

Material Selection*

Failures arising from hasty material selection are not uncommon in plastics or any other industry. In an application that demands high-impact resistance, a high-impact material must be specified. If the material is to be used outdoors for a long period, an Ultraviolet resistant (UV) material must be specified. For proper material selection, careful planning, a thorough understanding of plastic materials, and reasonable prototype testing are required. Plastics are viscoelastic materials. Viscoelasticity is defined as the tendency of plastics to respond to stress as if they were a combination of elastic solids and viscous fluids. This property possessed by all plastics to some degree, dictates that while plastics have solid-like characteristics such as elasticity, strength, and form stability, they also have liquid-like characteristics such as flow depending on time, temperature, rate, and amount of loading. This also means that unlike metals, ceramics and other traditional materials, plastics do not exhibit a linear stress-strain relationship. Designers accustomed to working with metals and other materials often make the mistake of selecting and specifying incorrect plastic materials. It is this non-linear relationship for plastics that makes an understanding of creep, stress relaxation, and fatigue properties extremely important.

Typically, for most designers the material selection process begins by reviewing the plastic material data sheets generally provided by the material suppliers. A misinterpretation of the data sheets is one of the most common reasons for selecting and specifying the wrong material, for a given application. First it is important to understand the purpose of a data sheet. Data sheets are useful only for comparing property values of different plastic materials such as the tensile strength of nylon versus polycarbonate or the impact strength of polystyrene versus ABS. Data sheets should be used for initial screenings of various materials. For example, if a designer is looking for a material that is strong and tough, he may start out by selecting materials whose reported values are higher than 7,000 psi tensile strength and impact strength values of better than 1.0 ft-lb/in and eliminating materials such as general purpose polystyrene, polypropylene, and polyethylene. Data sheets are never meant to be used for engineering design and final or ultimate material selections. First, the reported data is generally derived from the short term tests. Short term tests, as the name suggests, are the tests conducted without consideration of time, and the values derived are instantaneous. Tensile test, Izod impact test, and Heat Distortion Temperature, are the examples of such short term tests. Data reported on data sheets are also derived from single point measurements. These tests do not take into account the effect of time, temperature, environment, and chemicals, etc. A single number representing one point on a stress-strain curve cannot begin to convey plastics' behavior over a range of conditions. The standardized tests used to measure data sheet properties contain data measured in a laboratory under ideal conditions (as specified by ASTM or ISO standards) on standardized test specimens that bear little resemblance to the geometry of real-world parts. These tests likewise take place at temperatures, stress and strain rates that rarely corresponds to the real-world conditions (1).

The proper use of multi-point data for selecting the most appropriate plastic materials for the applications cannot be over emphasized. This point is well illustrated in a classic example of misinterpretation of published test data and the true meaning and usefulness of Heat Distortion Temperature (HDT) values. As discussed in Chapter 3, the

Heat Distortion Temperature test is a short term test conducted using standard test bars and laboratory conditions. The temperature values derived from this test for a particular plastic material is simply an indication of the temperature at which the test bar shall deform .010 in. under a specified load. The reported values are further distorted by factors such as residual stresses in the test bars, amount of load, and specimen thickness. This reported value is of limited practical importance and should not be used to select materials for applications requiring continuous exposure at elevated temperatures. Continuous use temperature data such as UL temperature index is a better indication of how plastic materials will perform for extended period at elevated temperatures. Table 15-1 shows temperature data derived from two different test methods.

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

If a designer were to select the material solely based on published heat deflection temperature data without understanding the true meaning of the test, test limitations and how the values are derived, the result could be disastrous. Note that the continuous use temperature for commercial grade of 40% Glass reinforced Polyphenylene Sulfide (PPS) is only 338°F while the Heat deflection temperature data derived from a short term test is greater than 500°F indicating that this material is not suitable in applications requiring continuous exposure to heat over 338°F.

Material Selection using multi-Point data

As discussed, material selection difficulties stem from limited availability of multi-point data from the material suppliers. Data sheets with single-point measurement data are readily available. However, with a little effort, the designers can find multi-point data from the sources such as CAMPUS (2) and IDES (3) and from all leading material suppliers. Multi-point data is presented in the form of chart and graphs of shear modulus versus temperature, isochronous stress-strain curves, and creep data at a minimum of three different temperatures and four stress levels. While designing a product to withstand multiple impact loads, the designer must take into consideration the data generated from instrumented impact tests which can provide valuable information such as ductile to brittle transition and behavior of the specimen during the entire impact event. Modulus values are also often misinterpreted. The flexural modulus values which are

derived from single-point measurement are frequently accepted as the indication of the stiffness of the material over a long period. Flexural modulus tests are conducted at a very low strain and generally represent only the linear portion of the stress-strain curve. The reported values do not correspond well with the actual use conditions and they tend to over predict the stiffness of the actual part. Plastic parts often fail due to the lack of consideration of creep values in material selection process. Plastics can creep or deform under a very small load at a very low strain, even at room temperature. Creep or apparent modulus data for the plastic materials over a long period at several temperatures should be evaluated.

Material Selection process

The material selection should not be solely based on cost. A systematic approach to material selection process is necessary in order to select the best material for any application. The proper material selection technique involves carefully defining the application requirement in terms of mechanical, thermal, environmental, electrical and chemical properties. In many instances, it makes sense to design a thinner wall part taking advantage of the stiffness-to-weight ratio offered by higher-priced, fast cycling engineering materials (4). Many companies including material suppliers have developed software to assist in material selection simply by selecting application requirement in the order of importance. Material selection process starts with carefully defining the requirements and narrowing down the choices by the process of elimination. Designer must identify application requirements including mechanical, thermal, environmental and chemical. All special needs such as outdoor UV exposure, light transmission, fatigue, creep, stress relaxation, and regulatory requirements must be considered. Processing techniques and assembly methods play a key role in selecting appropriate material and should be given consideration. Many plastics materials are susceptible to chemical attack and therefore behavior of plastics material in chemical environment is one of the most important considerations in selecting material. No single property defines material's ability to perform in a given chemical environment and factors such as external or molded-in stresses, length of exposure, temperature, chemical concentration etc. should be carefully scrutinized. Some of the common pitfalls in material selection process are relying on published material property data, misinterpretation of data sheets and blindly accepting material supplier's recommendations. Material property data sheets should only be used for screening various types and grades of materials and not for ultimate selection or engineering design. As discussed earlier, the reported data is generally derived from short term tests and single point measurements under laboratory condition using standard test bars. The published values are generally higher and do not correlate well with actual use conditions. Such data does not take into account the effect of time, temperature, environment and chemicals. Figure 15.4 shows a typical failure arising from improper material selection.

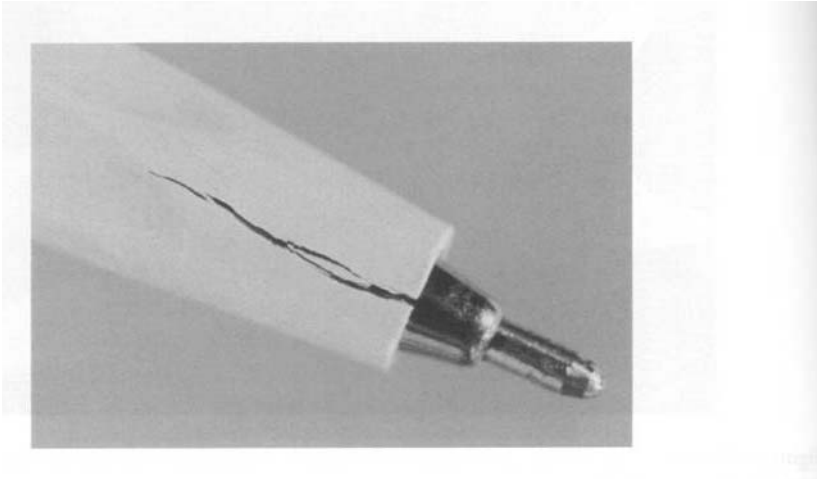


Figure 15-4

In order to assist designers with material selection process, material supplier have developed a comprehensive checklist such as one illustrated in figure 15-5.

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	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
sink marks	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
weld lines	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

Comments: _____

Critical structural areas — *please attach sketch*

Comments: _____

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15-5 Partial Checklist

Key considerations are:

Mechanical Properties

- Tensile strength and Modulus
- Flexural strength and Modulus
- Impact strength
- Compressive strength
- Fatigue endurance
- Creep
- Stress-relaxation

Both short and long term property data must be evaluated; Short term data for quick comparison and screening of the candidates and long term data for final material selection. Creep and stress relaxation data which represents deformation under load over a long period needs to be scrutinized over the usable range of temperatures. Isochronous stress-strain curves are very useful for comparing different materials on equal time basis. Multi-point impact data obtained from instrumented impact test which provide more meaningful information such as energy at a given strain or total energy at break must be taken into account. Plastic parts often fail due to the lack of consideration of sudden loss of impact in a very cold environment. Multi-point low temperature impact data, although generally not found on data sheets, is available from all major material suppliers.

Thermal Properties

As discussed earlier in the chapter short term values such as heat distortion temperature, Vicat softening point should only be used for initial screening. Meaningful values derived from continuous use temperature and co-efficient of thermal expansion test are more helpful for final material selection. Figure 15-6 shows the example of failed part resulting from selecting incorrect material based on short-term thermal test data.



Figure 15-6

Plastic materials tend to expand and contract anywhere from seven to ten times more than conventional materials like metals, wood and ceramics. Designers must be well aware of this and special consideration must be given if dissimilar materials are to be

assembled. The thermal expansion differences can develop internal stresses from push-pull effect along with internal stresses and cause the parts to fail prematurely. The restraining of the tendency of a piping system to expand/contract can result in significant stress reactions in pipe and fittings, or between the piping and its supporting structure. The allowing of a moderate change in length of an installed piping system as a consequence of a temperature change is generally beneficial, regardless of the piping material, in that it tends to reduce and redistribute the stresses that are generated should the tendency for a dimensional change be fully restrained. Thus, allowing controlled expansion/contraction to take place in one part of a piping system is an accepted means to prevent added stresses to rise to levels in other parts of the system that could compromise the performance of, or cause damage to the structural integrity of a piping component, or to the structure which supports the piping (5). Figure 15-7 illustrates a typical expansion loop and an expansion joint installed to compensate for expansion and contraction.

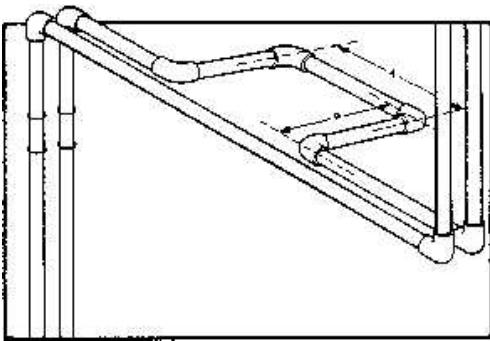


Figure 15-7

Exposure to Chemicals

One of the most important considerations in selecting the right material is its resistance to various chemicals. As discussed earlier, the resistance of plastics to various chemicals is dependent on time of contact with chemicals, temperature, molded-in or external stress, and concentration of the chemical. Part design and processing practices play a major role in material's ability to withstand chemical attack. For example, stress concentration factor increases significantly for the parts designed with radius to wall thickness ratio of less than 0.4. As a rule, crystalline polymers are more resistant to chemicals when compared to amorphous polymers (Figure 15-8) and therefore if the application requires the parts to be constantly exposed to chemicals, crystalline materials should be given serious consideration.

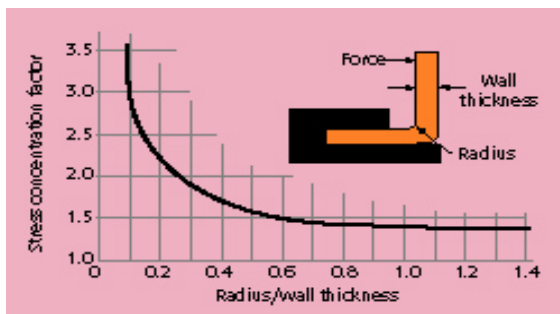


Figure 15-8

Chemical exposure to plastic parts may result in physical degradation such as stress cracking, softening, swelling, discoloration, and chemical attack in terms of reaction of chemicals with polymers and loss of properties. Figure 15-9 shows premature failure of a part that was exposed to aggressive chemicals.



Figure 15-9

Environmental Considerations

Plastic materials are sensitive to environmental conditions. Environmental considerations include exposure to UV, IR, X-ray, high humidity, weather extremes, pollution from industrial chemicals, micro-organisms, bacteria, fungus, and mold. The combined effect of various factors may be much more severe than any single factor and the degradation process is accelerated many times. It is very important to understand that the published test results do not include synergistic effects of various environmental factors, which almost always exist in real life situations. Designers should consider exposing fabricated parts to environmental extremes much similar to the ones encountered during the actual use of the product.

Regulatory Approval Requirements

Material selection may be driven by the regulatory requirements put forth by agencies such as Underwriters Laboratories (UL), National Sanitation Foundation (NSF), Food and Drug Administration (FDA) in terms of flammability, pressure ratings, and toxicological considerations.

Economics

As discussed earlier, material selection should not be driven by cost alone. The most logical approach calls for choosing 3 to 4 top candidates based on requirements and select one of them with economic considerations.

Other Considerations

Material selection process must also address processing considerations such as type of fabrication process, secondary operations, and component assembly.

- * From *Handbook of Testing and Failure Analysis*, 3rd edition by Vishu Shah, John Wiley & Sons.

