Plastic Materials Selection

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Introduction

- Engineers face several considerations when selecting the optimum polymer material for a product
  - Knowing full product requirements in a wide range of environments
  - Thoroughly understanding of the true functional behavior of the polymer
  - Using this knowledge to sift through an almost infinite number of resin/additive combinations

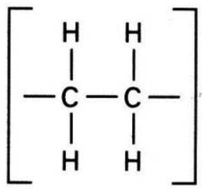
Introduction

- Polymer basics
  - Material behavior differences
- Selection considerations
- Material datasheets
- Q/A

What is a “Polymer”?

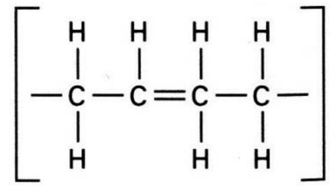
- “Polymer” is from the Greek “poly” (many) and “meros” (part)
- “Polymers” are long organic molecules made up of many small units (monomers) chemically joined end-to-end

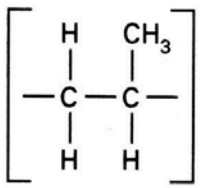
Common Mer Structures



Polyethylene

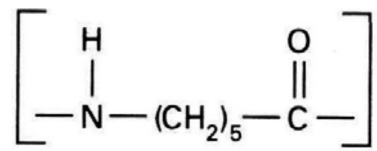
Polybutadiene

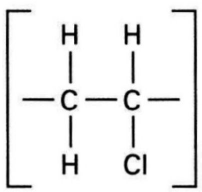




Polypropylene

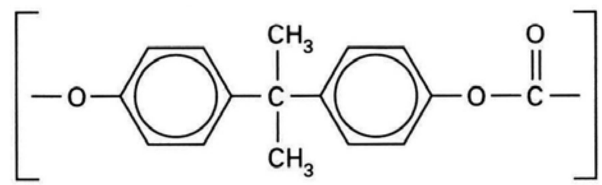
Nylon 6

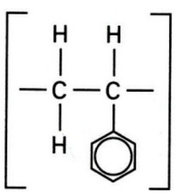




Polyvinyl chloride

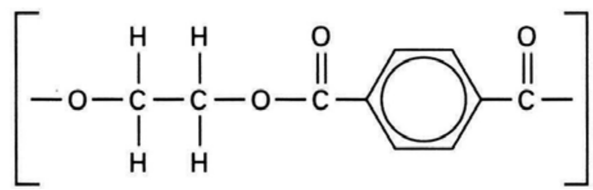
Polycarbonate

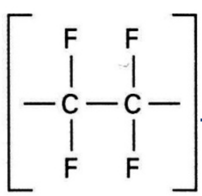




Polystyrene

Polyethylene terephthalate





Polytetrafluoroethylene

Polymer Characterization

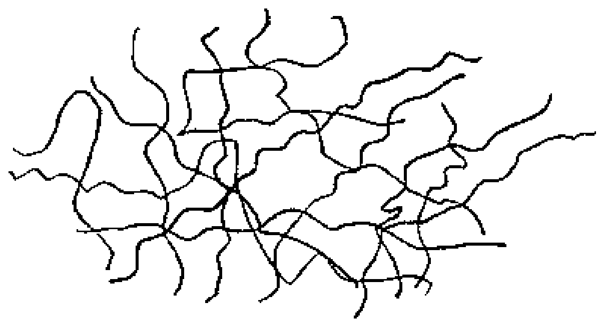
- Thermoplastic
  - Soften when heated, harden upon cooling
  - Can be re-softened
  - Limited upper service temperature
  - Readily recyclable
- Thermoset
  - Hardened when heated
  - Due to chemical cross links cannot be re-softened
  - Generally higher temperature
  - Difficult to recycle

Examples

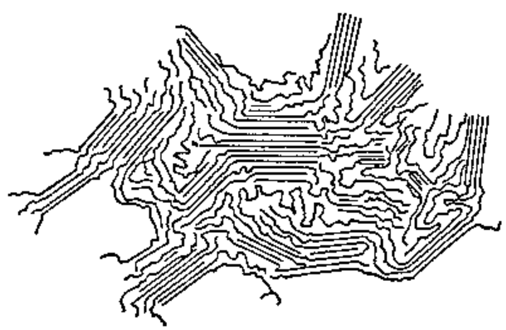
- Thermoplastic
  - Polypropylene (PP)
  - Polyamide (PA, a.k.a Nylon)
  - Polycarbonate (PC)
  - Acrylonitrile butadiene styrene (ABS)
  - Polyacetal (POM)
  - Poly(ethylene terephthalate) (PET)
- Thermoset
  - Phenolic (PF)
  - Epoxy (EP)
  - Unsaturated polyester (UP)
  - Polyurethane (PUR)
  - Acrylonitrile butadiene rubber (NBR)
  - Ethylene propylene-diene monomer (EPDM) rubber

Thermoplastic Types

- Amorphous – lacking long range order



- Semi-crystalline - polymers possessing long range molecular order



General Traits

(Many exceptions exist)

- Amorphous
  - Poor chemical resistance
  - Lower use temperature
  - Optically transparent
  - Less mold shrinkage
  - Tighter tolerances possible
  - Lower strength
  - Higher toughness
  - Lower density
- Semi-crystalline
  - Chemically resistant
  - Higher use temperature
  - Optically opaque
  - More mold shrinkage
  - Requires looser tolerance
  - Higher strength
  - Lower toughness
  - Higher density

General Traits

- Amorphous materials can be characterized by their glass transition temperature (Tg)

<u>Glass transition temperature</u> - The temperature at which a material's characteristics change from that of a glass to that of rubber.

- Semi-crystalline materials can be characterized by their Tg and melting temperature (Tm)

Thermal Properties

Material	T_g [°C (°F)]	T_m [°C (°F)]
Polyethylene (low density)	-110 (-165)	115 (240)
Polytetrafluoroethylene	-97 (-140)	327 (620)
Polyethylene (high density)	-90 (-130)	137 (279)
Polypropylene	-18 (0)	175 (347)
Nylon 6,6	57 (135)	265 (510)
Polyester (PET)	69 (155)	265 (510)
Polyvinyl chloride	87 (190)	212 (415)
Polystyrene	100 (212)	240 (465)
Polycarbonate	150 (300)	265 (510)
Polysulfone	185 (365)	360 (680)

Effect of Morphology

- As crystallinity increases so does:
  - Hardness
  - Density
  - Modulus
  - Tensile strength
  - Melting point
  - Permeability resistance
  - Resistance to oils and greases
  - Surface gloss
- As amorphous content increases so does:
  - Impact strength
  - Dimensional stability
  - Clarity
  - Stress crack resistance
  - Elongation

Examples

- Amorphous
  - Polyetherimide (PEI)
  - Polyethersulfone (PES)
  - Polysulfone (PSU)
  - Polycarbonate (PC)
  - Polyvinyl Chloride (PVC)
  - Acrylonitrile butadiene styrene (ABS)
  - Styrene Acrylonitrile (SAN)
  - Polystyrene (PS)
  - High Impact polystyrene (HIPS)
  - Polymethylmethacrylate (PMMA or Acrylic)
- Semi-Crystalline
  - Polyetheretherketone (PEEK)
  - Polyphenylene Sulfide (PPS)
  - Polythalamide (PPA)
  - Polyamide (PA)
  - Polyethylene Terephthalate (PET)
  - Polybutylene Terephthalate (PBT)
  - Polyoxymethylene (Acetal or POM)
  - Polypropylene (PP)
  - Polyethylene (HDPE/LDPE/LLDPE)

Costs range from <$1.50/lb for Commodity to >$4/lb for Hi-Temp/Hi-Performance

Data courtesy of RTP Company

Chemical Structure Influence

- Acrylonitrile butadiene styrene (ABS) - Amorphous

Pros	Cons
Good stiffness	Low maximum continuous use temperature
Excellent Toughness	
Class A surface	Not resistant to solvents, hydrocarbons and fuels
Platability	
Resistant to alkalis and acids	Poor weatherability

  - Specific properties dependent on amount of each phase
- Typical applications
  - Climate control and radio bezels in automotive
  - Housings in consumer electronics and appliances

element™ Chemical Structure Influence

- Polycarbonate (PC) - Amorphous

Pros	Cons
Excellent toughness	Poor chemical resistance
Low warpage	Processing difficulties
Dimensional stability	Low fatigue endurance
Transparency	
Low mold shrinkage	

- Typical applications
  - Lighting lenses, climate control and radio bezels in automotive
  - Housings in consumer electronics and appliances

Chemical Structure Influence

- Acetal (POM) – Semi-crystalline

Pros	Cons
Good mechanical strength	Not resistant to acids
Excellent fatigue resistance	High specific gravity
Abrasion resistance	Anisotropic shrinkage
Low coefficient of friction	Processing difficulties
Low creep	
Resistant to fuels and solvents	

  - Specific properties dependent on homopolymer versus copolymer
- Typical applications
  - Fuel system components in automotive
  - Gears in appliance and machinery industries

Chemical Structure Influence

- Nylon 6,6 (PA66) – Semi-crystalline

Pros	Cons
Excellent toughness	High water absorption
Heat resistance	Poor resistance to strong acids and bases
Abrasion resistance	
Resistant to fuels, solvents, and hydrocarbons	

  - Specific properties dependent on absorbed water content

- Typical applications
  - Engine and cooling system components in automotive
  - Cams and gears in appliance and machinery industries

element™ Chemical Structure Influence

- Polypropylene (PP) – Semi-crystalline

Pros	Cons
Chemical resistant	Low to moderate mechanical properties
Lightweight	
Heat resistant	Low surface energy
Low cost	

  - Specific properties dependent on homopolymer versus copolymer
- Typical applications
  - Fan shrouds, battery housings, windshield washer reservoirs, climate control housings and conduits in automotive
  - Housings in appliances
  - Consumer product packaging

Additives

- Plasticizers
  - Decreases the glass transition temperature (Tg), softens and adds flexibility to the product
- Flame retardants
  - Can increase resistance to ignition, reduce rate of burning, flame spread, and smoke emission
    - Halogenated vs. nonhalogenated

Property	Polypropylene Homopolymer		
	Unfilled	V0	V2
Tensile Strength (MPa)	32	23	30
Tensile Modulus (MPa)	1,724	1,862	1,517
Impact Strength (J/m)	53	43	37

Data courtesy of RTP Company

Additives

- Stabilizers
  - UV, oxidation, hydrolysis, etc…
- Antistatic agents
- Blowing agents
- Colorants
  - Organic vs. inorganic
- Fillers
  - Reinforcing, non-reinforcing, & specialty

Reinforcing Fillers

- Improves mechanical performance of the material by transferring stress to the reinforcement, which is then diluted before transfer back to the polymer matrix.
- Includes fibers and high aspect ratio minerals.
- Aspect ratio and coupling are key variables in the effectiveness of the reinforcement.

Aspect Ratio

- Defined as length divided by diameter.
- A higher aspect ratio will result in a higher increase in strength.

(1……………………………Aspect Ratio……………………………1,000)

Aspect Ratio

- Bead or Sphere
  - Not effective as reinforcement (except for compression)
- Short Fibers (~1 mm)
  - Most popular due to effectiveness
  - Accelerates tool wear
  - Increases potential for part warpage and anisotropy

Anisotropy - a state in which a physical characteristic varies in value along axes in different directions.

Aspect Ratio

- Long Fibers (≥10 mm)
  - Often used in large parts for increasing overall part strength
  - Fiber length retention critical to effectiveness
  - Increases potential for part warpage and anisotropy
  - Costs may increase as regrind should not be used within same part
- Nano Fibers
  - Excellent reinforcement without part warpage and anisotropy
  - High material costs

Aspect Ratio

Tensile Properties Comparison for Polypropylene Resins

Property	Unfilled	Glass Bead Filled	Glass Fiber Filled	Glass Fiber Reinforced	Long Glass Fiber Reinforced
Filler (Wt %)	0	30	30	30	30
Strength (MPa)	32	23	55	76	100
Elongation (%)	>10	>10	1.5 - 2.5	4 - 5	2.5 - 3.5
Modulus (GPa)	1.72	2.34	6.21	6.21	6.90

Data courtesy of RTP Company

Non-Reinforcing Fillers

- Low aspect ratio minerals and particles used to displace resin and reduce the cost of the overall material. Can also be added for cosmetic reasons, such as to reduce the appearance of sink marks.

- Includes kaolin clay, talc, calcium carbonate, titania, silica, glass beads, wollastonite, wood fiber, etc…

Non-Reinforcing Fillers

Tensile Properties Comparison for Polypropylene Resins

Property	Unfilled	Calcium Carbonate Filled	Talc Filled	Mica Filled	Glass Fiber Reinforced
Filler (Wt %)	0	40	40	40	40
Strength (MPa)	32	23	30	28	90
Elongation (%)	>10	>10	>10	9	3 - 4
Modulus (GPa)	1.72	3.10	5.17	6.21	8.96

Data courtesy of RTP Company

Specialty Fillers

- Electrically conductive, wear/friction inhibitors, thermally conductive, dampening control
- Includes carbon fiber, stainless steel fiber, nickel coated graphite, tungsten, molybdenum disulfide, PTFE, silicone oil, barium sulfate, graphite, barium sulfate, etc…

Selection Considerations

- General Information
- Assembly Method
- Mechanical Requirements
- Chemical Resistance
- Electrical Properties
- Operating Environment
- Appearance
- Codes and Specifications
- Disposal
- Cost Parameters
- Other Needs

***Rank from most to least important**

General Information

- Part function
- Part geometry and tolerancing
- Design constraints (e.g. weight)
- Required service life
- Servicing requirements
- Consequences of part failure
- Production scale

Assembly Method

- Mechanical fastening
  - Self tapping screws, press fit, snap fit, heading, insert
- Welding
  - Hot plate, induction, vibration, spin,
- Adhesive methods
  - Adhesive bonding, solvent bonding

Mechanical Requirements

- Applied stress while in service
  - Magnitude, speed, frequency, duration
- Maximum tolerable deformation
  - % of Yield
- Effects of friction and wear
  - Add a lubricant?
- Dimensional stability
  - Add filler

Operating Environment

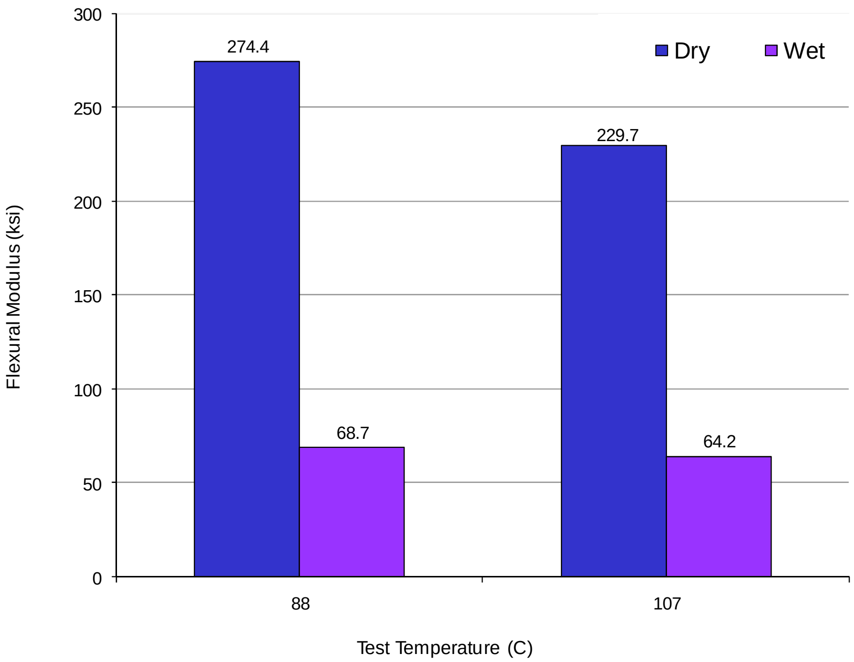
- Sunlight and weathering
  - Duration
  - Intensity
- Humidity
- Ozone
- Temperature
  - Maximum continuous
  - Short term elevated
  - Minimum operating

Polyethylene Polypropylene Nylon Polycarbonate Teflon®

#1 DRIVER OF RESIN COST

Operating Environment Temperature

- Door comprised of glass bead filled nylon resin
- Used in an HVAC system in an automotive application
- Improper sealing was evident due to permanent deformation of the door following a short time in service



Chemical Resistance

- Chemical exposure while in service and during secondary processes and assembly.

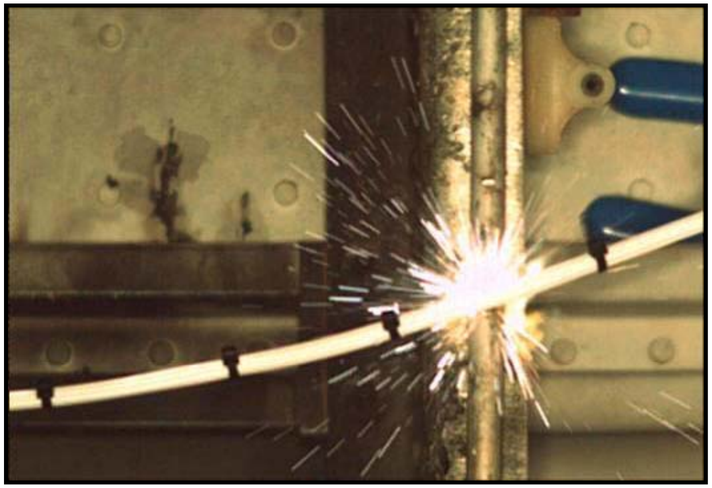
Material Description	Organic Solvents	Alcohols	Hydrocarbons	Fuels
Polycarbonate (PC)	P	G	P	P
High Density Polyethylene (HDPE)	G	E	G	G
Polypropylene (PP)	P	G	F	F
Nylon 6/6 (PA66)	E	G	G	G
Acetal (POM)	E	F	G	G
Polysulfone (PSU)	G	G	P	P
Polybutylene Terephthalate (PBT)	E	G	P	G
Polyetherehterketone (PEEK)	E	E	E	G

Data courtesy of RTP Company

P = Poor F = Fair G = Good E = Excellent

Electrical Properties

- Voltage requirements
  - Dielectric strength
- Tracking requirements
- Insulation requirements
  - Surface and volume resistivity
- Conductive/Dissipative



Appearance

- Color
  - Inorganic pigments can change material's physical properties
  - Color concentrates must be compatible with resin
  - Transparency is only possible with amorphous resins
- Surface finish
  - Class "A", machined, matte, textured
  - Secondary operations such as painting, plating, or graphic appliqués

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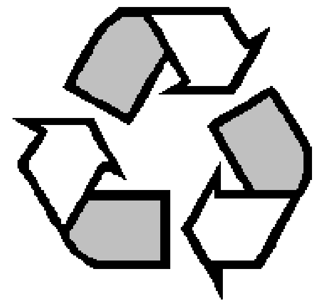
Codes and Specifications

- Underwriters Laboratories - UL
  - Flammability
  - Electrical insulation
  - Temperature index
- National Sanitary Foundation - N.S.F.
- Food and Drug Administration - F.D.A.
- U.S. Department of Agriculture
- 3A Sanitary Standards
- OEM/Supplier Material Specifications

Disposal

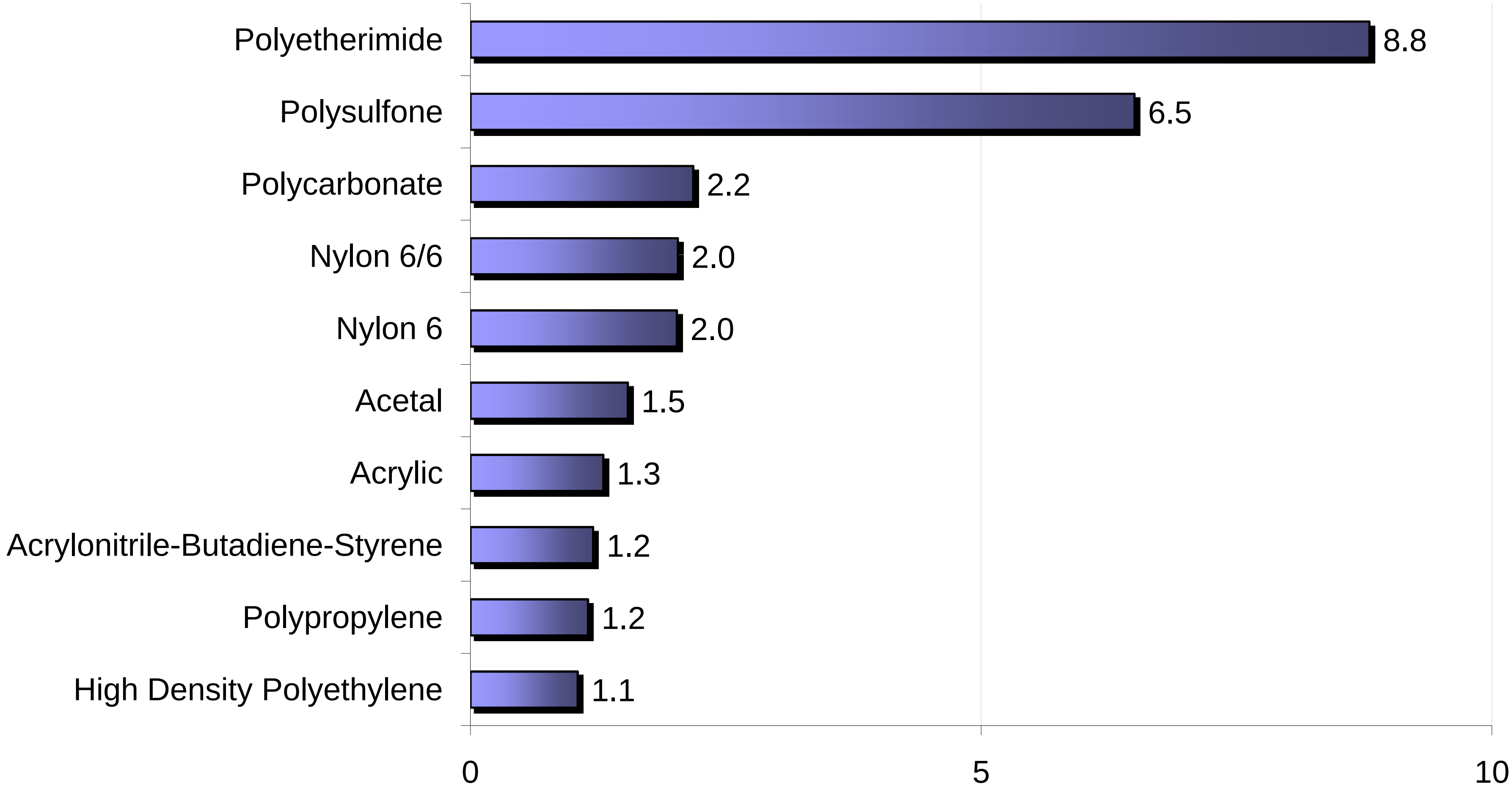
- Recycle
- Reclaim / Blend
- Landfill
  - Restricted substances
- Incinerate



Cost

- What are the cost and pricing limitations on the part?
- Total part cost
  - Material costs
  - Cycle time
  - Labor rate
  - Machine rate
  - Scrap rate
  - Amortized mold costs
  - Secondary operations

Relative Market Resin Prices (Cost/pound)
Effective October 2013



Polyetheretherketone off the chart @ $45/lb!

Other Additional Needs

- Odor
- Noise, Vibration, Harshness (NVH)
- Fogging
- Microbial resistance
- Etc…

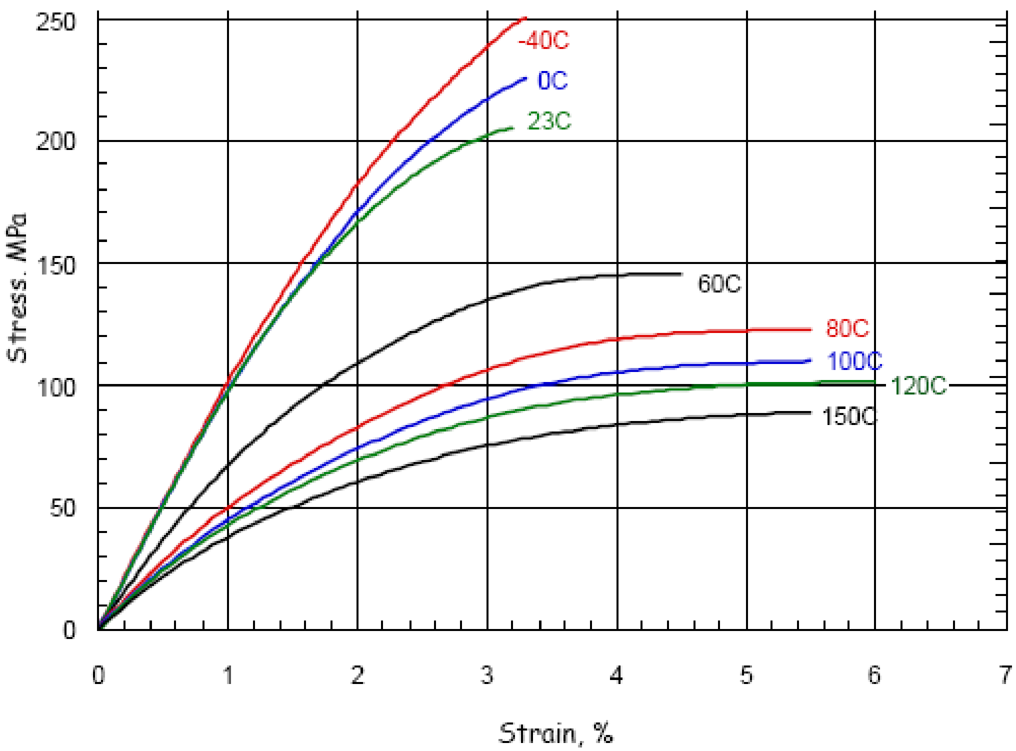
Material Datasheets

- Correlation between datasheets and relevance to design considerations is not completely understood
  - Material property versus significance
- Purpose of datasheets is often sales and marketing related
  - Technical content not always intended for use as engineering data
- In general, datasheets contain short term, single point, room temperature data, for dry as molded samples
- Every data point on a datasheet represents a point at which something bad happened to the material

Temperature & Humidity Effect

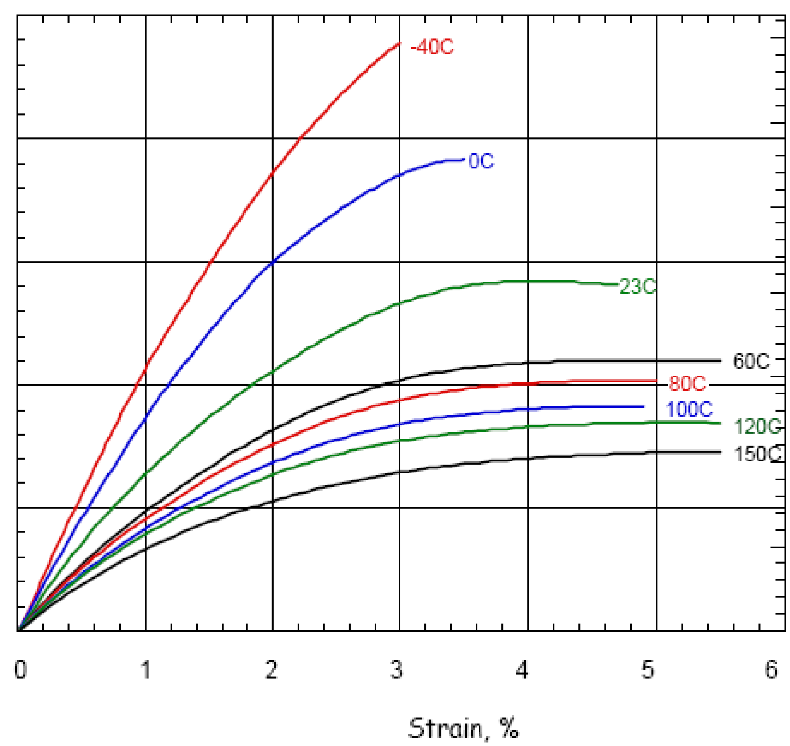
30% Glass Reinforced, Heat Stabilized, Nylon 6,6

Dry as Molded



Data courtesy of DuPont

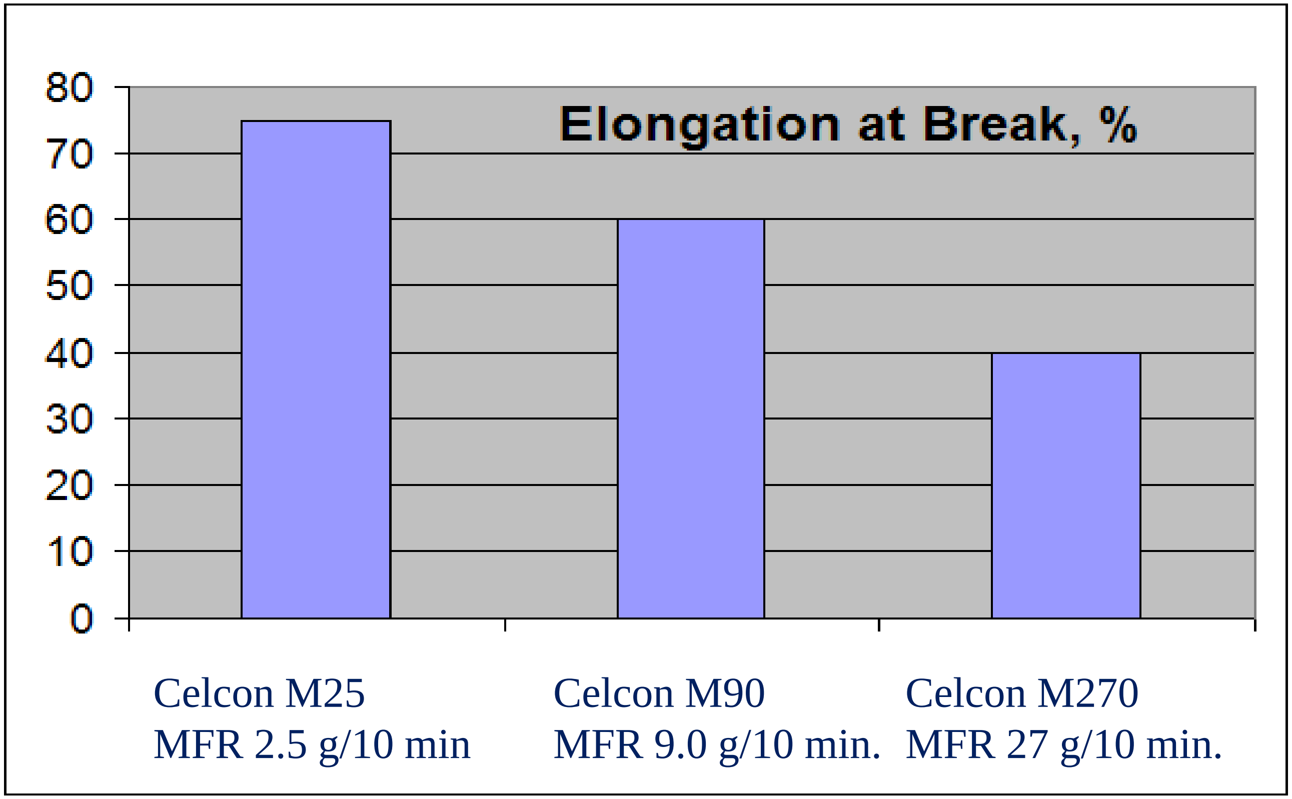
Equilibrated at 50% Relative Humidity



Data courtesy of DuPont

Additional Property Influences

- Molecular weight



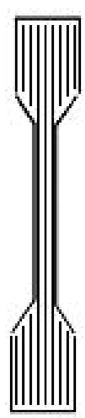
Effect of Molecular Weight

	Increasing MW
• Tensile Strength	+
• Elongation	+
• Yield Strength	+
• Toughness	+
• Brittleness	-
• Hardness	+
• Abrasion Resistance	+
• Softening Temperature	+
• Chemical Resistance	+

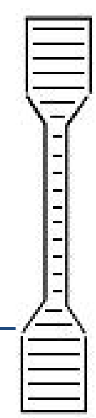
Orientation Effect

Tensile Properties	30% Long Glass Reinforced, Heat Stabilized, Polypropylene Homopolymer			40% Long Glass Reinforced, Heat Stabilized, Polypropylene Homopolymer		
	Flow Direction	Cross Flow Direction	Change (%)	Flow Direction	Cross Flow Direction	Change (%)
Modulus (GPa)	7.45	6.17	-16	9.71	7.39	-24
Strength (MPa)	106	60	-43	115	57	-50
Strain @ Ultimate (%)	2.35	1.29	-45	2.11	1.03	-51

Data courtesy of Owens Corning



Flow Direction



Cross Flow Direction

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Alternatives

- Engineering design data
  - Material supplier
    - May not include orientation or wall thickness effects
    - Long term test data difficult to obtain especially at exact application conditions
    - Computer databases
      - SABIC Innovative Plastics™ http://www.geplastics.com
      - CAMPUS http://www.campusplastics.com
      - IDES Prospector http://www.ides.com
  - Internal test laboratory
  - External test laboratory

References

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Questions?

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