How precipitous Material Selection can

lead to Premature Part Failures? *

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 (UV)-resistant 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 nonlinear 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 7000-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 are 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, chemicals, and so on. 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 rates, and strain rates that rarely correspond to the real-world conditions.

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.

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 0.010 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 an extended period at elevated temperatures. Table below shows temperature data derived from two different test methods. 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 a 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.

HDT vs. Continuous-Use Temperature (UL Temperature Index)

Material	HDT	Continuous Use Temperature
Ryton R-4 (Polypropylene Sulfide)	➢ 500 °F	338 °F
Ultem 4000 (Polyetherimide)	412 °F	122 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 and Prospector and from all leading material suppliers. Multi-point data are 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. Many companies including material suppliers have developed software to assist in material selection simply by selecting application requirement in the order of importance. The material selection process starts with carefully defining the requirements and narrowing down the choices by the process of elimination. The 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 a 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, and so on, 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 are generally derived from short-term tests and single-point measurements under laboratory conditions using standard test bars. The published values are generally higher and do not correlate well with actual use conditions. Such data do not take into account the effect of time, temperature, environment, and chemicals.

In order to assist designers with the material selection process, material supplier have developed a comprehensive checklist such as one illustrated in Figure 1

Key considerations are as follows.

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 represent deformation under load over a long period, need to be scrutinized over the usable range of temperatures. Isochronous stress–strain curves are very useful for comparing different materials on an 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.

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: ______________________

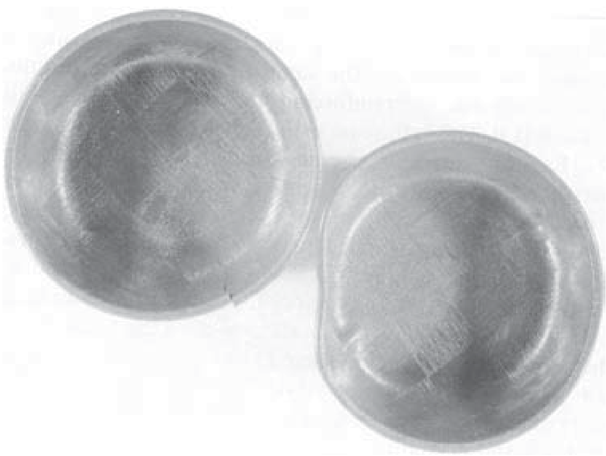
Critical appearance areas* — *please attach sketch

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

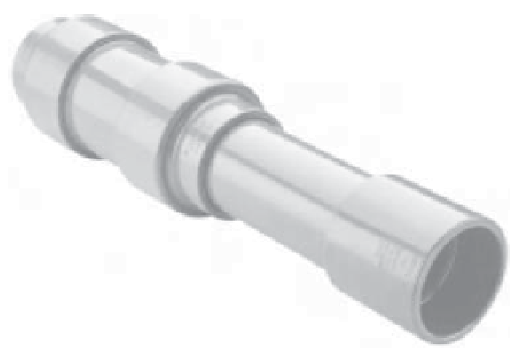
Comments: ______________________

Thermal Properties

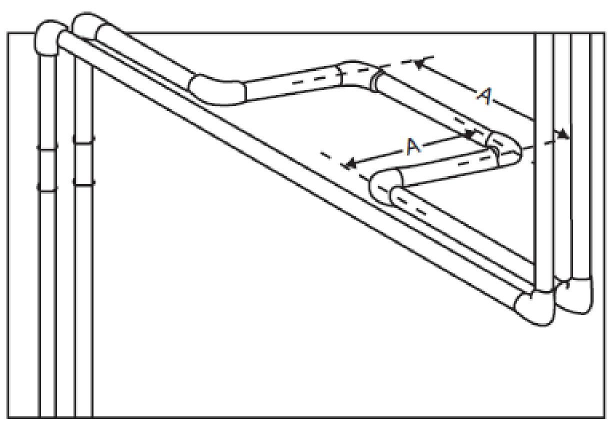
As discussed earlier in the chapter, short-term values such as heat distortion temperature and Vicat softening point should only be used for initial screening. Meaningful values derived from continuous-use temperature and coefficient of thermal expansion test are more helpful for final material selection. Figure 2 below shows the example of a failed part resulting from selecting incorrect material based on short-term thermal test data.



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. Figure 3 below illustrates a typical expansion loop and an expansion joint installed to compensate for expansion and contraction.



(*a*)



(*b*)

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 a material's ability to withstand chemical attack. For example, the 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 4); therefore, if the application requires the parts to be constantly exposed to chemicals, crystalline materials should be given serious consideration. 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.

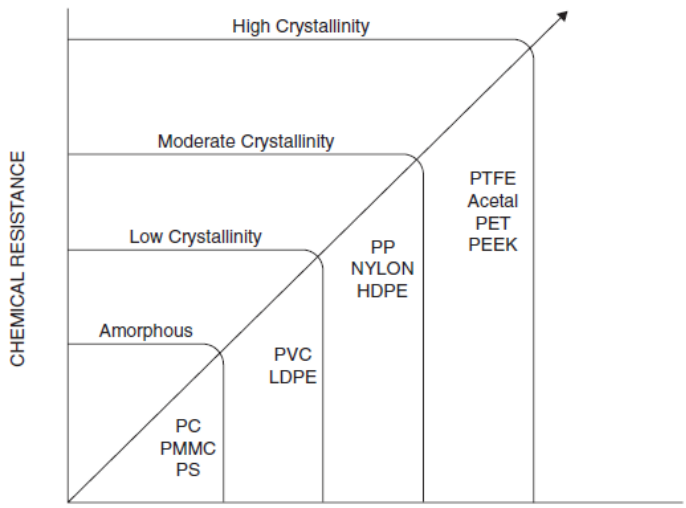


Figure 4

Figure 5 shows premature failure of a part that was exposed to aggressive chemicals.

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, microorganisms, bacteria, fungus, and mold. The combined effect of various factors may be much more severe than any single factor and the degradation process in 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), and 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 three to four top candidates based on requirements and selecting 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.

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