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Navigating the Plastic Material Selection Process

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Consideration of a Plastic Material

Choosing a specific material for a project can be a complex, daunting, and intimidating process when one is faced with endless material options. Although the material selection process is unique for each product, the goals are common to all. This article is framed around this definition:

Material selection involves the process of choosing one substance that meets performance and cosmetic goals over the lifetime of the product, that can be readily processed and assembled using commonly available techniques—all at an acceptable cost.

For the material selection process to be successful, it should be intimately involved during part design and in selecting the manufacturing process, processing conditions, and post assembly procedures, as well as during mold design. Of course, it is important to be aware that costs must be considered during every aspect of product development (Fig. 1).

Material selection should be integral to the product development discussion from the very start. Too many failures are the result of forcing a material to a part and/or mold design for which it is not suited. Materials commonly are used to solve structural shortcomings or processing issues. The most successful parts result from leveraging the properties of the material together with its geometric features, all the while understanding how molding will influence the material properties and part shape.

There are numerous reasons why a plastic material should be considered for a product:

- Strength to weight ratio
- Strength to cost ratio
- Additives/reinforcements
- Design freedom
- Combining many components into one
- Cosmetic benefits
- Chemical resistance
- Thermal properties
- Assembly options

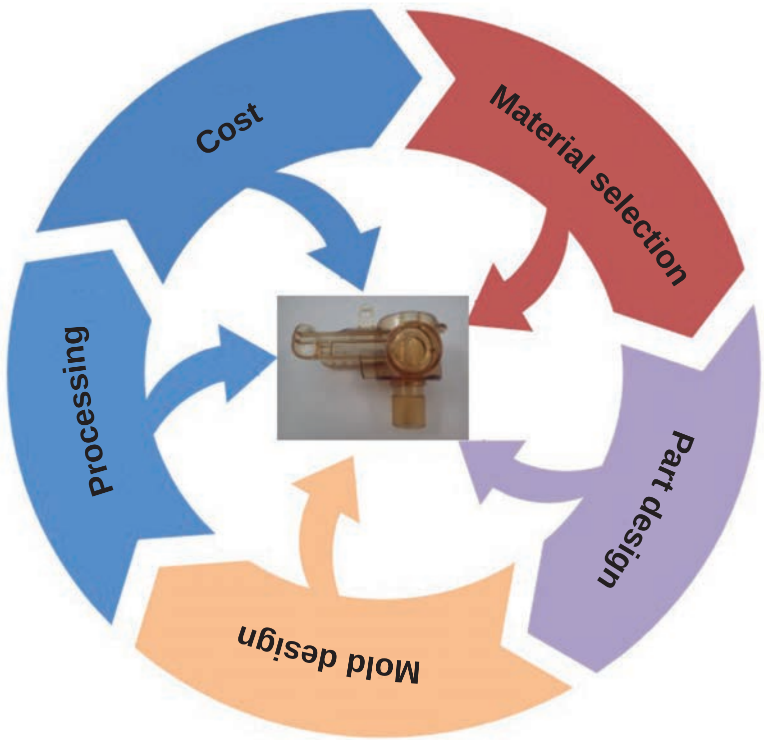

Fig. 1 The five facets of a successful product development

Many of these benefits come with important considerations. For example, plastics are excellent thermal insulators, but they can expand and contract 5 to 10 times more than metals over the same temperature change. Ignoring this property can result in a huge amount of stress or warpage and eventually failure of the part.

Every year, new materials are being introduced with an ever-increasing array of available properties. These enhanced properties permit plastic to be used in applications once considered beyond its capability. It was not too long ago that the idea of using a plastic material for a structural component in a bridge was unthinkable. However, the chemical resistance, weight reduction, and increase in lifetime that modern plastics can provide were too compelling to ignore. Plastic bridges that have projected lifetimes well past similar metal bridges are successfully being used throughout the world (Ref 1).

There are also many reasons why plastic materials should not be considered for an application. It is the responsibility of the design/materials engineer to recognize when the expected demands are outside of what the plastic can provide during the expected lifetime of the product. This article reviews the many considerations that are equally important to help ensure that part failure does not occur.

Plastic Materials

Although this article does not go into depth on the structure of polymeric materials, a quick review of thermoplastic and thermoset plastics is in order. Since the molecular structure and arrangement plays such an important role in how the material will process and function, the reader is encouraged to do a thorough investigation (Ref 2). Additionally, the article "Engineering Plastics: An Introduction" in this volume describes the various aspects of chemical structure and composition that are important to an understanding of polymer properties and their eventual effect on the end-use performance of engineering plastics, especially thermoplastics and thermosets.

Thermoplastics

The most popular plastic materials are those classified as thermoplastic. These plastic materials solidify in response to a reduction in temperature. Heating of the plastic to reduce the viscosity of the material so it can be molded and then cooled to create a solid part is a reversible process with thermoplastics. There are two primary types of thermoplastic materials, which are classified by molecular arrangement: amorphous and semi-crystalline. When choosing a plastic, deciding whether the material will be amorphous or semi-crystalline will be critical prior to designing the mold.

Amorphous Plastics

Plastic materials in which all of the molecules are randomly oriented with no molecular alignment are classified as amorphous. Because there is no crystalline structure, amorphous materials will not truly melt, but they will soften as they approach their glass transition temperature (T_g). Some of the key attributes of amorphous plastics are:

- Transparency (in most cases)
- Toughness and impact resistance
- Not as prone to oxidation
- Lower shrinkage during molding
- Large softening range—key for thermoforming
- Lower chemical attack resistance
- Lower environmental stress crack resistance
- High viscosity—more difficult to fill out the mold

The functional group that is part of the repeating monomer influences the characteristics of the amorphous plastic. For example, polycarbonate and polystyrene both have excellent transparency, but this is where the similarities stop. Polycarbonate is tough and has good high temperature properties, whereas polystyrene is comparatively brittle and cannot tolerate temperatures that polycarbonate can. The difference has to do primarily with the location of the two benzene rings that are in line with the backbone of the polycarbonate repeating unit, and the single benzene ring that sticks out from the backbone of the polystyrene repeating unit (Fig. 2).

Semi-crystalline Plastics

An ordered arrangement of molecules upon solidification can occur with some polymeric materials. The crystalline structure that results provides the polymer with a distinct melting point. However, because the molecules are relatively long, which reduces their mobility, the polymer never approaches 100% crystallinity. Semi-crystalline polymers will have a significant region of unordered (amorphous) molecules. These regions provide the polymer with a glass transition temperature. Semi-crystalline thermoplastics have general attributes which should be considered when selecting a material:

- Greater chemical resistance
- Greater modulus and strength
- Maintains some modulus after the glass transition temperature
- Opaque and translucent
- Lower viscosity during molding—easier to fill the mold cavity
- Greater shrinkage during solidification—part warpage, lower tolerance

Thermosets

Unfortunately, it is common to limit the plastic material selection process to thermoplastics. This is perhaps due to the fact that they are generally more familiar. If the material selection process is limited to this type of plastic, a large class of plastic materials with attractive properties—thermosets—will be ignored. Because thermoset materials solidify by a chemical reaction to create a cross-linked molecular network, they provide key attributes that thermoplastics lack. The general characteristics of thermosets are:

- Better mechanical properties
- High chemical resistance
- High flammability resistance
- High creep properties
- Easier mold filling
- Brittle behavior
- Greater molding times due to the chemical reaction
- Fewer joining options

Thermosets come in a wide range of colors/finishes, can be injection and compression molded, can be recycled, and generally have attractive pricing.

This article focuses primarily on thermoset materials that at room temperature are below their glass transition temperature. However, there is a large class of thermoset materials that operate above their glass transition temperature. These materials are commonly known as rubbers and elastomers. Different rubbers/elastomers have unique properties which allow them to be used in specific environments. Selecting the correct material for an application, such as an O-ring, is critically important in order to avoid a potentially catastrophic failure.

Motivation for Material Selection

There are numerous reasons why an engineer or designer will select a specific material for a particular application. These reasons should be part of the conversation during the selection process. They can help to direct some of the key decisions that will need to be made. At a minimum, a replacement material will typically require different processing conditions than the material it is replacing. It may also require a completely new mold if the new material is from a different material class, as when the process is changing from amorphous to semi-crystalline material.

New Product

Selecting a plastic for a new part is perhaps the one situation that provides the most design freedom. If the selection is executed properly, it will be done alongside part design, mold design, and assembly consideration. Creating a new product provides the largest window of materials from which to choose. This does

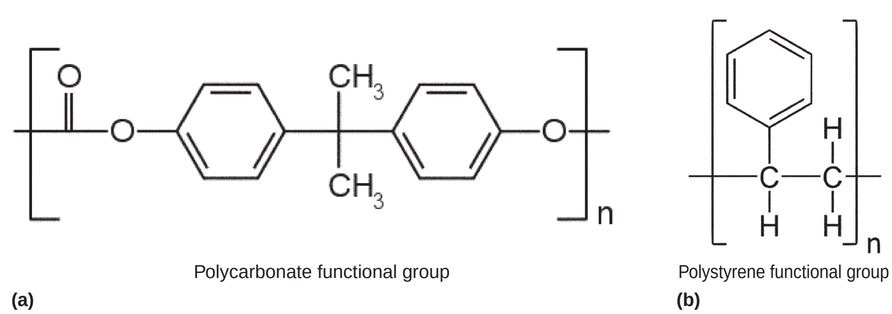

Fig. 2 (a) Repeating polycarbonate and (b) polystyrene structure

not mean that material, mold, and assembly costs can be ignored. However, it does mean that the material selection is not necessarily tied to a strict part design and mold layout.

Cost Savings

One of the major benefits plastics can provide is a tremendous savings with respect to cost. This is especially true when all costs are considered, including material, molding, assembly, and lifecycle. If a new plastic material is being considered as part of a cost reduction program, one must understand which properties of the new material will or will not meet or exceed those of the material being replaced. For the cost reduction program to be successful, all costs need to be considered, including mold design, molding, post assembly, and shipping. When material costs are being calculated, one should keep in mind that materials are purchased on a per mass basis, while the part itself is usually priced based on volume and/or complexity. For instance, polypropylene has a specific gravity of 0.91, while a polyacetal homopolymer has a specific gravity of approximately 1.41. Before analyzing the cost of either material, the polyacetal will have a 50% premium over the polypropylene, based solely on the specific gravity of the materials.

Addressing Failure of an Existing Product

A common reason for needing to select a new material is that an existing material has failed. To ensure success with the new material, a failure analysis is recommended to determine "how" and "why" the original material failed. The information from this analysis will be front and center during the material selection process. The obvious goal is to avoid repeating the same failure or creating a different failure with the new material. The failure analysis will also influence the selection of the type and conditions of performance testing.

Metal to Plastic Conversion

Changing a product from metal to plastic is one popular reason for going through a material selection process—the primary motivations being cost and weight savings, or to address a corrosion or chemical attack issue. These are justifiable reasons for making the conversion. However, there are major drawbacks which must be considered when changing from a metal to a plastic component. Perhaps the most important and least understood is that the molecules of the plastic are always "on the move" (Ref 3, 4). This is due primarily to the relatively weak secondary attraction forces that bond the molecules of the plastic together. This results in a change in the properties and characteristics of the plastics over time when they are subjected to a relatively low stress, for example, below the yield point of the material. This is unlike metals in which, unless corrosion or chemical attack occurs, the grain structure holds the metal together. Although all materials are sensitive to sharp transitions, plastic materials suffer more when these features are present (Ref 5). Another important consideration is that the thermal expansion of most plastic materials is much greater than that of metals.

Additional Reasons for the Material Selection Process

Some other reasons why one may need to go through the material selection process:

- Current material has been discontinued
- Need for a material backup
- New product generation warrants a material review
- New regulatory requirements were put into place
- New processing technique is being considered, e.g., additive manufacturing

Goal of the Material Selection Process

Perhaps the most important decision made during product development is choosing the resin, additives, and reinforcements. The material should not be chosen to meet part design, and the part geometry should not be designed to the material selected. These both should be done concurrently, and the process will likely be an iterative one. Likewise, before the mold is made, the material should be selected to ensure the part can be molded properly.

Structural Expectations

Plastics can provide excellent structural properties. For a material to be successful, the structural requirements of the application should be well understood. The type, magnitude, and frequency of stress repetitions need to be specified. Equally important is an understanding of how the material handles such stresses over time and the expected temperature range. The properties of the plastics under consideration should be tested as closely as possible to the environmental conditions the part will be exposed to while in the field. For example, if the part is expected to experience 100 °C, tensile testing following ASTM D638 at this temperature is recommended. Alternatively, the part can be exposed to environmental conditions for a set period of time, such as in an accelerated weathering chamber, and then tested. Measuring the storage and loss modulus over a broad temperature range using dynamic mechanical analysis (DMA) is also recommended (Ref 6).

It is very common to use reinforcements to increase the mechanical properties of the material. The most common reinforcement is glass fiber, but carbon fiber, wood fiber, and aramid fiber also are used. It is recommended that these reinforcements be investigated as options when enhanced properties are needed. However, the use of reinforcements typically results in the loss of some other properties, an increase in weight, and part warpage. Ductility at fracture will likely be the most important property that will be reduced. However, strength at the knit line in flow regions during molding is also an important concern. Table 1 shows the loss in strength at the knit line for various plastic materials (Ref 7). For example, the strength of a polypropylene part reinforced with glass fiber can be much lower at the knit line than for a polypropylene part without glass reinforcement. Processing will create highly anisotropic properties throughout the part from the fiber orientation that is created. This can make it difficult to predict how the part will perform when it is exposed to forces and deformations in an actual application.

Cosmetic Properties

There is not another material that can provide a greater range of cosmetic properties than plastics. The surface of plastic parts can be made to be "defect free" with a surface curvature that is continuous in all directions, providing a tangency alignment to near perfect reflective quality. Depending on the class, plastics can bring the following cosmetic considerations to the material selection process. In fact, the cosmetic requirements will likely play a crucial role during the material selection process.

- Coated or molded-in with nearly any color
- Transparent
- Translucent
- Dull or shiny/reflective
- Smooth or textured
- Class A finish

In addition, additives can help to ensure that the cosmetic properties are retained. For example, antifogging agents can be added to ensure transparency.

Molding

A plastic that meets all physical, chemical, and cosmetic requirements has not been successfully selected until it is proven that the part can be molded within set tolerances. Filling a mold with very hot liquid plastic, under extremely high pressures and shear rates, without defects, is difficult. The requirement of higher tolerances and more complex geometries narrows the selection of plastic materials that can be used. It is sometimes difficult to completely fill out the cavity of the mold using amorphous plastics because of their greater viscosity, but the resulting part is typically more dimensionally stable. While semi-crystalline materials are more effective at filling the mold, their dimensional stability is not as reliable due to the shrinkage created by their structure.

Survive in the Intended Environment

One of the primary goals of material selection is to choose one that will survive in the environment in which it is intended to be used. One of the more challenging conditions for plastics is high temperature. Typical thermoplastics will behave differently as the temperature increases. One feature common to all plastics is that the modulus and strength will decrease as the temperature increases. In general, plastics that can survive at higher temperatures, the so-called "engineered plastics," are typically more expensive and can be quite challenging to mold. Because of the cross-linking structure of thermoset plastics, many of these materials can maintain modulus and strength at higher temperature than most thermoplastics.

Avoid Failure

Failure of a plastic part can occur for many different reasons. The most obvious reason is its inability to perform the function for which it was intended. Types of failures can include:

- Cracking of the part due to an applied force
- Warpage
- Cosmetic (e.g., loss of color or surface finish)
- Total part cost is too high
- Does not perform functionally as expected (e.g., snap-fit does not fasten or release properly)
- Flammability or smoke generation is too high
- Plastic or additives contain hazardous materials
- Failure to crack when or where expected (e.g., opening of a water bottle)

Knowing how the part could fail is an important consideration during the material selection process. If the failure of the plastic can result in the loss of human life or major property degradation, and/or if methods to avoid possible failure are known, appropriate warnings and instructions must be provided (Ref 8, 9).

Material Selection Process

Plastics are formed of chains of carbon and hydrogen atoms, and they may also include other atoms, such as oxygen, nitrogen, chlorine, fluorine, and/or sulfur atoms. The atoms are arranged into a functional group that forms the monomer (Fig. 2). The atoms and their arrangement determine many of the plastic properties. The arrangement of these atoms into countless functional groups provides the engineer with hundreds of plastic families from which to choose. Most plastic products actually are made from a list of approximately 50 plastics (Fig. 3). These 50 plastics provide the engineer with a long list of various available properties from which to choose. In addition to these 50 plastics, the creation of blends, using different additives and reinforcements, and utilizing different processing techniques (e.g., foaming or co-injection molding), provides a nearly endless list to tailor the material to the application and environment to ensure that failure does not occur.

Understanding the Demands on the Material

With so many material options available to the engineer, the material selection process

Table 1 Tensile strength of various polymers with and without a knit line

Material	Reinforcement	Tensile strength MPa (psi)		
		One gate	Two gates	Percent retained
Nylon 66	None	79.29 (11,500)	77.01 (11,170)	97
Nylon 66	10% Glass	96.39 (13,980)	90.05 (13,060)	93
Nylon 66	30% Glass	166.85 (24,200)	101.77 (14,760)	61
Nylon 66	40% Glass	198.71 (28,820)	103.35 (14,990)	52
Polycarbonate	None	62.74 (9100)	62.26 (9030)	99
Polycarbonate	10% Glass	81.36 (11,800)	70.33 (10,200)	86
Polycarbonate	30% Glass	120.66 (17,500)	77.50 (11,240)	64
Polycarbonate	40% Glass	144.79 (21,000)	79.98 (11,600)	55
Polypropylene	None	37.23 (5,400)	32.06 (4,650)	86
Polypropylene	30% Glass	67.57 (9,800)	22.96 (3,330)	34
Polypropylene	40% Glass	94.46 (13,700)	32.41 (4,700)	34
Styrene Acrylonitrile	None	77.91 (11,300)	66.36 (9,625)	80
Styrene Acrylonitrile	30% Glass	111.56 (16,180)	44.61 (6,470)	40
Polysulfone	None	66.19 (9,600)	66.19 (9,600)	100
Polysulfone	30% Glass	115.83 (16,800)	71.71 (10,400)	62
Acrylonitrile Butadiene Styrene	30% Glass	57.23 (8,300)	14.48 (2,100)	25
Polyacetal	30% Glass	86.18 (12,500)	39.30 (5,700)	46
Polyphthalamide	45% Glass	262.00 (38,000)	87.56 (12,700)	33
Polybutylene Terephthalate	30% Glass	115.14 (16,700)	67.57 (9,800)	59

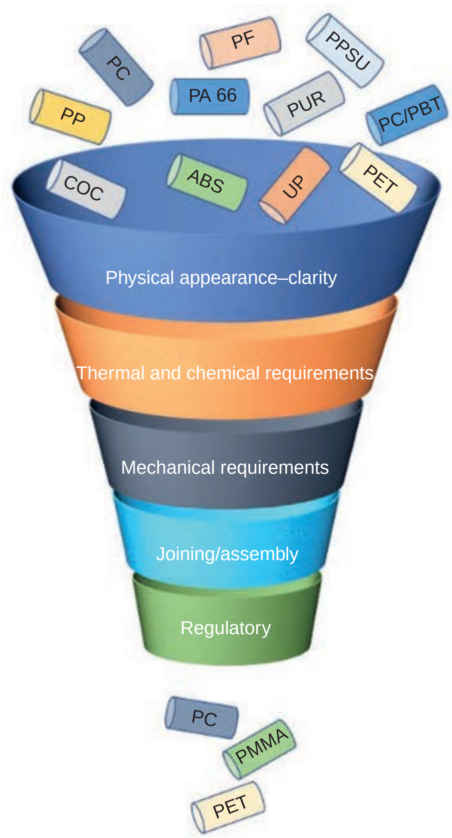

Fig. 3 The material selection funneling process

plays an important role in finding that perfect combination so that the part will function well mechanically and cosmetically for years. The first step in the material selection process, and perhaps the most important, is to understand the demands that will be placed on the material while it is in use. Going through a material selection process without understanding the requirements of the material is a recipe for part failure. In addition to knowing the forces the material might experience, anticipating the type of loads is equally important. For example, will the part be exposed to impact, or to constant and/or cyclic forces? Will material wear be an issue with this product? What electrical requirements will be required? Knowing the environment that the part will be exposed to is critically important. This includes the expected temperature range, moisture, ultraviolet light, and foreign substance exposure. If the product application is more unique, the environmental conditions will be more numerous and may go beyond those mentioned.

Material Selection Funneling Process

After the material requirements are known, the material selection process can begin. The method used most by industry starts with considering the all of 50 materials listed (and more) as possible candidates (Table 2). Since the selection process should be unbiased, it is **not** recommended to start with a phone call to a material supplier. The material supplier will become an important resource down the road, after the list has been narrowed to a handful or fewer. Most material suppliers will be able to provide excellent insight into their particular plastics. This should include input on how well their material is expected to perform in the application, as well as possible concerns. Many times, the material supplier will have physical property data that is not publicly available, in addition to experience with the material in a similar application.

The selection process or narrowing of candidate materials starts by asking key questions or listing the properties that the plastics must satisfy. At each question, plastics that do not meet the requirements are eliminated from the list. This process is called the material selection funneling process, as illustrated in Fig. 3. After all critical requirements are met, it is hoped that there is one or possibly a few materials left from which to choose. However, it is not uncommon that in the end there are no plastics meeting all of the requirements. If this occurs, there are several options:

- Expand the initial list of potential plastics beyond the original 50
- Consider additives, reinforcements, blends, and/or processing techniques to enhance material properties
- Conclude plastic may not be a viable candidate for the application. Consider another class of material. It is important not to convince yourself that a specific plastic material will meet all of the stated requirements.

Table 2 Primary plastic materials typically considered during material selection process

Type	Material	Abbreviation	Type	Material	Abbreviation
Amorphous			**Semi-crystalline**		
	Acrylonitrile-butadiene-styrene	ABS		Polypropylene	PP
	Acrylonitile styrene acrylic ester	ASA		Polyethylene	PE
	Cyclopolyolefine-copolymers	COC		Polyamide 6	PA6
	Polycarbonate	PC		Polyamide 6/6	PA6/6
	Polyetherimide	PEI		Polyamide 11	PA11
	Polyethylene terephthalate	PET		Polyamide 12	PA 12
	Polyimide	PI		Polyamide 4/6	PA4/6
	Polymethylmethacrylate	PMMA		Polyamide 6/12	PA6/12
	Polystyrene	PS		Polyphthalamide	PPA
	Polysulfone	PSU		Polyarylamide	PARA
	Polyphenylene sulfone	PPSU		Polybutylene terephthalate	PBT
	Polyethersulfone	PES		Liquid crystal polymer	LCP
	Polyphenylene ether	PPE/PPO		Polyoxymethylene	POM
	Polyethylene naphthalate	PEN		Polyphenylene sulfide	PPS
	poly(vinyl chloride)	PVC		Ethylene vinylacetate	EVA
	Chlorinated poly(vinyl chloride)	CPVC		Polyetheretherketone	PEEK
	Styrene acrylonitrile	SAN		Polytetrafluoroethylene	PTFE
	Polyamidimide	PAI		Polylactide	PLA
				Polymethylpentene	PMP
Elatomers			**Thermoset**		
	Thermoplastic polyurethane elastomer	TPU		Epoxy	EP
	Styrene ethene butene styrene	SEBS		Melamine	ME
	Ethylene propylene diene monomer rubber	EPDM		Phenolic	PF
				Unsaturated polyester	UP
	Styrene butadiene rubber	SBR		Polyurethane	PUR
	Acrylonitrile butadiene rubber	NBR		Vinyl ester	VE
	Silicone rubber	SI			
	Isoprene rubber	IR			
	Chloroprene rubber	CR			

Understanding and listing the requirements that the material must meet are key to any material selection process. Determining the latitude or flexibility of these requirements will be important as you narrow the list of available materials to a select few. Some requirements will be non-negotiable, while others can be modified. The order of posing the requirements to the material candidates will play a role in how efficient the material selection process occurs. It is recommended to apply the most critical and important requirements first. This will likely eliminate a larger number of materials from consideration early in the process. The least important requirements should be considered afterward. This will allow the engineer to tweak or relax some requirements if needed to increase the number of suitable material candidates at the end of the funneling processing.

Each material selection process will have its own set of requirements. To start, get a feel for what and how the part will be used, and why a plastic is being considered. Some common requirements and questions to put forth are:

- Is this a medical device, consumable/packaging, automotive, used for water management, heat and ventilating, electronics, etc.?
- Does the material need to be transparent? If the answer to this requirement is yes, many materials are going to be eliminated quickly from consideration. Most semi-crystalline and thermoset materials will be eliminated, along with the use of reinforcements. A follow-up question could be: How transparent does the material have to be? Does it need to be water-clear, or can it be translucent?
- What regulatory requirements need to be met? For example:
  - NSF/ANSI for water contact
  - FDA for food contact
  - USP for pharmaceuticals
  - RoHS that restricts the use of 10 substances in plastic
  - Flammability requirements such as those specified under UL 94
- What are the magnitude and type of forces the part will be subjected to? If the force is cyclic, fatigue issues must be considered. If the force is constant, creep issues need to be considered. If cyclic or constant forces are applied, the maximum force/stress the material can experience relative to its maximum tensile strength needs to be significantly reduced. There is no exact number that can be given for this reduction.
- What is the temperature range at which the part will be expected to perform? Figure 4 provides a relative temperature use scale of various polymers. It is important to know the glass transition temperature of the material. If the material is semi-crystalline, in most situations it is acceptable that the material goes through its glass transition temperature. However, the change in material properties that will result should be understood and

considered. If the part is expected to be exposed to high temperatures, the material selection will likely be narrowed to the so-called "engineered plastics" or perhaps a thermoset.

- What manufacturing process will be used to make the part? If the part will be injection molded, the ability of the material to fill the mold, along with part shrinkage and warpage, are issues that can create manufacturing failures. If the part is relatively thin, a material that is highly shear-thinning (thixotropic) or grades with flow enhancers are an option.
- Where is the part going to be molded? Using an offshore molder will make the material selection process more challenging, since the materials available in North America are not always available in other countries. Furthermore, procuring material for testing can be laborious.
- How is the part going to be assembled relative to other parts? If a welding process is going to be used, thermoset materials will not be an option. Adhesives can be used for most plastics, but this will be challenging with polyolefins and it is usually the most expensive and time consuming option. As with welding, once the part is assembled with adhesives, the assembly cannot be undone. Fasteners are likely the most versatile option, but they will require bosses that will add weight to the part. Snap fits are an option for most plastic materials, but this requires additional considerations and engineering/design for proper implementation.
- What materials can your molder process? Most molders have experience with molding certain materials. If the molder has been selected, it is critical to know those materials with which they are most familiar. This is a requirement that may be asked near the end of the material selection process. If this requirement eliminates all remaining materials in the funneling process, it may be necessary to find a different molder.

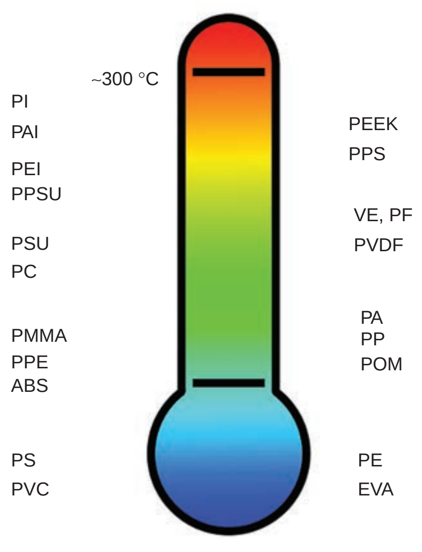

Fig. 4 Relative temperature use scale of various plastics. PI, Polyimide; PAI, Polyamidimide; PEI, Polyetherimide; PPSU, Polyphenylene sulfone; PSU, Polysulfone; PC, Polycarbonate; PMMA, Polymethylmethacrylate; PPE, Polyphenylene ether; ABS, Acrylonitrile-butadiene-styrene; PS, Polystyrene; PVC, poly(vinyl chloride); PEEK, Polyetheretherketone; PPS, Polyphenylene sulfide; VE, Vinyl ester; PF, Phenolic; PVDF, Polyvinylidene difluoride; PA, Polyamide; PP, Polypropylene; POM, Polyoxymethylene; PE, Polyethylene; EVA, Ethylene vinylacetate

Case Study: Plastic Bushing

General use: The part is a plastic bushing used between a metal rod and a roller (Fig. 5).

General dimensions: 30 mm long, 35 mm in diameter, 2.5 mm nominal thickness.

Requirements: 15 MPa (2175.57 psi) tensile/compressive stress, dimensional stability, low coefficient friction, good wear properties.

Environment: Indoor industrial, 23 to 40 °C, humidity, various lubricants.

Manufacturing: Injection molding in the U.S., molder not chosen.

Regulatory: None.

Going through the requirements of the material and using the funneling process to narrow to a few materials, one can quickly eliminate most amorphous materials due to the lubricant exposure and the need for abrasion resistance. Although an amorphous plastic would provide better molding dimensional stability, the part complexity is relatively low and should not be an issue for a properly molded semicrystalline plastic. The temperature demands are low; thus, a highly engineered thermoplastic or thermoset is not required but could be an option if environmental demands change. Three materials that remain after the funneling process are polyacetal (POM), polyamide (PA), and aliphatic polyketone (POK). These three materials have excellent abrasion resistance and satisfy the required mechanical properties. Although the POK material is not as tough as PA 66, for this application it will work well. POK is not hygroscopic; thus, dimensional stability and performance in a changing humid environment are attractive. Further, the supply constraints that have been common with PA and POM have not been an issue with POK. The cost of POK is similar to that of PA and POM.

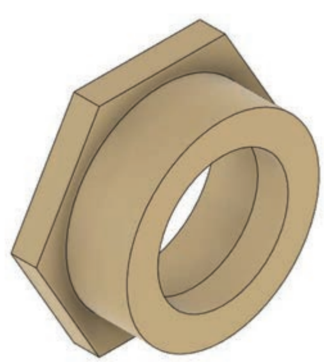

Fig. 5 Plastic bushing

Use of Material Datasheets for Material Selection

The material selection process will involve the use of material datasheets. These datasheets are available from the resin manufacturer, or they can also be found at several websites, including UL Prospector (Ref 10), CAMPUS (Ref 11), and MatWeb (Ref 12). These datasheets can provide a great quantity of pertinent information for the material selection process. They can also give ambiguous information that should be ignored, such as "chemical resistant."

Single-Point Material Property Data

Information typically found in material datasheets includes:

- General Background Information
  - Regions of the world where the material is available
  - Reinforcements and additives in the grade of resin
  - Standards and industry specifications that have been met
  - Yellow card availability
- Physical Properties
  - Density
  - Melt volume-flow rate
  - Mold shrinkage
  - Water absorption
  - Viscosity number
- Mechanical Properties
  - Tensile strength and modulus
  - Flexural strength and modulus
  - Tensile creep modulus
  - Compressive strength
  - Poisson's ratio
- Impact
  - Charpy (notched and unnotched strength)
  - Izod (notched and unnotched strength)
- Thermal
  - Heat deflection temperature
  - Glass transition temperature
  - Melting temperature
  - Ball pressure test
  - Coefficient of linear thermal expansion
  - Thermal diffusivity
- Electrical
  - Volume and surface resistivity
  - Dissipation factor
- Flammability
  - Burning rate
  - UL 94 flammability rating
  - Glow wire ignition temperature
- Molding
  - Ejection temperature
  - Melt density

- ○ Specific heat of melt
- ○ Thermal conductivity of melt
- ○ Drying temperature
- ○ Injection rate
- ○ Processing temperatures
- ○ Hold pressure time
- ○ Hot runner temperatures
- ○ Maximum screw tangential speed

Multi-Point Material Property Data

All the mechanical and thermal data listed are single point data—data from a single point in time and at one temperature, which is typically 23 °C. However, plastic materials are highly temperature and time dependent. It is nearly impossible to estimate the tensile modulus or strength at different temperatures. In addition, the modulus is nonlinear over strain and temperature. Better material selection decisions are made using multipoint data at conditions that best represent what the part will experience in the field. For a very select and limited number of materials, multipoint data can be found, such as Ref: 10, 11:

- Stress-strain curves at various temperatures
- Modulus versus temperature
- Fatigue behavior
- Creep modulus vs. time
- Specific volume vs. temperature
- Coefficient of thermal expansion vs. temperature

For example, the single point modulus for Zytel 70G33HS1L NC010, which is a 33% glass reinforced polyamide, is listed as having a modulus of 11000 MPa (1595415.1 psi) (dry) and 8000 MPa (1160302 psi) (conditioned), and a strength of 200 MPa (29007.5 psi) (dry) and 140 MPa (20305.3) (conditioned) (Ref 10). (Zytel is a registered trademark of DuPont.) These datapoints were tested at 23 °C following ISO 537-2. Figure 6 shows the isothermal stress vs. strain at various temperatures and moisture conditions for this material. Figure 7 shows the modulus of this material from −20 to 220 °C (dry). It would be a mistake to assume that the strength or modulus of this material does not change significantly at elevated temperatures or moisture conditions.

If multi-point data is critical for the application and it is not available, material testing should be considered.

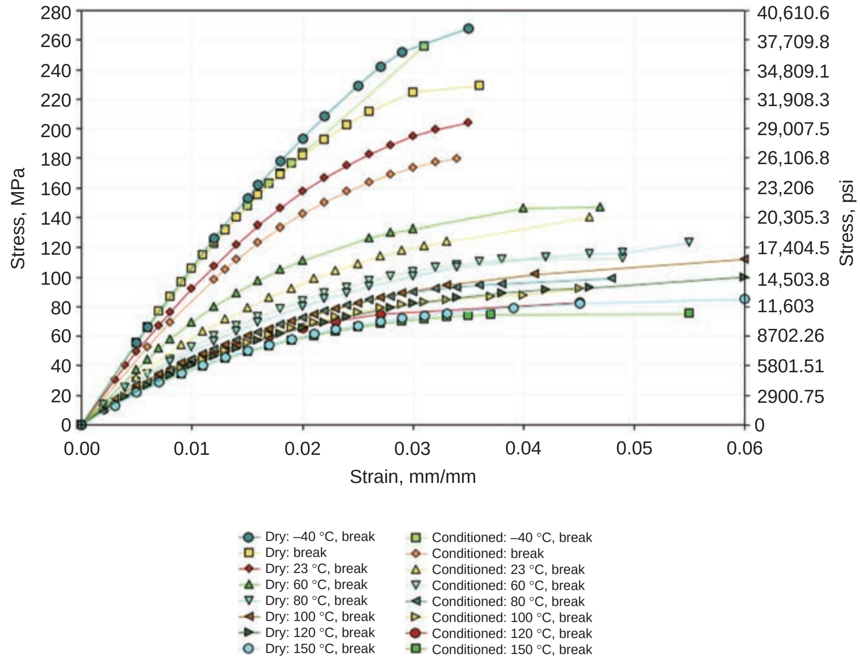

Fig. 6 Isothermal stress vs. strain at various conditions for Zytel 70G33HS1L NC010. Source: Ref 10

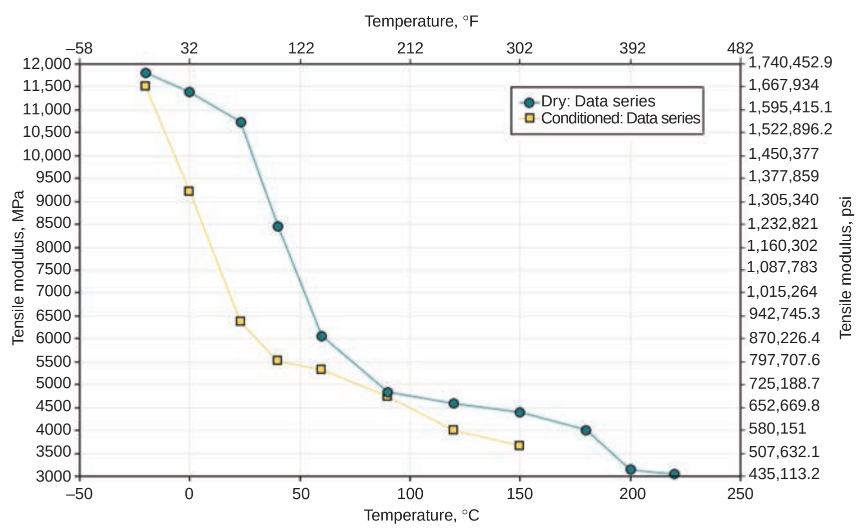

Fig. 7 Tensile modulus vs. temperature for Zytel 70G33HS1L NC010. Source: Ref 10

Case Study: Selecting a New Material after Cracking Occurred

General use: The part is a plastic electrical connector (Fig. 8)

General dimensions: 35 mm long, 20 mm wide, 5 mm deep, 2.3 mm nominal thickness.

Requirements: 45 MPa (6526.7 psi) continuous tensile stress, resistant to automotive oil.

Environment: Outdoor, −40 to 50 °C, humidity, lubricants.

Manufacturing: Injection molding in North America.

Regulatory: None.

Situation: The sidewall of the electrical connector that was exposed to 45 MPa (6526.7 psi) of continuous tensile stress formed a crack 7 to 21 days after assembly, but prior to being placed in the field (temperature did not play a role in the failure). The material used was unreinforced polybutylene terephthalate (PBT) Celanex 2360. (Celanex is a registered trademark of Celanese Corporation.) This is a semicrystalline plastic with a tensile strength of 55 MPa (7977.08 psi), a modulus of 3000 MPa (435113.2 psi), and a strain at break of 2.5%. In general, PBT is an ideal material for this application since it has the appropriate electrical properties and chemical resistance. A failure analysis was performed, which indicated the mode of failure was brittle with signs of micro-ductility. The cause of failure was creep rupture caused by a stress that was below the yield point of the material, but too high for a continuous load. Reviewing multi-point data strain vs. time at different tensile forces for this material shows that at a tensile stress of 30 MPa (4351.13 psi) this material fails after approximately 1000 hours (Fig. 9) (Ref 11).

New Material Selection: The client preferred to stay with a PBT material since this had been approved for the application, and the mold was made for this material. This limitation forced the material selection process to investigate the use of fiber reinforcements. A 20% glass reinforced PBT Celanex 2360 was investigated as a possible replacement. This material has a stress at break/yield of 120 MPa (17404.5 psi), a modulus of 8000 MPa (1160302 psi), and a strain at break of 2.5%. A review of multi-point data strain vs. time at different tensile forces for this material showed that at a tensile stress of 45 MPa (6526.7 psi) the material would have a strain of approximately 1% and no indications of failure at 10,000 hours (Fig. 10) (Ref 11). With a 50% increase in tensile force, failure was not observed after 10,000 hours. The mold did require some modest modifications because of the glass fiber. Overall, this material change proved to be successful with a high confidence that the product would survive its expected lifetime.

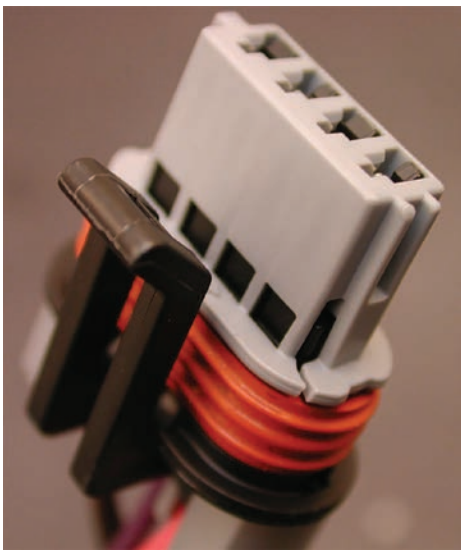

Fig. 8 A new material was needed after cracking occurred in this electrical connector.

Post Material Selection

The plastic material selection process does not end once the part has been successfully molded and is being sold into the field. The engineer needs to ensure that the correct material is being received and that molding is creating the appropriate crystalline structure and is not abusing the material.

Confirmation of Resin Received by Supplier

The first course of action is to implement some type of quality control program to ensure the material being put into the hopper is not changing, and the material coming out of the mold is not being adversely affected by the molding process. There are four primary material aspects to test for, and this should ideally occur every time a new batch of material or parts is received. These tests are relatively inexpensive and easy to implement, especially if one considers the ramifications of a part being made from the wrong material:

- Material identification with Fourier transform infrared spectroscopy (FTIR). This analytical testing technique is well established in the plastics industry as a method to identify the base resin and any possible contamination.
- Insight into the quantity of reinforcements, additives, and fillers using thermogravimetric analysis (TGA). These are added at specific levels to the polymer to increase material behavior. Some identification can be provided using FTIR and energy dispersive x-ray spectroscopy (EDS) on the remaining ash.
- Relative molecular weight of the resin before and after molding using melt flow rate (MFR). This testing method uses ASTM D1238 to provide a comparative number that should not shift more than 30 to 40% for the unreinforced plastic. Since many of the properties of the plastic are a direct result of the plastic's molecular weight, knowing it prior to molding, as well as the reduction caused by the molding process, can be an important quality control measure.
- Differential scanning calorimetry (DSC) to monitor the melt temperature and relative degree of crystallinity of the molded part. This technique will help assure that the molding process is not changing, as well as provide insight into any contamination that may occur.

Resist Value Engineering

Once the product is successfully being produced, there may be forces outside of engineering attempting to change the material to one that is less expensive. In these situations, it is common for purchasing to stay with the same base resin and level of additive and reinforcements while changing the grade or material supplier. It is rare that one material can be "plugged-in" for another without experiencing a change in properties. Further, it is likely that the substituted material is going to process differently, which is going to require that

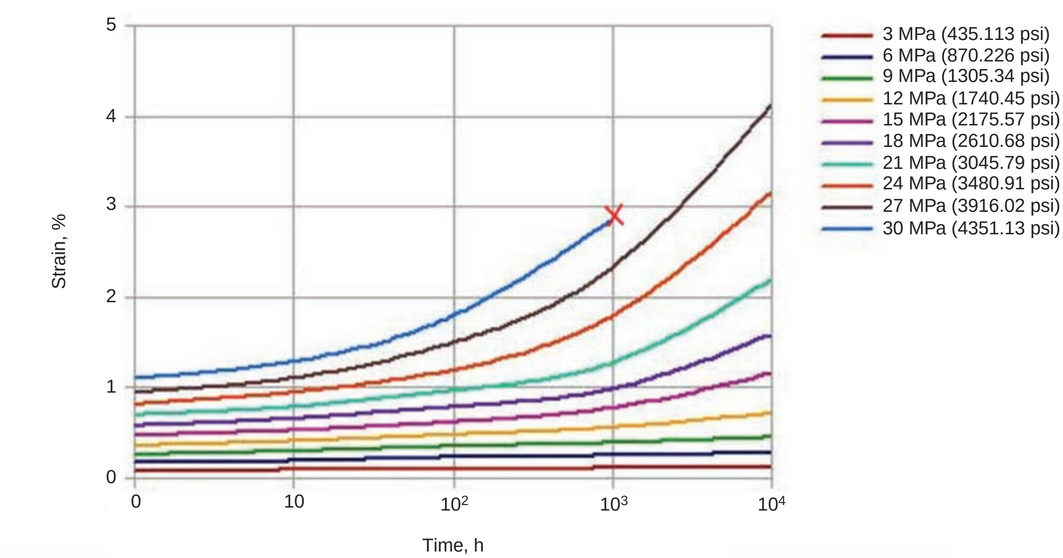

Fig. 9 Strain over time at constant loads for PBT Celanex 2360 FL. Failure occurs at 1,000 hours at 30 MPa of tensile load. Source: Ref 11

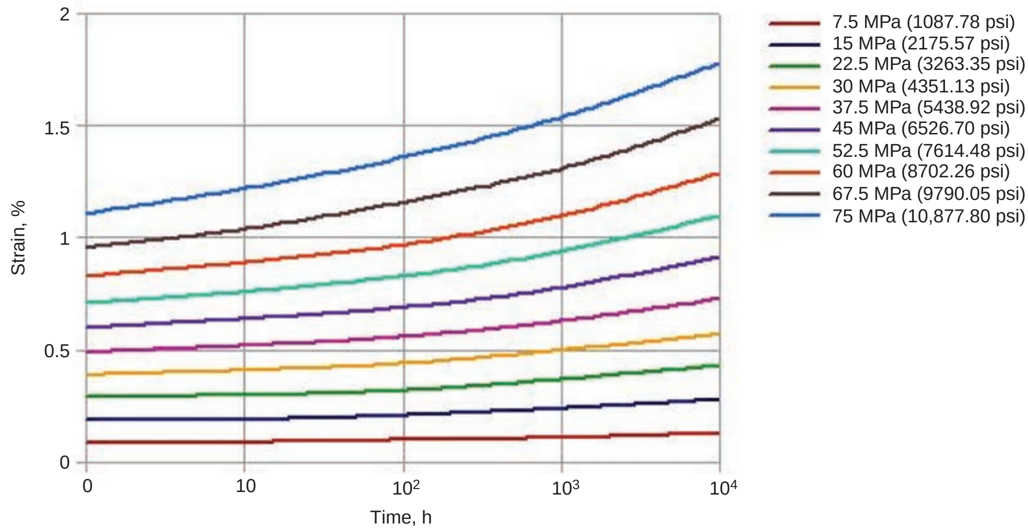

Fig. 10 Strain over time at constant loads for PBT Celanex 2360 GV1/20FL. No failure was observed at higher loads over 10,000 hours of constant load. Source: Ref 11

molding trials be redone. Prior to accepting the material change, it is recommended that a review of all costs associated with requalifying the new material be performed.

Finding a Backup Material

Even after the ideal material is chosen and the part is molding seamlessly and performing as expected, the material selection work is not yet done. Finding a backup material is the next critical step in the product development process (Ref 13).

What happens if your material supply is suddenly cut off? Molders are being informed at an accelerated rate that the material they are using will suddenly be unavailable for the foreseeable future. This is happening with many different types of resins, from materials that are lightly used to very popular ones. This leaves many molders scrambling at the eleventh hour to find a replacement to meet their client's production demands. This is especially true with the *Just in Time* inventory management strategy.

For plastic materials, it is recommended that this system be changed to *Just in Case*. This means that the material selection process be duplicated for one of the other materials that made it to the end of the funneling process. This includes running molding trials and performing material testing to ensure that the alternate resin is an adequate plug-in material.

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