is a close but not exact correspondence between these descriptions and the generic types used in the main sections of the book.

ABS (ABS/PC, ABS/Polysulfone, ABS/PVC)
Acetal
Acrylic
Alkyd
Allylic Esters or Allyls (DAP)
Cellulosic Esters
Chlorinated Polyalkylene Ether
Cyanate/Cyanamide
Epoxy (Brominated Epoxy, Cycloaliphatic Epoxy, Epoxyimide)
Furan
Melamine-Formaldehyde, Urea-Formaldehyde,
  Casein-Formaldehyde
Phenolic
Poly (bis-maleimide)
Polyalkylene Ether
Polyamide (Nylon)
Polyarylene Ether (Phenylene Oxide)
Polybutadiene (1,2)
Polybutylene
Polycarbonate
Polyester (Saturated) (PETP, Polyterephthalate)
Polyester (Unsaturated)
Polyethylene (C-1 Polyethylene, Ionomer, Polyallomer)
Polyfluorocarbon:
  Fluorinated Ethylene-Propylene (FEP)
  Perfluoroalkoxy (PFA)
  Polychlorotrifluoroethylene (CTFE)
  Polytetrafluorethylene (TFE)
  Polyvinylfluoride (PVF)
  Polyvinylidene Fluoride ($PVF_2$)
Polyimide (Polyamid -imide)
Polyphenylene
Polyphenylene Sulfide
Polypropylene
Polystryrene
Polysulfone (Polyether Sulfone, Polyphenylene Sulfone)
Polyurethane
Polyvinyl Acetate
Polyvinyl Chloride
Polyvinyl Chloride-Vinylidene Chloride

## ABS



This material is a terpolymer of acrylonitrile, butadiene and styrene. Usual compositions are about half styrene with the balance divided between butadiene and acrylonitrile. Considerable variation is, of course, possible. Many blends with other materials such as polyvinylchloride, polycarbonates and polysulfones have been developed and are the most common class of plastics used in electroplated metal coatings for decorative hardware.

### ADVANTAGES

Good impact resistance with toughness and rigidity

Metal coatings have excellent adhesion to ABS

Formed by conventional thermoplastic methods

A light-weight plastic

### DISADVANTAGES AND LIMITATIONS

Poor solvent resistance

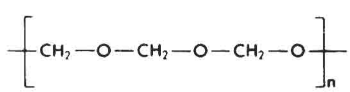
Low dielectric strength

Only low elongations available

Low continuous service temperature

**Typical Applications:** Automotive hardware, appliance cases, pipe, plated items.

## Acetal



This polymer class was first introduced in 1956 and has achieved important application because of a good profile of properties. Two types of acetals are available including a homopolymer (Du Pont's Delrin) and a copolymer (Celanese's Celcon).

### ADVANTAGES

High tensile strength with rigidity and toughness

Glossy molded surfaces

Low static and dynamic coefficients of friction

Retains electrical and mechanical properties up to 250°F

Low gas and vapor permeability

### DISADVANTAGES AND LIMITATIONS

Poor resistance to acids and bases

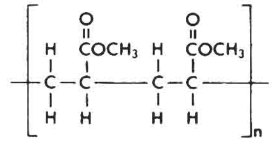
Subject to UV degradation

Flammable

Difficult to bond

**Typical Applications:** Automotive applications in place of die-cast metals, slides, rollers, gears and cams.

## Acrylic



Most acrylics are polymers of methyl methacrylate (PMMA). The cost of acrylic is intermediate, with the average price falling between the more expensive cellulosics and PVC.

### ADVANTAGES

Excellent optical clarity

Excellent weatherability and resistance to sunlight

Rigid, with good impact strength

Excellent dimensional stability and low mold shrinkage

Stretch forming increases bi-axial toughness

### DISADVANTAGES AND LIMITATIONS

Poor solvent resistance; attacked especially by ketones, esters, chlorocarbons and aromatic hydrocarbons, freons.

Subject to stress cracking

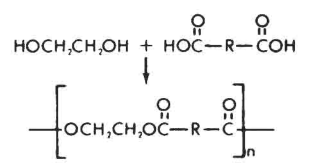
Combustible

Continuous service temperature limited to about 200°F

Flexible grades unavailable

**Typical Applications:** Transparent items such as lenses, automotive trim, household items, light fixtures and decorator items, conformed coatings for printed wiring boards.

## Alkyd



Alkyds are formed by the reaction of polyhydroxy compounds with dibasic acids. Many structural variations are possible.

Perhaps one of the most important variations is brought about by the use of an unsaturated acid such as maleic acid. The resulting unsaturation in the polymer backbone can be utilized to crosslink the polymer and form a thermoset resin. Systems which are produced by reaction of saturated alcohols and acids are thermoplastic and are usually used in solution typically for coatings.

### ADVANTAGES

One of the most inexpensive resin types available.

Wide structural variations possible.

May be thermosetting.

Sometimes modified with styrene or acrylic monomers.

Very suitable for fiberglass composites.

### DISADVANTAGES

Chemical resistance is marginal.

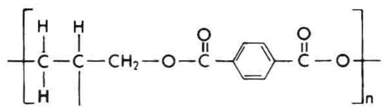
## Alkyd (Cont.)

Shrinkage during cure is high (unsaturated types).

Solvent resistance of thermoplastic types is poor.

**Typical Applications:** Boat hulls and other fiber reinforced items, sheet molding compounds, coatings and filled molding compounds.

## Allylic Esters or Allyls



These materials are commonly supplied as "B" staged prepolymers, such as diallyl phthalate (DAP) or diallyl isophthalate and are cured by peroxides to yield thermoset resins. Other variations include trifunctional diallyl maleate (DAM), triallylcyanurate (TAC) and transparent allyl carbonate.

### ADVANTAGES

Excellent moisture resistance

Low burning and self-extinguishing grades are available

Service temperatures as high as 400-450°F

Good chemical resistance

### DISADVANTAGES AND LIMITATIONS

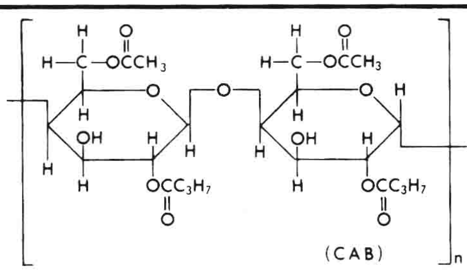
More expensive than alkyds

High shrinkage during curing

Not recommended for use in contact with phenols and oxidizing acids

**Typical Applications:** Electronic connectors, appliance handles, automotive distributor caps — frequently molded by transfer or simple compression molding, transformer cases.

## Cellulosic Esters



(CAB)

Cellulose nitrate, over one hundred years old, is man's first successful effort in modifying a natural polymer to improve processability. Celluloid and pyroxylin were two forms of this resin used in many moldings and coated articles. Also known as gun cotton, it is rarely used today in plastic articles because of its high flammability. It has been largely displaced in thermoplastic applications by organic acid esters of cellulose such as acetates, propionates and butyrates.

### ADVANTAGES

Forms glossy moldings by conventional thermoplastic methods

Tough materials even at low temperatures

Non-petrochemical base

Wide processing characteristics available

Resists stress cracking

Has good "feel" due to low specific heat and low conductivity

### DISADVANTAGES AND LIMITATIONS

Poor solvent resistance

Poor resistance to alkaline materials and fungus

High moisture pick-up and high permeability

Compressive strength tends to be low

Flammable

**Typical Applications:** Telephone and appliance cases, automotive steering wheels, pens and pencils.

## Chlorinated Polyalkylene Ether

These chloro-polymers have a unique characteristic among chlorine-containing polymers in that there is no hydrogen on the carbon atom adjacent to the halogen. As a result the polymer is more thermally stable than other chlorine-containing structures because of the reduced tendency to lose hydrogen chloride.

### ADVANTAGES

Good chemical resistance

Servicable up to 140°C

Greater thermal stability than other chlorinated resins

### DISADVANTAGES AND LIMITATIONS

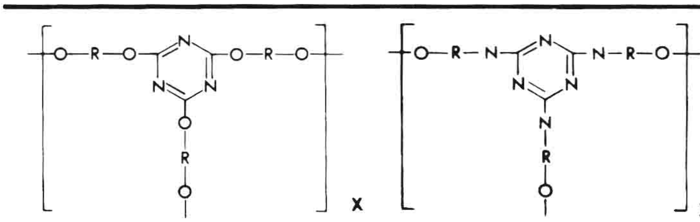
Extremely limited availability

Comparatively high cost

Low impact strength

**Typical Applications:** Pipe and chemical-processing equipment.

## Cyanate/Cyanamide



Introduced in the early 1970's, these resins represent a future alternative to epoxy resins. The monomers essentially trimerize to form thermosetting modified triazine structures with capability up to 450°F. They are addition polymers and consequently hold promise as adhesive and composite matrix resins.

### ADVANTAGES

No volatiles evolved during cure (epoxy alternative)

Temp. capability to 450°F

Excellent adhesion

### DISADVANTAGES AND LIMITATIONS

High shrinkage during cure

## Cyanate/Cyanamide (Cont.)

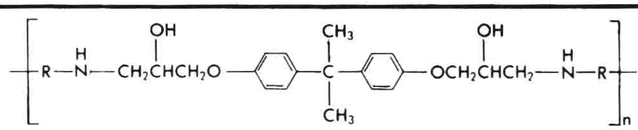
Very small data base and considered still developmental

Limited availability

Comparatively high cost

**Typical Applications:** Adhesives and composites including printed circuit boards.

## Epoxy



Epoxy resins are available in a wide variety of thermosetting structures and curing-agent variations. Physical properties can thus be varied over a wide range of rigidity and flexibility. Since their introduction in the late 40's and early 50's, the market has expanded to over 100 million pounds per year. This group of resins form the foundation for the structural adhesives industry, as well as being used extensively in fiber reinforced composites.

A number of epoxy resins are now available which are nonflammable due to introduction of bromine in aromatic ring substitution. Also, a few hybrids have been introduced such as epoxy urethanes and epoxyimides.

In addition to older glycidyl ether types, newer cycloaliphatic types have been produced which are synthesized by the epoxidation of the corresponding olefin, usually by peracetic acid. They differ from glycidyl ether types in that amine cures are usually not suitable and they are polymerized by anhydride cures.

### ADVANTAGES

Convenient range of cure conditions from RT to 350°F

No volatiles formed during cure

Excellent adhesion

Suitable for all thermosetting processing methods

### DISADVANTAGES AND LIMITATIONS

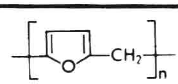
Poor oxidative stability and some moisture sensitivity

Thermal stability limited to 350°-450°F

Specialty grades are comparatively expensive

**Typical Applications:** Adhesives, electonics encapsulation, composites and printed circuit boards, coatings, solder maskants.

## Furans



By acid catalysis, furfural or furfuryl alcohol will condense to form thermosetting resins with very good chemical, solvent and temperature resistance. Resins crosslink through unsaturation in the furan ring.

### ADVANTAGES

Produced from non-petrochemical sources.

Excellent chemical resistance

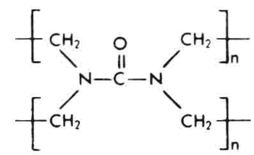
### DISADVANTAGES AND LIMITATIONS

Difficult to process, limited to fiber-reinforced plastics

Attacked by halogens

**Typical Applications:** Chemical processing towers, tanks and pipe for use in corrosive environments.

## Melamine-Formaldehyde, Urea-Formaldehyde, Casein-Formaldehyde



These similar comparatively inexpensive thermosetting resins are frequently referred to as aminos or amino plastics. They are formed by condensation of melamine, urea or casein with formaldehyde, resulting in a highly crosslinked resin which is similar to a phenolic in utility.

### ADVANTAGES

Good Hardness and Scratch resistance

Comparatively low cost

Wide range of colors possible

Self extinguishing

Solvent resistant, including hot water

### DISADVANTAGES OR LIMITATIONS

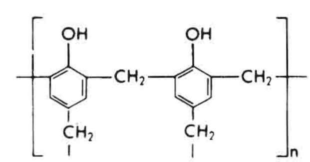
Must be filled for successful molding

Long-term oxidation resistance is poor

Attacked by strong acids and bases

**Typical Applications:** Electrical insulators, tableware, buttons

## Phenolic



Phenolics, discovered in 1904 by George Backeland, is one of the oldest types of thermosetting resins. Phenolics now are considered the work-horse of the plastics industry. Usually, the resin is extended by combining with a filler. The resin is highly crosslinked.

### ADVANTAGES

Comparatively low cost

Thermoset resin suitable for use as high as 400°F

Excellent solvent resistance

High modulus (rigid)

Good compressive strength

High resistivity

Self-extinguishing

### DISADVANTAGES AND LIMITATIONS

Requires fillers for moldings