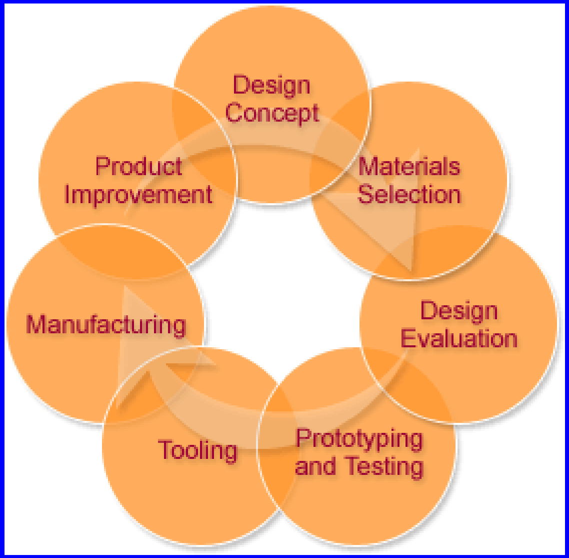
Applied Plastics Product Design - Workshop

Material Selection and Datasheet Interpretation



October 12, 2006

Vishu Shah

Consultek

Material Selection Process

Understanding Material Basics

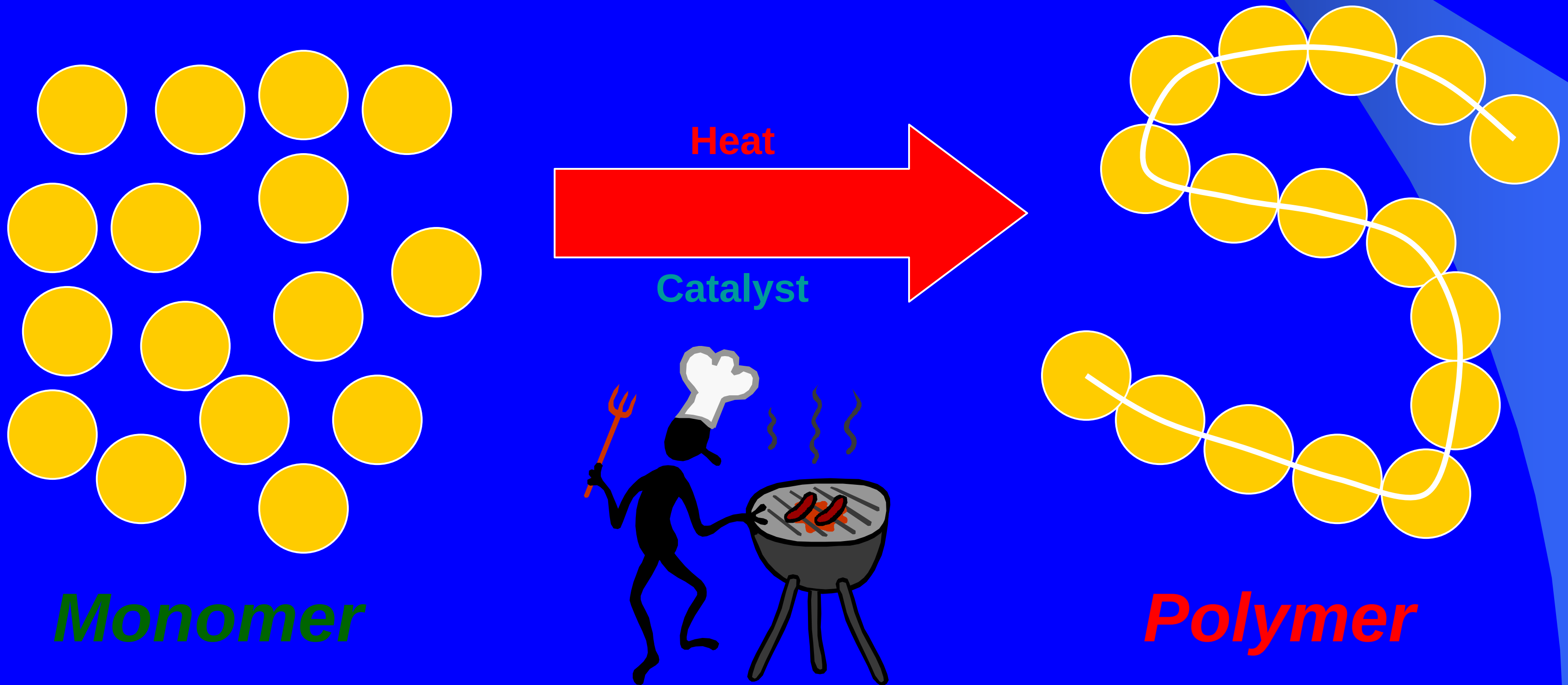
- Structure
- Properties
- Applications

Polymer Structure

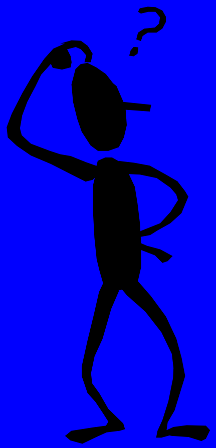
- Polymer chemistry
- How are polymers derived?
- How do they differ in their structure?
- PE vs. PS vs. Polyester vs. Phenolics
- Thermoplastics vs. Thermoset
- Crystallinity
- Branching
- Mechanical effects of structure

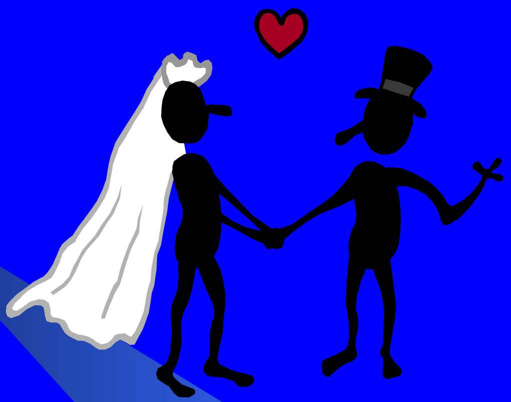
Polymers

Chemical compounds formed when many small chemical units (***monomers***) combine to form large molecules with a regular repeating structure.



Families of Polymer Materials

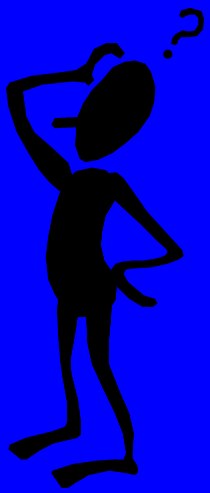




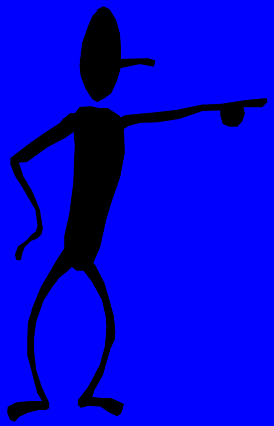
Polymers

- **Thermosets** (Cannot be melted)
  - (Phenolics, epoxies, etc.)
- **Thermoplastics** (Can be melted)
  - **Semi-Crystalline** (Structured)
    - (Polyethylene, PET, nylon, etc.)
  - **Amorphous** (No structure)
    - (Polystyrene, polycarbonate, etc.)

Polymers



What Molecular Factors Control the Solid and Melt Properties of Polymers?



1.) *Chemical Composition*

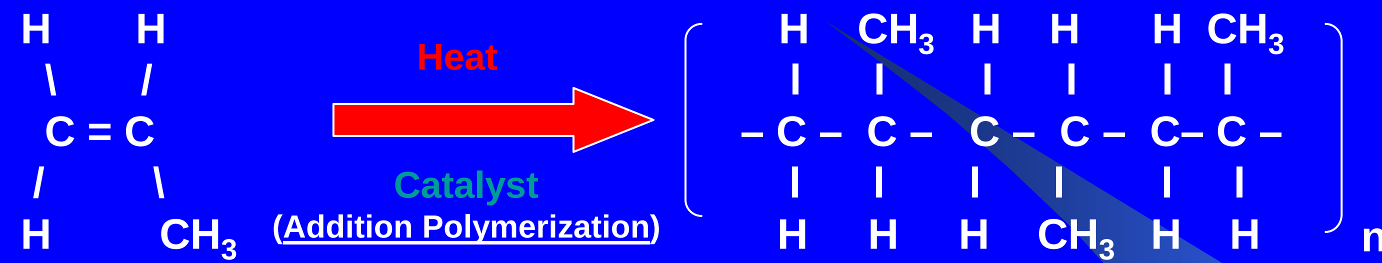
2.) *Size of the Molecules*

3.) *Shape of the Molecules*

4.) *Organization of the Molecules*

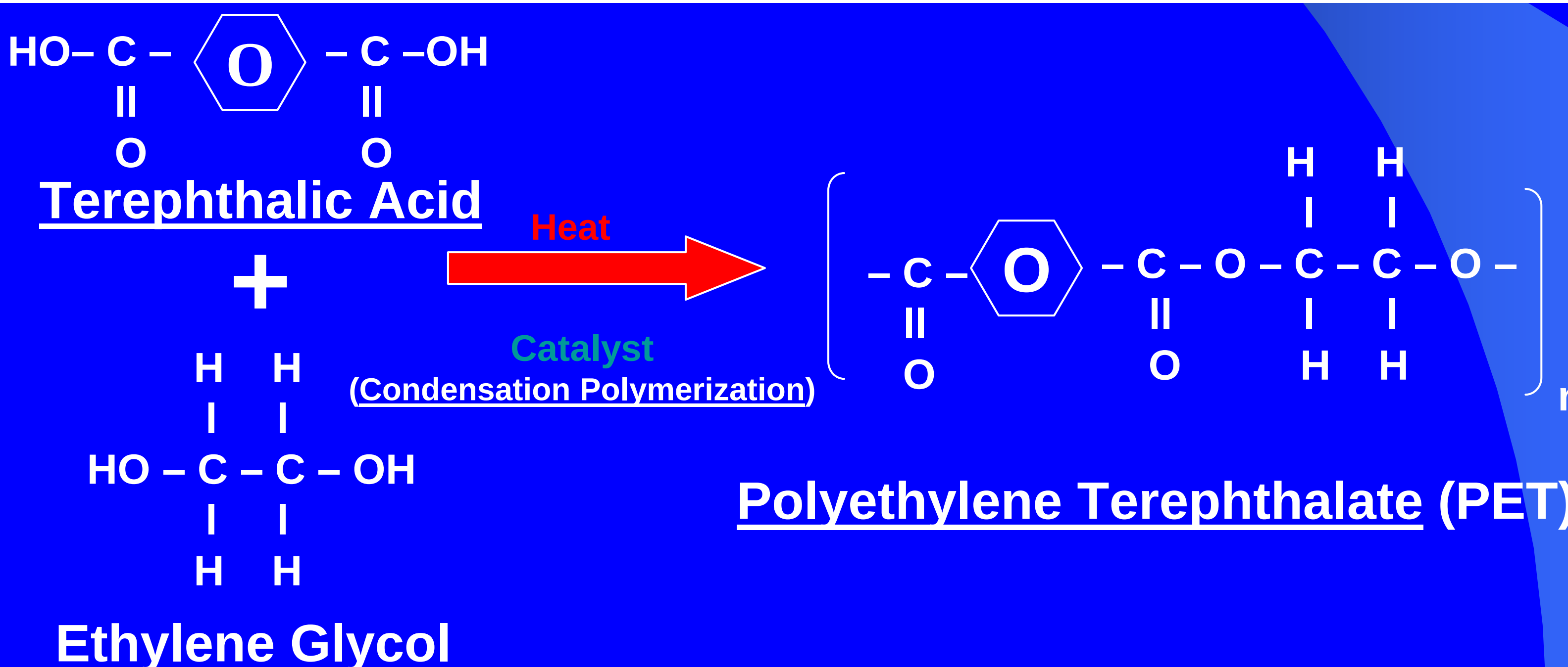
Polymers

Chemical Composition



Propylene

Polypropylene (PP)



Polyethylene Terephthalate (PET)

Polymers

Size of the Molecules

Methane = CH_4 $\downarrow$ Gas

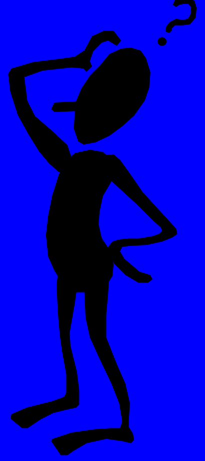
Octane = C_8H_{18} $\downarrow$ Liquid

Paraffin Wax = $C_{50}H_{102}$ $\downarrow$ Solid

Polyethylene = $C_{2000}H_{4002}$ $\downarrow$ Polymer

Polymers

Why Do We Need to Know the Molecular Weight (Size) of the Polymer?!



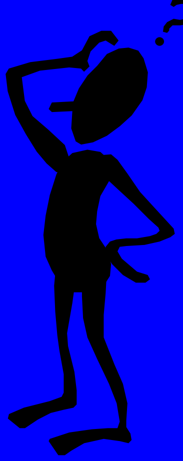
Along with chemical structure, MW determines material properties.

An *<u>increase</u>* in MW generally results in:

Tensile Strength ↑	**Tensile Modulus ↑**
Flexural Strength ↑	**Flexural Modulus ↑**
Elongation ↓	**Creep ↓**
Melt Flow ↓	**Viscosity ↑**
Impact Resistance ↑	**Chemical Resistance ↑**

Polymers

Why Do We Need to Know the Molecular Weight Distribution of the Polymer?!



The MWD also affects material properties.

An *<u>increase</u>* in MWD generally results in:

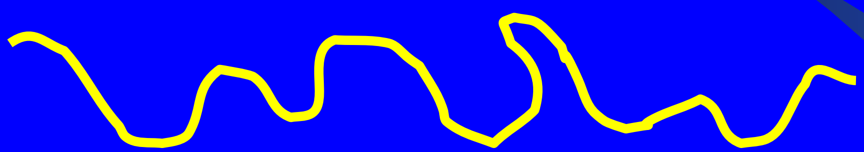
Tensile Strength ↓
Elongation ↑
Fatigue Resistance ↓
"Processability" ↑
Extrudate Swell ↓

Yield Strength ↓
Creep ↑
Melt Strength ↓
Shear Sensitivity ↑
"Shark Skin" Formation ↓

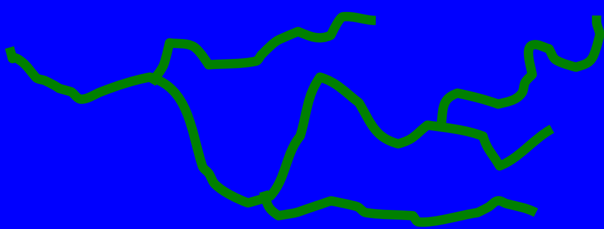
Polymers

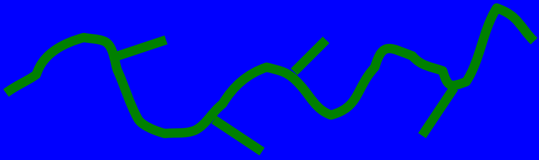
Shape of the Molecules

Linear



Branched

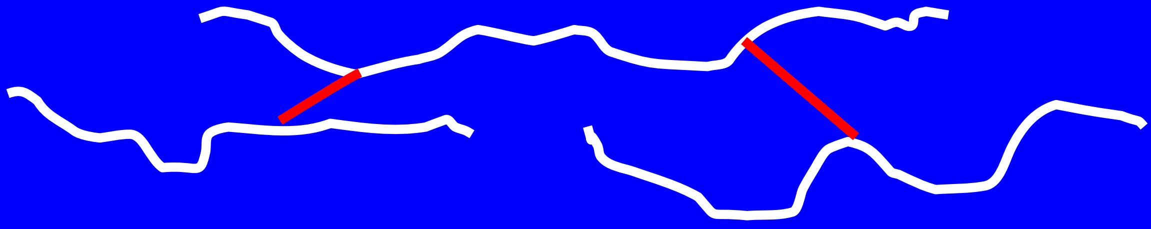




Long-Chain

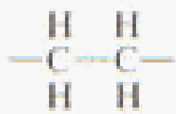
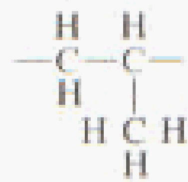
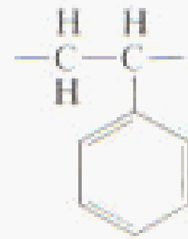
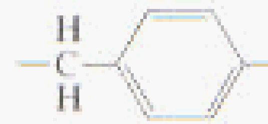
Short-Chain

Cross-Linked



Thermoplastics structure vs.Mechanical properties

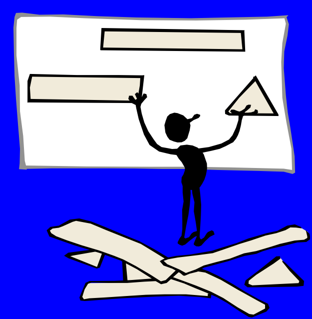
Table 4-4. Thermoplastic Structure vs Mechanical Properties.

	STRAIGHT CHAIN	SIDE GROUPS	SIDE RINGS	RINGS IN BACKBONE
Structure				
Characteristics	Soft, tough, high creep	Hard, tough, medium creep	Hard, brittle, low creep	Hard, tough, low creep
Examples	Polyethylene, TFE	Polypropylene, polymethyl methacrylate, polymethyl pentene	Polystyrene	Linear polyester, polycarbonate, polysulfone

Polymers

Organization of the Molecules

Solid State Structure of *Thermoplastics*



Amorphous

No polymer structure.

Examples: Polystyrene
Polycarbonate
PMMA

Semi-Crystalline

Contains both crystalline (ordered)and amorphous polymer.

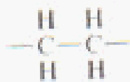
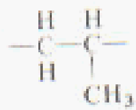
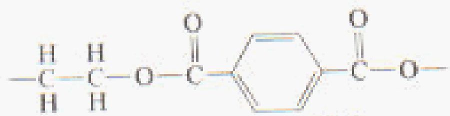
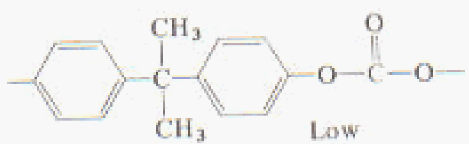
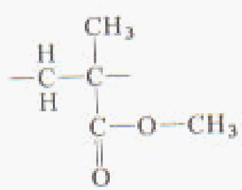
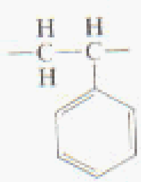
Examples: Polyethylene
Polypropylene
PET
Polyamides (nylon)

Crystallinity and effect on properties

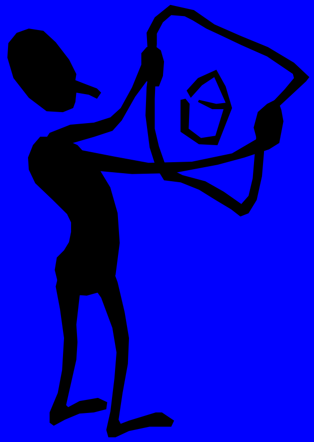
- Transparency and Optical properties
- Mechanical properties
- Thermal properties
- Chemical properties
- Electrical properties

Crystallinity and Transparency

Table 4-3. Crystallinity and Transparency of Polymers.[4]

POLYMER	STRUCTURE	CRYSTALLINITY	TRANSPARENCY
PTFE		High	White opaque
Polyethylene		Medium to High*	Opaque, except in thin films
Polypropylene		Medium	Cloudy
Polyethylene teraphthalate		High	Opaque
Polycarbonate		Low	Clear
Polymethyl methacrylate		Very low	Clear
Polystyrene		Very low	Clear

*Branched (low density) polyethylene is less crystalline and clearer than the linear high density polymer.



Polymers

Material Properties

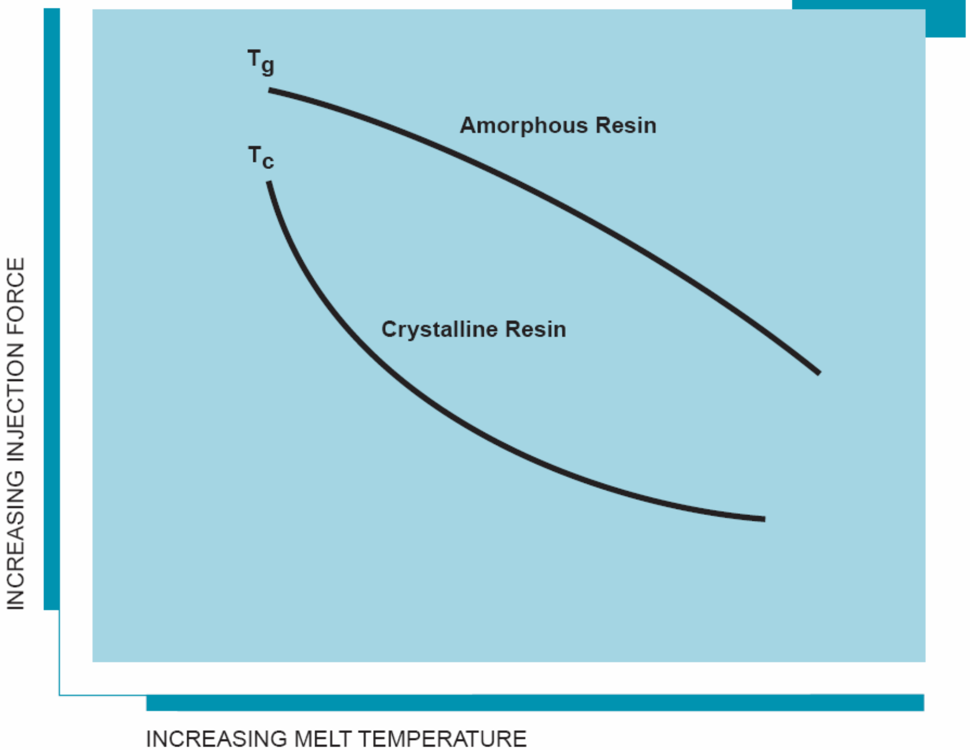
Amorphous Polymers

- Generally clear.
- Depends on polymer chain entanglements for strength.
- No specific melting temperature.
- Low shrinkage on freezing.
- Cooling rate has a moderate effect on properties.
- Orientation has a low to moderate effect on properties.
- Low to medium chemical resistance.

Semi-Crystalline Polymers

- Generally cloudy to opaque.
- Crystallinity provides strength up to the melting temperature
- Specific melting temperature.
- High shrinkage on freezing.
- Cooling rate significantly effects properties.
- Orientation has a strong effect on properties (anisotropic).
- Good to high chemical resistance.

Injection Force vs. Temperature **Figure 1-5**



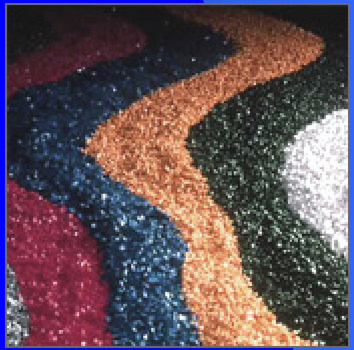
The force required to generate flow in a mold diminishes slowly above the glass transition temperature (T_g) in amorphous thermoplastics, but drops quickly above the crystalline melt temperature (T_c) in crystalline resins.

Because of these easier flow characteristics, crystalline resins have an advantage in filling thin-walled sections, as in electrical connectors.

Source: Bayer

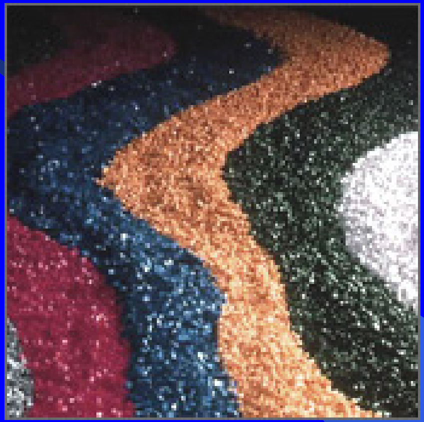
Material Selection Challenge

- Large Data base………50 major types – 500 suppliers – 50,000 Grades
- Standardization issues….Tests, test specimen, testing organizations
- Difficulty in comparing data on equal basis
- Lack of multipoint measurement data
- Overzealous sales and marketing efforts
- Limited educational material availability



Material Selection

Material Selection Pitfalls



- Datasheet interpretation
- Synergistic effects
- Economics
- Supplier Recommendations
- Application checklist

Material Selection Process

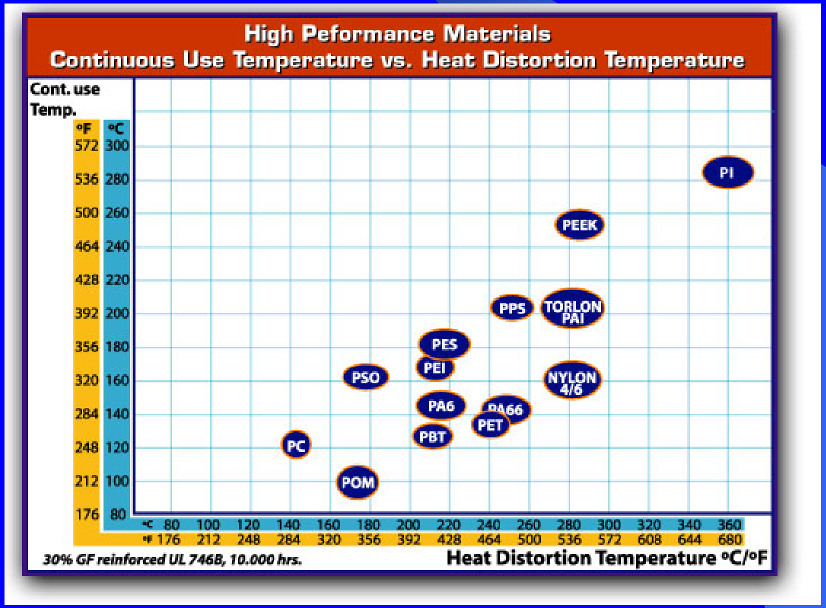
- Define requirements
- Narrow down choices…process of elimination…clear vs. opaque….High Heat
- Rigid, flexible, elastomeric?
- Specific application? Medical?
- Material selection guidelines
- Specific property requirement…

Narrowing the choices

Clear Thermoplastics

- Polystyrene
- Acrylics
- Polycarbonate
- SAN
- Polysulfone
- ASA
- Polyurethane

High Heat



Material Selection Process

- **Identify application requirements**
  Mechanical (Load, Stiffness, Impact etc.)
  Thermal (temperature range, Maximum use temperature, etc)
  Environmental considerations (Weather, UV, Moisture)
- **Identify the chemical environment**
  Define the chemical stress, temperature, contact time, type of chemical
- **Identify special needs**
  Regulatory (UL, FDA, NSF, etc.)
  Outdoor or UV exposure
  Light transmission, Fatigue and creep requirements
- **Define Economics**
- **Define Processing Considerations**
  Type of Process (Injection Molding, Extrusion, Blow Molding, Thermoforming, etc.)
- **Define Assembly requirements**
  Painting/Plating
  Shielding
- **Search history for similar commercial applications**

Identifying Application Requirements

- **Physical Properties**
  Specific Gravity
  Mold Shrinkage
  Rheology

- **Mechanical Properties**
  Tensile Strength
  Tensile Modulus (Stiffness-Resistance to bending)
  Tensile Elongation/Ductility
  Impact strength
  Fatigue Endurance (Resistance to high frequency cyclic loading)
  Creep resistance (Resistance to long-term deformation under load)
- **Thermal Properties**
  Deflection Temperature Under Load (DTUL,HDT)
  Thermal Conductivity
  Thermal expansion coefficient
  Continuous Use Temperature (Relative thermal Index)
- **Regulatory Performance**
  Flammability (UL 94)
  High Voltage Arc Tracking
  FDA

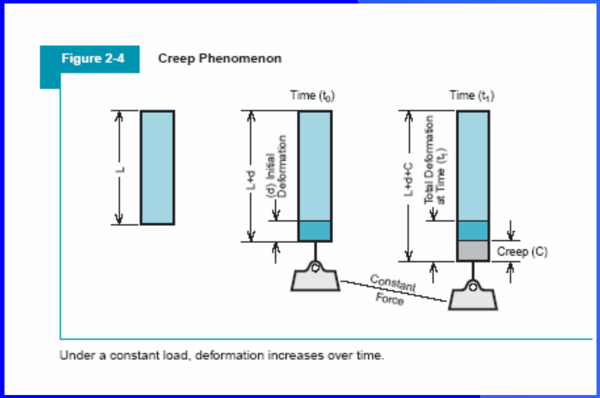


Figure 2-4 Creep Phenomenon
Under a constant load, deformation increases over time.

Source: GE Plastics

Identifying Application Requirements (cont.)

- **Environmental Considerations**

  Exposure to UV, IR, X-Ray
  High humidity
  Weather Extremes
  Pollution: Industrial chemicals
  Microorganisms, bacteria, fungus, mold

The combined effect of the factors may be much more severe than any single factor, and the degradation processes are accelerated many times.

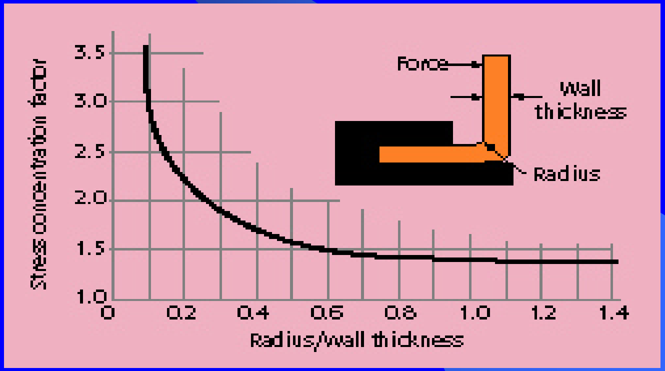
Published test results do not include synergistic effects…always existent in real - life situations.

Identifying Application requirements (Cont.)

- **Chemical Behavior/Chemical resistance**

Resistance of Thermoplastics to various chemicals is dependent on:

- **Time (of contact with chemical)**
- **Temperature**
- **Stress (Molded-in or External)**
- **Concentration of the chemical**



- **Chemical Exposure may result in:**

- **Physical Degradation - Stress cracking, Crazing, Softening, Swelling, Discoloration**
- **Chemical Attack – Reaction of chemical with polymer and loss of properties**

TABLE 7.3 SOME CHOICE MATERIALS

Property	Thermoplastics	Thermosets
Low temperature	TFE	DAP
Low cost	PP, PE, PVC, PS	phenolic
Low gravity	polypropylene methylpentene	phenolic/nylon
Thermal expansion	phenoxy glass	epoxy-glass
Volume resistivity	TFE	DAP
Dielectric strength	PVC	DAP, polyester
Elasticity	EVA, PVC, TPR	silicone
Moisture absorption	chlorotrifluroethylene	alkyd-glass
Steam resistance	polysulfone	DAP
Flame resistance	TFE, PI	melamine
Water immersion	chlorinated polyether	DAP
Stress craze resistance	polypropylene	all
High temperature	TFE, PPS, PI, PAS	silicones
Gasoline resistance	acetal	phenolic
Impact	UHMW PE	epoxy-glass
Cold flow	polysulfone	melamine-glass
Chemical resistance	TFE, FEP, PE, PP	epoxy
Scratch resistance	acrylic	allyl diglycol carbonate
Abrasive wear	polyurethane	phenolic-canvas
Colors	acetate, PS	urea, melamine

EXAMPLES…………ACETAL……PU

HOW DO I MAKE SURE THAT I HAVE CONSIDERED EVERYTHING?

New Application Checklist

This checklist includes critical considerations for new part development.
Its use will help provide a more rapid and more accurate recommendation.

Name ______________________ Date ______________________

Customer ______________________ Part ______________________

Project timing ______________________

Driving force ______________________

Current product ______________________

Its performance ______________________

Comments ______________________

***Part Function** — What is the part supposed to do?* ______________________

Appearance

Clear

- ☐ water clear
- ☐ very clear
- ☐ generally clear, maximum haze level: ________
- ☐ transparent color, maximum haze level: ________

Comments: ______________________

Opaque

- ☐ high gloss
- ☐ medium gloss
- ☐ low gloss
  - ☐ from the plastic ☐ from paint ☐ from the mold

Comments: ______________________

Colors desired: ______________________

☐ from the plastic ☐ from paint ☐ from both

Criticality of color match: ________ %

☐ daylight ☐ tungsten light ☐ fluorescent light ☐ all (no metamerism allowed)

Comments: ______________________

***Critical appearance areas** — please attach sketch*

	None	Invisible	Minor	OK
gate blemishes	☐	☐	☐	☐
sink marks	☐	☐	☐	☐
weld lines	☐	☐	☐	☐

Comments: ______________________

***Critical structural areas** — please attach sketch*

Comments: ______________________

Monsanto Plastics

Where the best end products begin.

***Required physical characteristics** — please attach sketch*

	not too important	from plastic	from design	from both
Rigidity	☐	☐	☐	☐
Strength (load bearing)	☐	☐	☐	☐
Heat resistance	☐	☐	☐	☐
Creep resistance	☐	☐	☐	☐
Impact resistance	☐	☐	☐	☐
Chemical resistance	☐	☐	☐	☐
Electrical properties	☐	☐	☐	☐

Details:

applied load/stress	☐ static load	☐ pressure	☐ cyclic
amount	normal ____	min. ____	max. ____
duration	normal ____	min. ____	max. ____
frequency (if cyclic)	normal ____	min. ____	max. ____
operating temperature	normal ____	min. ____	max. ____
operating lifetime	normal ____	min. ____	max. ____

Comments: ____

____

____

impact resistance

room temp.	acceptable ____	min. ____
low temp., ____ °C/°F	acceptable ____	min. ____

Comments: ____

____

____

dimensional tolerances

deflection (under stress)	acceptable ____	max. ____
expansion (thermal)	acceptable ____	max. ____
shrinkage (mold)	acceptable ____	max. ____
creep	acceptable ____	max. ____

Comments: ____

____

electrical properties

dielectric constant	acceptable ____	min. ____
dissipation factor	acceptable ____	max. ____
volume resistivity	acceptable ____	min. ____
dielectric strength	acceptable ____	min. ____

Comments: ____

____

chemical resistance (List chemicals, frequency & duration of exposure, part stress/strain level, and type of resistance required.)

____

____

____

permanence	not too important	from plastic	from paint, etc.
color stability, indoor	☐	☐	☐
color stability, outdoor	☐	☐	☐
property retention, outdoor	☐	☐	☐

Comments: ____

____

____

***Required physical characteristics** — continued*

miscellaneous

Rockwell hardness target ____ min. ____ max. ____

Others: ____

____

____

Regulatory Approvals Required?

- ☐ Underwriters Laboratory, Inc.
  - ☐ U.L. 94 rating ______ thickness ______
  - ☐ R.T.I. electrical ____ °C mechanical ____ °C with impact ____ °C
- ☐ National Sanitation Foundation type ______
- ☐ Federal Specifications (Mil. Specs.) type ______
- ☐ Canadian Standards Administration type ______
- ☐ Food and Drug Association type ______
- ☐ U. S. Pharmacopeia type ______
- ☐ Automotive Specifications type ______
- ☐ Other: type ______

Comments: ______

Process

- ☐ Extrusion
  - ☐ profile extrusion
  - ☐ sheet extrusion — monolayer
  - ☐ sheet extrusion — co-extruded
  - ☐ thermoforming
  - ☐ extrusion/blow molding

  Comments: ______
- ☐ Injection Molding

  Comments: ______
- ☐ Secondary Operations
  - ☐ decorating
    - ☐ painting
    - ☐ plating
    - ☐ hot stamping
    - ☐ laminating
  - ☐ assembly
    - ☐ gluing
    - ☐ sonic welding
    - ☐ vibrational welding
    - ☐ mechanical assembly

  Comments (What is attached to what, difference in types of plastic, etc.?) ______

Customer Part Testing Requirements

______

Final Comments

______

Why Reinvent the Wheel?

Search history for similar commercial applications

Material Selection

Previous Applications

Before addressing a detailed material selection process, it is often worthwhile to determine if a similar part has been made before, and if so, from which material it was made. If such an application exists, it may be advisable to conduct further investigation into the specifics of the particular application to see whether newer or more appropriate materials can now be used.

Since it is impossible to list all applications – some grades are used for a multitude of parts in many industries – a relatively limited number has been listed.

This Application Matrix provides an overview of some typical applications in some of the numerous market segments served by GE Plastics.

For further information on a particular grade, please contact your local GE Plastics' representative.

Table 1-6. Application Matrix.

Products		Automotive Interior
CYCOLAC ABS Resin	• ease of molding • surface quality • thermal stability • impact resistance • wide range of colors	Instrument clusters and panels; glove box lids; pillar trim; vents, speaker grilles; door liners, pock ets; seat covers and knobs; ash trays; steering column covers; c soles, cladding
CYCOLOY PC/ABS Resin	• ease of molding • very good flow • low temperature impact • very good indoor UV stability • flame resistance	Dashboard components and car ers, center consoles; glove box pillar trim, vents, grilles; air nozz parcel shelves
ENDURAN PBT Resin	• chemical and stain resistance • dimensional stability • low water absorption • very good processibility • noise attenuation	
GELOY ASA Resin	• excellent weatherability • heat resistance • impact resistance • aesthetics, colorability	Dashboard and door skins
GESAN SAN Resin	• clarity • chemical resistance • very good flow • thermal stability	Instrument lenses
LEXAN PC Resin	• transparency • high impact • dimensional stability • temperature resistance • flame resistance	Seat belts; boot panels; speake grilles; dashboard components, instrument panels and clusters, center consoles; heater covers; instrumentation lenses
NORYL Modified PPO Resin	• electrical properties • dimensional stability • hydrolysis resistance • temperature resistance • low water absorption • flame resistance	Dashboards and components, instrument clusters, center con soles; glove boxes, vents, grille ashtrays; panel trim; airducts, a nozzles; steering wheel parts; p cel shelves; roof liners; seats; s belts, armrests, headrests; han winders
NORYL GTX PPE/PA Resin	• on-line paintability • low temperature impact • temperature resistance • chemical resistance • low mold shrinkage	Dashboard components, center consoles; parcel shelf speaker covers; headrest frames; demis rails; heater covers; air nozzles vents, grilles; seat-parts; switc
SUPEC PPS Resin	• chemical resistance • inherent flame resistance • heat resistance • high strength • very good electrical properties	
ULTEM PEI Resin	• chemical resistance • temperature resistance • dimensional stability • inherent flame resistance	
VALOX PBT Resin	• very good electrical properties • chemical resistance • temperature resistance • flame resistance • fast molding	Dashboard components, conne tors instrument clusters; windo cranks, door handles; pillar trin
XENOY PC/PBT Resin	• high impact resistance • chemical resistance • dimensional stability • UV stability	Structural components for das boards and instrument clusters door liners and cladding; boot els; roof liners; seat componen sunroof components; door han

Material Selection

Table 1-6. (Continued)

Products	Appliances	Office Automation	Communication Equipment
CYCOLAC ABS Resin	Bathroom and kitchen appliances; vacuum cleaners, refrigerator door liners and panels, fans; covers, fronts and panels for washing machines; food preparation: mixers, processors, fruit presses; dental showers; lawn mower housings	Components and housings for business machines: computers, copying machines, printers, paper trays, cassettes, calculators; keyboard caps and housings	Telephones: cordless handsets; cassettes; terminals
CYCOLOY PC/ABS Resin	Coffee makers, hairdryers, irons, mixers; shower backplates; control panels; computer housings: terminals, towers, desktops, laptops, notebooks, palmtops; printer housings and components; copier parts	Structural components and housings for business machines: computers, printers, copiers, fax machines	Telephones: portable phones, car phones; telephone racks; modems; fax machine components; franking machines; battery chargers
ENDURAN PBT Resin	Speaker housings; oven handles, iron handles, shaver handles		
GELOY ASA Resin			Outdoor, telecom
GESAN SAN Resin	Small appliances: blender jars, mincer jars, water pitchers, fans	Inkjet cassette housings, clear covers	Inkjet cassette housing, clear covers
LEXAN PC Resin	Chainsaw housings; iron handles, heated combs, hairdryers; food mixers and processors; sewing machines; air filters; mini vacuum cleaners; oven doors; components for dishwasher and laundry washing machines	Structural components for business machines: chassis, frames, covers; paper trays, brackets and supports, card cages, copier internals, disk drives, terminals; barcode scanners; smart cards; cassettes, cartridges	Exchange equipment; switchboards; telephone modems and housings; smart cards
NORYL Modified PPO Resin	Washing machines, dryers, dishwasher components; vacuum cleaners, hairdryers, mixers, coffee makers	Business machine chassis, frames and housings; components for computers, printers, copiers; keyboard parts	Telephone components
NORYL GTX PPE/PA Resin	Laundry washer and dryer doors, top loader frames, powder coatable panels; electrical engine frames; diffusors, gears, impellers		
SUPEC PPS Resin			
ULTEM PEI Resin	Hot combs, styling brushes, internal hairdryer parts; microwave oven parts; food preparation appliances; iron reservoirs	Disk drive cartridges, cooling fans; copier gears; sleeve bearings	Molded circuit boards, molded interconnect devices; telephone components
VALOX PBT Resin	Various housings such as chainsaw – grinder – powertool housings; vacuum cleaners, irons, coffeemakers, oven grilles, mixers, deep fat fryers, toasters; handles and knobs; motor components	Components for business machines: fans, fan housings, frames, keys and keyboards, switches, connectors	Components for telephones
XENOY PC/PBT Resin	Grinder and powertool housings, lawn mower decks, snowblowers, weed trimmers		Wire and cable; fiber optic tubing

Other Important Considerations

- Cost
- Product design
- Tooling
- Shrinkage
- Secondary Operations
- Assembly
- Interpreting Data Sheets
- Prototyping and Testing

Material Supplier Data Sheets

- Material supplier data sheet - purpose
- Origination of data sheets
- Meaning of reported values
- How are the values generated
- Interpretation of the data
- Application of the data for practical use

Typical data sheet

Table 2. Typical Properties of Delrin

Category	Property[1]	Method ASTM	Method ISO	Unit	Standard Delrin Products[2] Melt Flow Rates[1] 100	500	900	1700
Mechanical – Strength	Tensile Elongation at Break (5.1 mm/min) −55°C +23°C +70°C +100°C +121°C	D638	R527	%	38 75 230 >250 >250	15 40 220 >250 >250	10 25 180 >250 >250	— 17 — >250 >250
Mechanical – Strength	Tensile Strength (5.1 mm/min) −55°C +23°C +70°C +100°C +121°C	D638	R527	MPa	101 69 48 36 26	101 69 48 36 26	101 69 48 36 26	88 68 40 27 21
Mechanical – Strength	Shear Strength +23°C	D732	—	MPa	66	66	66	58
Mechanical – Strength	Flexural Yield Strength (1.3 mm/min) +23°C	D790	178	MPa	99	97	97	—
Mechanical – Strength	Poisson Ratio	—	—	—	0.35	0.35	0.35	0.35
Mechanical – Stiffness and Creep	Tensile Modulus (5.1 mm/min) +23°C	D638	R527	MPa	2800	3100	3100	3100
Mechanical – Stiffness and Creep	Flexural Modulus (1.3 mm/min) −55°C +23°C +70°C +100°C +121°C	D790	178	MPa	3650 2900 1550 900 600	3900 2950 1600 900 600	4130 2960 1650 950 600	4500 3000 1400 900 700
Mechanical – Stiffness and Creep	Compressive Stress (1.3 mm/min) +23°C at 1% Def. +23°C at 10% Def.	D695	604	MPa	36 124	36 124	34 121	22 106
Mechanical – Stiffness and Creep	Deformation under Load 13.8 MPa at +50°C	D621	—	%	0.5	0.5	0.5	0.9
Mechanical – Stiffness and Creep	Flexural Fatigue Endurance Limit 50% RH, +23°C, 10^6 Cycles	D671	—	MPa	32	31	32	—
Mechanical – Toughness	Tensile-Impact Strength +23°C	D1822 Long	8256 Long	kJ/m^2	358	210	147	213
Mechanical – Toughness	Izod Impact (Notched) −40°C +23°C	D256	R180	J/m	96 123	64 80	53 70	53 58
Mechanical – Toughness	Izod Impact (Unnotched) +23°C	D256	R180	J/m	(no break)	(no break)	854	1060

[1] Values listed are only to be used on a comparative basis between melt flow rates. Colorants, additives, and stabilizers used in, or added to, different grades of Delrin may alter some or all of these properties. Contact DuPont for specific data sheets.

[2] Colorants, additives, and stabilizers used in, or added to, different grades of Delrin may alter some or all of these properties. Contact DuPont for specific data sheets.

[3] All of the values reported in this table are based on ASTM methods. ISO methods may produce different test results due to differences in test specimen dimensions and/or test procedures.

[4] 100ST and 500T tensile and elongation values are determined at a strain rate of 5.0 cm/min. Values for other compositions were determined at 0.5 cm/min.

Table 2. Typical Properties of Delrin

Category	Property[1]	Method ASTM	Method ISO	Unit	Standard Delrin Products[2] Melt Flow Rates[1] 100	500	900	1700
Thermal	Heat Deflection Temperature[9] 1.8 MPa 0.5 MPa	D648	75	°C	125 169	129 168	130 167	123 171
Thermal	Melting Point (Crystalline)	D2117	3146	°C	175	175	175	175
Thermal	Coefficient of Linear Thermal Expansion −40 to +29°C +29 to +60°C +60 to +104°C +104 to + 149°C	D696	—	10^{-5} m/m°C	10.4 12.2 13.7 14.9	10.4 12.2 13.7 14.9	10.4 12.2 13.7 14.9	— — — —
Thermal	Thermal Conductivity			W/mK	0.4	0.4	0.4	0.33
Electrical	Volume Resistivity at 2% water, +23°C	D257	IEC 93	ohm-cm	10^{15}	10^{15}	10^{15}	10^{14}
Electrical	Dielectric Constant 50% RH, +23°C, 10^6 Hz	D150	IEC 250	—	3.7	3.7	3.7	4.7
Electrical	Dissipation Factor 50% RH, +23°C, 10^6 Hz	D150	IEC 250	—	0.005	0.005	0.005	0.011
Electrical	Dielectric Strength Short Time (2.3 mm)	D149	IEC 243	MV/m	19.7	19.7	19.7	16.0
Electrical	Arc Resistance Flame extinguishes when arcing stops (3.1 mm)	D495	—	sec	220 no tracking	220 no tracking	220 no tracking	120.0 no tracking
Miscellaneous	Water Absorption, +23°C 24 hr Immersion Equilibrium, 50% RH Equilibrium, Immersion	D570	62	%	0.25 0.22 0.90	0.25 0.22 0.90	0.25 0.22 0.90	— — —
Miscellaneous	Rockwell Hardness	D785	2039	—	M94, R120	M94, R120	M94, R120	M91, R122
Miscellaneous	Combustibility[4]	UL94	—	—	94HB	94HB	94HB	94HB
Miscellaneous	Coefficient of Friction (no lubricant)[5] Static Dynamic	D3702	—	— — —	0.20 0.35	0.20 0.35	0.20 0.35	— —
Miscellaneous	Specific Gravity[7]	D792	R1183	—	1.42	1.42	1.42	1.41
Miscellaneous	Melt Flow Rate[8]	D1238	1133	g/10 min	1.0	6.0	11.0	16.0
Miscellaneous	Chemical Resistance[6]	All resins have outstanding resistance to neutral chemicals including a wide variety of solvents.						

[1] Values listed are only to be used on a comparative basis between melt flow rates. Colorants, additives, and stabilizers used in, or added to, different grades of Delrin may alter some or all of these properties. Contact DuPont for specific data sheets.

[2] Colorants, additives, and stabilizers used in, or added to, different grades of Delrin, may alter some or all of these properties. Contact DuPont for specific data sheets.

[3] All of the values reported in this table are based on ASTM methods. ISO methods may produce different test results due to differences in test specimen dimensions and/or test procedures.

[4] The UL 94 test is a laboratory test and does not relate to actual fire hazard.

[5] Thrust washer test results depend upon pressure and velocity. The test conditions for Delrin were 10 fpm (50 mm/s) and 300 psi (2 MPa) rubbing against AISI carbon steel, Rc 20 finished to 16 μm (AA) using a Faville-LeValley rotating disk tester.

Typical Data Sheet

Product Data

RADEL® R
polyphenylsulfone

R-5000, R-5100 NT15, R-5500

RADEL R polyphenylsulfone resins offer exceptional hydrolytic stability, and toughness superior to other commercially-available, high-temperature engineering resins. They offer high deflection temperatures and outstanding resistance to environmental stress cracking. The polymer is inherently flame retardant, and also has excellent thermal stability and good electrical properties.

RADEL R resins are available as an opaque general purpose injection molding grade–R-5100 NT15, a transparent injection molding grade–R-5000, and a transparent extrusion grade–R-5500.

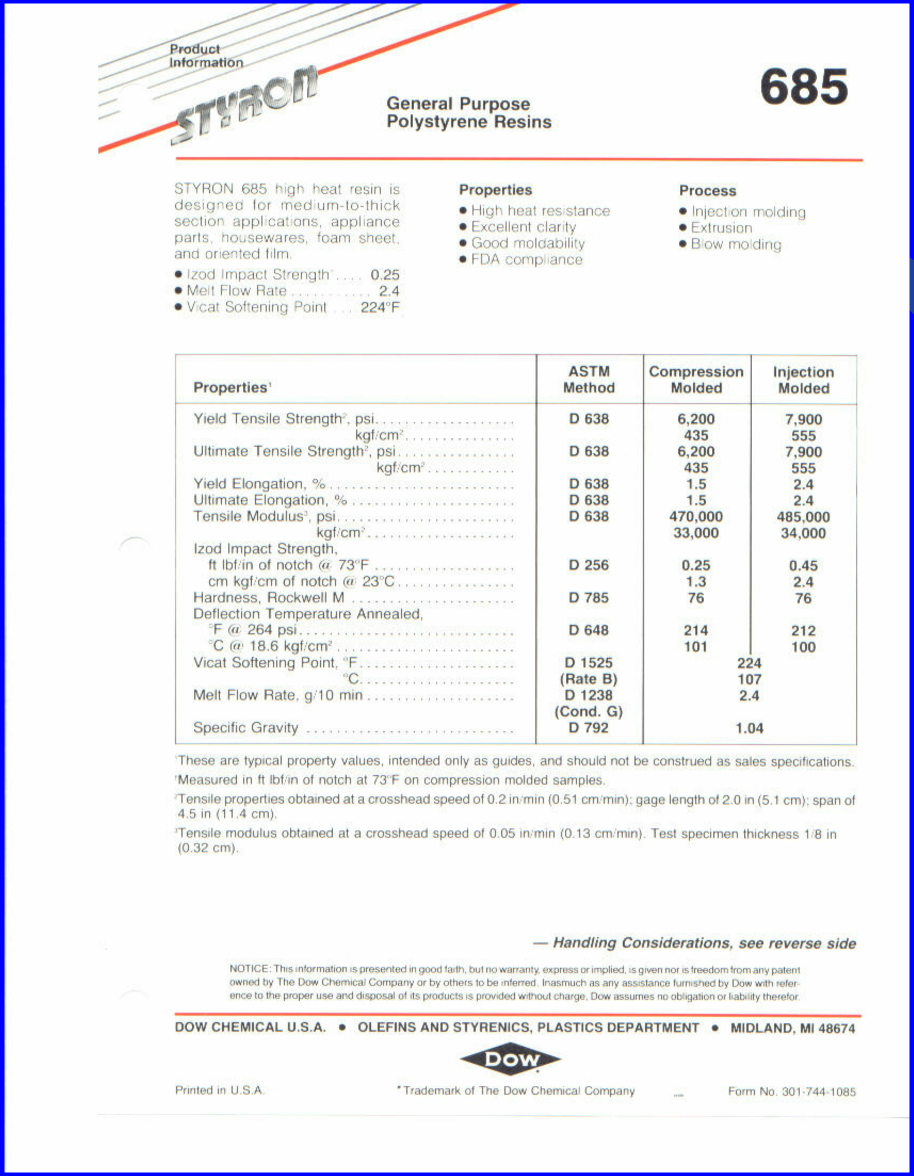
Typical Properties of RADEL R-5000, R-5100 NT15, and R-5500 Resins

	ASTM	Typical Values(1)			
	Test	U.S. Customary Units		SI Units	
Property	**Method**	**Value**	**Units**	**Value**	**Units**
Mechanical					
Tensile Strength	D 638	10.1	kpsi	70	MPa
Tensile Modulus	D 638	340	kpsi	2.3	GPa
Tensile Elongation at yield	D 638	7.2	%	7.2	%
Tensile Elongation at break	D 638	60-120	%	60-120	%
Flexural Strength(2)	D 790	13.2	kpsi	91	MPa
Flexural Modulus	D 790	350	kpsi	2.4	GPa
Tensile Impact Strength	D 1822	190	ft-lb/in²	400	kJ/m²
Izod Impact, Notched	D 256	13	ft-lb/in	690	J/m
Thermal					
Deflection Temperature at 264 psi (1.82 MPa)	D 648	405	°F	207	°C
Flammability Rating(3)	UL-94	V-0	0.030 in	V-0	0.75 mm
Coefficient of Thermal Expansion	D 696	31	ppm/°F	56	ppm/°C
Glass Transition Temperature(4)		428	°F	220	°C
Electrical					
Dielectric Strength at 0.125 in. (3.2 mm)	D 149	380	V/mil	15	kV/mm
Dielectric Strength at 0.001 in. (0.02 mm)		>5,000	V/mil	>200	kV/mm
Dielectric Constant at 60 Hz	D 150	3.44		3.44	
Volume Resistivity	D 257	9×10^{15}	ohm-cm	9×10^{15}	ohm-cm
Chemical					
Steam Sterilization (5) w/ Morpholine, cycles passed without cracking, crazing, or rupture		>1000	cycles	>1000	cycles
Water Absorption at 24 hours	D 570	0.37	%	0.37	%
Water Absorption at Equilibrium	D 570	1.10	%	1.10	%

General and Fabrication		**R-5000**	**R-5100 NT15**	**R-5500**
Specific Gravity	D 792	1.29	1.30	1.29
Refractive Index	D 542	1.672	opaque	1.672
Melt Flow at 689°F (365°C), 5.0 kg, g/10 min	D 1238	17	17	11.5
Mold Shrinkage, %	D 955	0.7	0.7	0.7

(1) Actual properties of individual batches will vary within specification limits. Unless otherwise specified, properties were measured using one-eighth inch (3.2 mm) thick injection molded specimens.
(2) at 5% strain
(3) These flammability ratings are not intended to reflect hazards presented by these or any other materials under actual fire conditions.
(4) Measured by differential scanning calorimetry at a heating rate of 36°F (20°C) per minute.
(5) Steam Autoclave Conditions : Temperature - 270°F 132°C; Time - 30 minutes/cycle; Steam Pressure - 27 psig 0.19 MPa; Stress Level - 1000 psi 7.0 MPa) in flexure; Additive - Morpholine at 50 ppm.

Typical Data Sheet


Product Information

STYRON

General Purpose Polystyrene Resins

685

STYRON 685 high heat resin is designed for medium-to-thick section applications, appliance parts, housewares, foam sheet, and oriented film.

- Izod Impact Strength[2] 0.25
- Melt Flow Rate 2.4
- Vicat Softening Point ... 224°F

Properties
- High heat resistance
- Excellent clarity
- Good moldability
- FDA compliance

Process
- Injection molding
- Extrusion
- Blow molding

Properties[1]	ASTM Method	Compression Molded	Injection Molded
Yield Tensile Strength[3], psi	D 638	6,200	7,900
kgf/cm²		435	555
Ultimate Tensile Strength[3], psi	D 638	6,200	7,900
kgf/cm²		435	555
Yield Elongation, %	D 638	1.5	2.4
Ultimate Elongation, %	D 638	1.5	2.4
Tensile Modulus[4], psi	D 638	470,000	485,000
kgf/cm²		33,000	34,000
Izod Impact Strength,			
ft lbf/in of notch @ 73°F	D 256	0.25	0.45
cm kgf/cm of notch @ 23°C		1.3	2.4
Hardness, Rockwell M	D 785	76	76
Deflection Temperature Annealed,			
°F @ 264 psi	D 648	214	212
°C @ 18.6 kgf/cm²		101	100
Vicat Softening Point, °F	D 1525	224	
°C	(Rate B)	107	
Melt Flow Rate, g/10 min	D 1238 (Cond. G)	2.4	
Specific Gravity	D 792	1.04	

[1] These are typical property values, intended only as guides, and should not be construed as sales specifications.
[2] Measured in ft lbf/in of notch at 73°F on compression molded samples.
[3] Tensile properties obtained at a crosshead speed of 0.2 in/min (0.51 cm/min); gage length of 2.0 in (5.1 cm); span of 4.5 in (11.4 cm).
[4] Tensile modulus obtained at a crosshead speed of 0.05 in/min (0.13 cm/min). Test specimen thickness 1/8 in (0.32 cm).

— Handling Considerations, see reverse side

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Purpose of a data Sheet

- Compare property values of different plastics materials (Tensile strength of nylon vs. Polystyrene, Impact strength of ABS vs. Polycarbonate)
- Quality control guidelines for material manufacturers
- Purchasing/Material specifications
- Initial screening of various materials

Data Sheets Are **NOT** Meant to Be Used for

- Engineering design
- Final(ultimate) material selection

- Why?

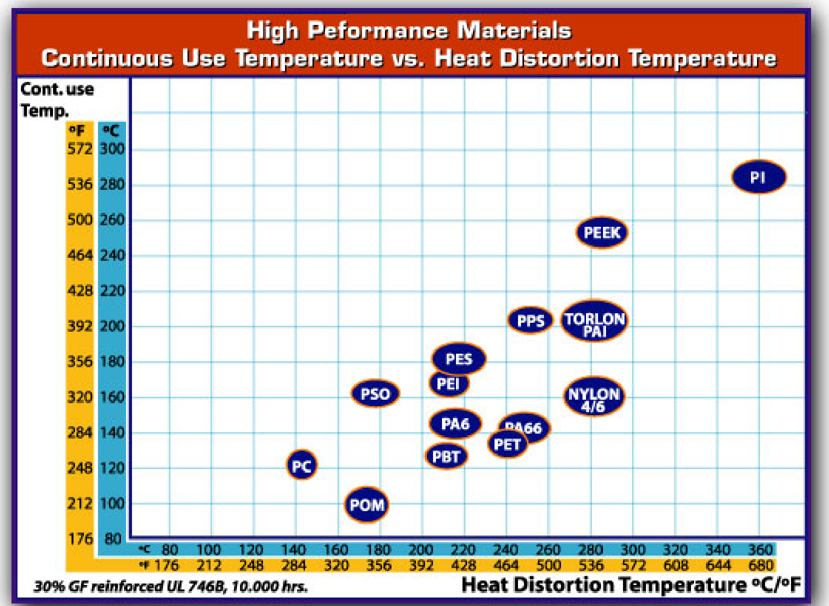
- Reported data generally derived from short term tests
- Usually from single point measurement
- Laboratory conditions
- Standard test bars
- Values are generally higher and do not correlate with actual use conditions

Factors affecting Properties

- Type of plastic - Thermoplastic or Thermoset
- Processing (Fabricating) conditions
- Morphology
- Molecular Weight
- Additives

HDT vs. CONTINUOUS USE TEMPERATURE(UL TEMPERATURE INDEX)

Material	HDT	Continuous Use Temp.
Ryton R-4 (Polyphenylene Sulfide)	>500 ° F	338 ° F
Radal (Polyphenylsulfone)	400 ° F	300 ° F



HDT (DTUL) TEST

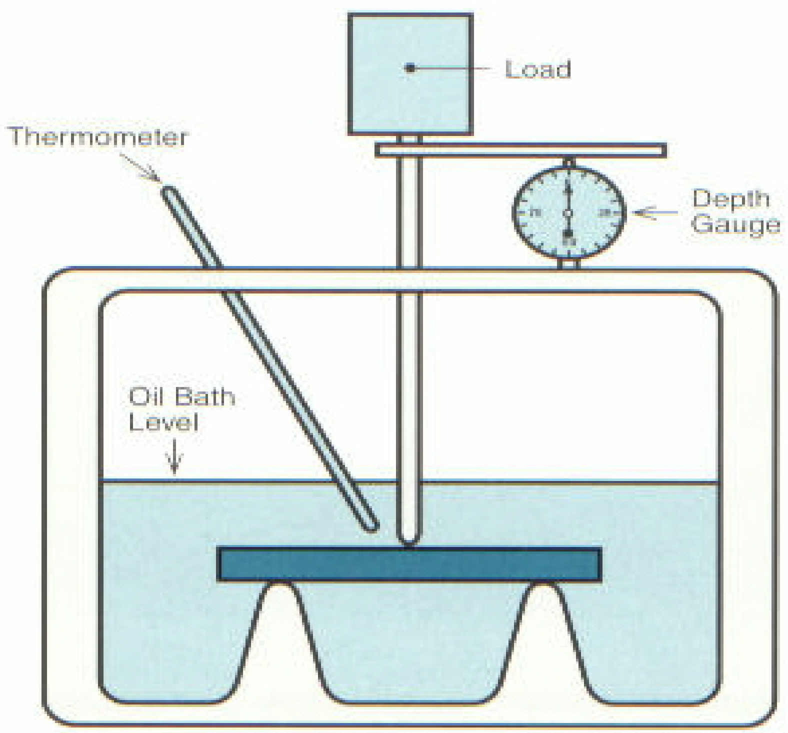
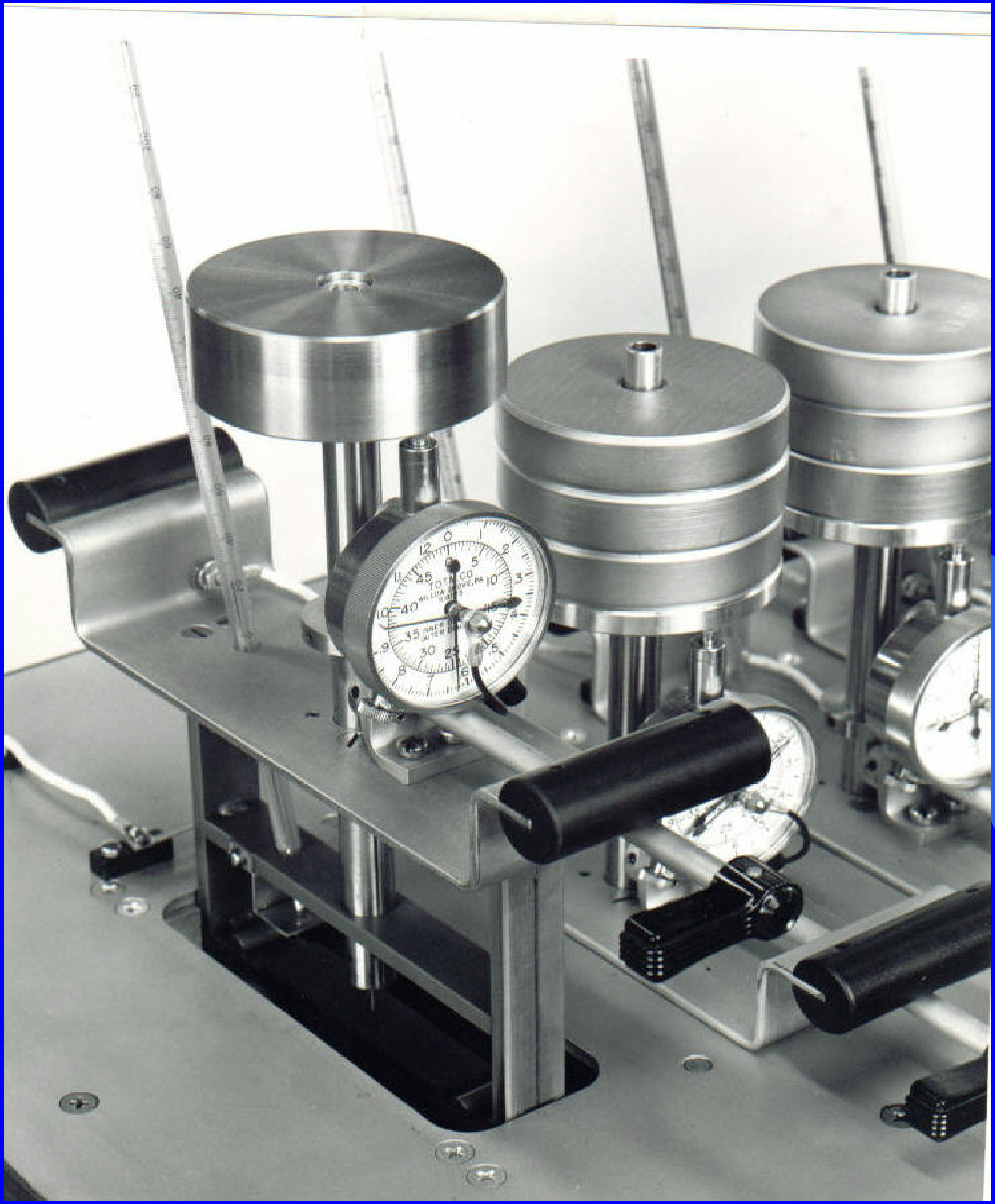


Figure 4-1 Test apparatus for deflection temperature under load (DTUL).

Commercial HDT measurement apparatus

HDT Test



Continuous use Temperature

UL's relative Thermal Index based upon historical records

Material	Generic Thermal Index °C
Nylon (type 6, 6/6, 6/10, 11)	65
Polycarbonate	80
Phenolic	150
PTFE	180
RTV Silicone	105
PET Film	105

Material Selection using Web

- Matweb www.matweb.com
- Ides www.freemds.com
- Plaspec www.plaspec.com
- M-Base http://www.m-base.de

- Consultek www.consultekusa.com

Where to Get More Information

- BOOKS & Design Guides

  Deanin, R.D., *Polymer Structure Property & Applications*, Cahners Books, ISBN 0-8436-1202-9
  Shah, V. H., *Handbook of Plastics Testing Technology*, John Wiley & Sons, www.wiley.com
  Product Design Handbooks
  GE, BAYER & TICONA

- SEMINARS

  University of Massachusetts Lowell Continuing Studies and Corporate Education, Lowell, MA
  www.continuinged.uml.edu/plastics
  Paulson Training Programs, Inc. www.paulson-training.com
  A. Routsis Associates Inc. www.traininteractive.com
  Society of Manufacturing Engineers, www.sme.org

- TRADE PUBLICATIONS

  Injection Molding Magazine immnet.com
  Plastics Engineering www.4spe.org
  Plastics Technology www.plasticstechnology.com
  Modern Plastics www.modernplas.com

- PLASTICS TESTING LABORATORIES

  Plastics Testing Laboratories, Inc. www.ptli.com
  Delsen Testing Laboratories, Inc. www.delsen.com
  CRT Laboratories, Inc. e-mail, crtlabs@pacbell.net

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Plastics Engineering Technology Certificate

This three-course certificate program provides practical instruction applicable to materials, processing, product design and tooling. The program is targeted to technical and non-technical audiences desiring to acquire basic knowledge, expand their horizon, enhance their career or simply take as a refresher course. The main emphasis is on practical aspects of Plastics Engineering Technology without being extremely technical so that the knowledge achieved can be applied in day-to-day applications.

PLASTICS: THEORY AND PRACTICE	WINTER
SCIENTIFIC INJECTION MOLDING	SPRING
PLASTICS PART DESIGN/Tooling	FALL

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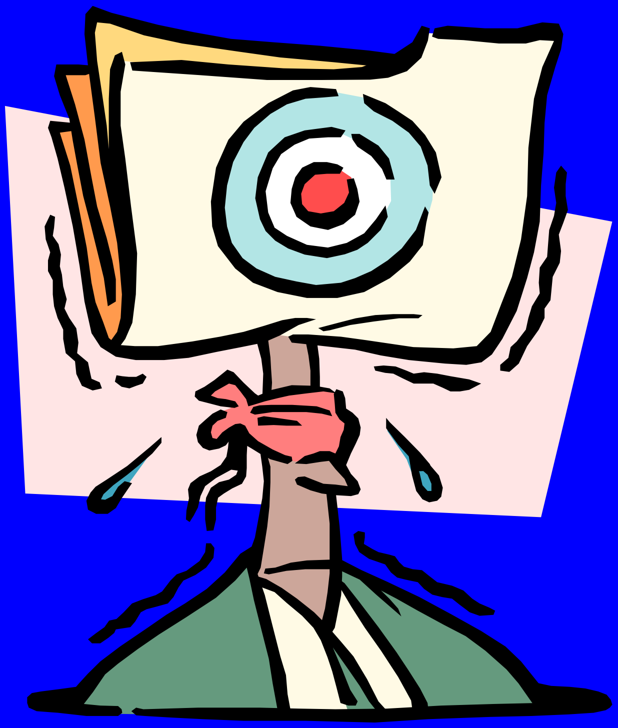
Any Questions?

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