FAILURE OF THERMOSET VERSUS THERMOPLASTIC MATERIALS

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Abstract

Plastic materials can be divided into several classes, the most common being thermoset and thermoplastic. Within each of these groups there are subgroups that further define plastic. For example, a thermoplastic is generally classified as being semicrystalline or amorphous depending on the level of crystallinity that exists. All these different groups of plastics have unique properties that give an engineer numerous options when choosing for an application. Unfortunately, one common *property* of all plastics is their vulnerability to fail under certain conditions. Fortunately, conditions for failure to occur are also unique to each class or subclass of plastic - failure of an amorphous thermoplastic may not result in failure of a thermoset under similar conditions. It is the understanding and knowledge of what conditions cause failure in each class of plastic that an engineer must know to properly specify a material. This paper will shed some light on some differences between these two classes of materials.

Background of Plastics

There is no doubt that the unique properties of plastic makes it one of the most sought after materials in the world today. Their low weight, ability to be easily shaped or molded, low cost, rigidity or flexibility, and the ability to insulate are only a few of the characteristics that make plastics a popular option when designing a new product or replacing an existing non-plastic one. Products such as home siding, electrical components, medical devices, piping, disposable packaging, automotive body panels and engine components are all products that have successfully been made from plastic.

Plastic has been in use for over a millennia. South American Indians used natural rubber in the manufacture of waterproof containers, shoes and torches. Thanks to the development of new plastics and processing equipment, application of plastic in every industry has exploded over the last 50 years. Nearly everyone can think of at least one product that was once made of metal or wood that is now plastic.

Similar to every other material, as long as there have been plastic materials, there have been failures. Because plastics have been limited in use at elevated and sustained load bearing applications, their exposure to high profile losses has been relatively small. However, as industry becomes more comfortable with plastic, further utilizing and pushing the boundaries of its unique properties and cost savings, exposure to more critical applications will certainly increase. This is never more evident than in the current race to develop the next generation of passenger aircraft. Utilization of plastics in this extremely high profile, as well as structurally demanding, industry is the ultimate key to their success.

Plastics are a unique material that can behave quite differently under varying conditions. The degree of change in behavior is again unique to each class of plastics. This is an obvious distinction between thermoset and thermoplastic materials. Many thermoplastics are ductile under one condition, and with a relatively small change in condition are brittle. A common example of this is seen with Silly Putty®. If one pulls this material slowly it can be stretched almost indefinitely (ductile). However, if one pulls quickly on this material it breaks (brittle). Decreasing the temperature of the Silly Putty®, decreases the stretching rate at which it becomes brittle. In essence, thermoplastics have important properties that are temperature and time (rate) dependent – a characteristic that is not seen with other materials. On the other hand most properties of thermosets are more stable over *normal* conditions. If failure does occur it will more than likely be in a brittle mode. Both scenarios have their advantage, and again, it is up to the engineer to understand what situation applies best for the application at hand. If the engineer does not take this into account, a plastic part may be able to absorb loads under one condition, but completely fail under another condition – two conditions that might possibly be relatively close to one another.

Failure of Plastics

Knowledge of why a plastic part fails is extremely important. The old adage that *something cannot be fixed unless it is known why it failed* applies here more than ever. There are numerous reasons why a plastic part may fail. Was it due to the plastic not performing up to specification? Was the failure the result of an incorrect design? Was the plastic introduced to an unexpected environmental change? Under certain conditions plastics are designed to fail under certain conditions. One such example is a Formula 1® racecar crashing into the side of a wall. When an impact like this occurs the plastic body panels and other components are designed to absorb the energy and release it as they crack; keeping the energy away from the driver. This could be viewed as a plastic failure; however, the driver that walks away from this high-speed crash would probably have a different opinion.

Human causes of failure can generally be grouped into four categories: material, processing, design and use (abuse). A study done by Wright [1] analyzed over 3,000 failures and found that 45% of these failures are due to material, as shown in Fig. 1. Possibly, choosing a material that was better suited for the application may have resulted in the failure not occurring. Today, there are more materials to choose from than ever, especially in the realm of plastics. In addition, a wide variety of additives, fillers and reinforcements to improve against failure are available for the engineer to choose from.

Also analyzed in Wright's study were underlying causes of failure, Fig. 2. The primary being:

- Environmental Stress Cracking
- Fatigue
- Overload
- Creep
- Chemical Attack
- Ultraviolet Attack
- Temperature

As mentioned earlier, all plastics will fail under some condition that may not result in the failure of a different plastic. However, traditionally thermoset materials have better tolerance or larger operating range than thermoplastics. For example, resistance against common household chemicals is not a common problem with most thermoset materials. However, polycarbonate, a wonderful tough amorphous thermoplastic, is notorious for failing when exposed to relatively harmless chemicals, i.e. whiteboard cleaner and pens.

Fatigue of plastics is strongly dependent on temperature, part surface finish, frequency of loading, etc. The results of fatigue tests are typically plotted on S-N curves – stress versus number of cycles to failure. Figure 3 shows S-N curves for various materials at a frequency of 30Hz [2]. A thermoset material, epoxy, shows a higher fatigue strength than the thermoplastics. This is due to the fact that thermoset materials have a greater rigidity and lower internal dampening (friction), which leads to reduced temperature rise during cycle loading.

Thermoset materials are typically more brittle than thermoplastic materials. This is well known and should be considered when designing with them. However, when glass is added to thermoplastic materials to increase stiffness to a level that is par with thermosets, the energy absorption before cracking occurs decreases dramatically. Figure 4 shows how the impact resistance of Nylon 6™ is dramatically reduced with the addition of 6% and 30% glass reinforcement [2].

Perhaps the operating condition that thermosets perform better than thermoplastics is at high temperatures. Figure 5 shows the modulus for various thermoplastics and thermosets over a large temperature range [3]. The two materials that have the highest modulus over a greater temperature range are thermosets, the other are thermoplastic. From this graph it is obvious these materials will outperform (in terms of stiffness) the Nylon at higher temperatures. This is clearly shown in Fig. 6 of a 4.6 liter Crown Victor intake manifold made of Nylon. A crack formed on this manifold after being exposed to the high temperature conditions around the engine. Thermoset materials have been successfully used in under-the-hood applications for over a decade. Over 60 million valve covers from thermoset polyester have been produced without one material related failure [4].

Analyzing Plastic Failures

There are several steps that can be taken while analyzing a plastic failure. One of the first steps begins with collecting as much historical information as possible. This includes information such as the age of the product, when and under what conditions did the failure occur, previous conditions that the part may have been exposed to, what stress or loads was the part under, did any of these conditions recently change. This information could be critical to help determine the cause of the failure. For example, if one finds that a plastic component was recently cleaned with a solvent that the plastic is not resistant too, this would be investigated further to determine its role in the failure.

This next step is a visual examination of the failed part is done. Cosmetically displeasing features on the part may point to improper processing conditions. Burn marks on the part may indicate degradation during processing. Degradation of the polymer's molecular structure may adversely affect its mechanical properties. Likewise, sink marks on the part may also indicate improper conditions were used during the making of the part. Some troubleshooting techniques when cosmetic failures occur are given in [5-6]

Visual examination will also disclose the extent of assembly and consumer abuse. Gouges and deep marks in the plastic show signs of possible excessive use of the part. A foreign substance, such as a liquid, on the part should be investigated for possibly chemical attack on the plastic.

After macroscopic visual examination is completed higher-end microscopy can be utilized. A scanning electron microscope can be used to find fingerprints of stress overload, chemical attack, fatigue, environmental stress cracking, and much more. This gives the engineer a powerful tool for determining the cause of failure.

An important part of failure analysis may be to determine what the part is made of. At times this could simply be determining if the plastic is a thermoset or thermoplastic. Verifying what type of thermoplastic or thermoset the resin is, along with the additives, fillers and amount of reinforcements can be done. Identification of the plastic recipe is an important step in many failure analyses. This is done due to the fact that a primary reason for a plastic part to fail is merely because the wrong material was used for the application. In a similar fashion, the failure may have been caused by the lack of an additive, such as, an impact modifier to increase ductility. There are several techniques that can be employed to accurately determine the type of plastic and all of its constituents [7]. Moreover, these techniques can also give an idea of the processing history that the plastic experienced.

As one moves forward with the investigation history on part processing may become critical. As illustrated in Fig. 1, incorrect processing is the underlying cause of many failures. A short list of reasons:

- Improper Moisture Content
- Inadequate Mixing
- Improper Barrel Temperatures
- Too High Residence Time in Barrel
- Excessive Shear Rates
- To High/Low Mold Temperatures
- Inadequate Packing
- Bad Gate/Charge Placement
- Chemical Exposure During Processing
- Cycle Time Too Short/Long

The order of tasks of a failure investigation will certainly be different for each failure. Each failure is typically quite unique, and the process of discerning the failure's 'smoking gun' is itself unique. There are numerous tools at the engineer's disposal to determine the cause of failure. These tools include high-end instruments, software and literature.

Conclusions

Failures of plastic components are being seen more often in industrial, household and commercial settings. Many of these failures involve high monetary losses and at times loss of life. These failures can be caused by improper material specification, bad design, over loading or incorrect molding conditions. Issues such as chemical resistance, environmental deterioration, geometric sensitivity, temperature dependence and aging are at times neglected. As plastics proliferate into more demanding applications proper material selection, design and processing will be increasingly important. Overlooking them may result in a costly product failure.

There are tools available to assist in determine the cause of most plastic failures. Even better is a proactive approach that uses these tools to predict when failure will occur and assist in choosing the best material for the applications; thermoplastic or thermoset.

References

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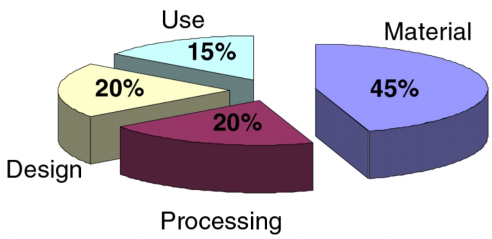

Figure 1. Human causes of plastic failure [1].

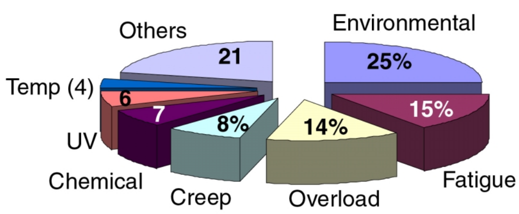

Figure 2. Root causes of plastic failure [1].

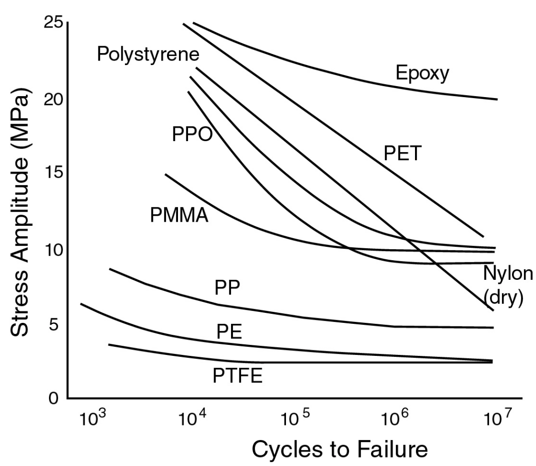

Figure 3 – Stress-Life (fatigue) curves for various plastics [2].

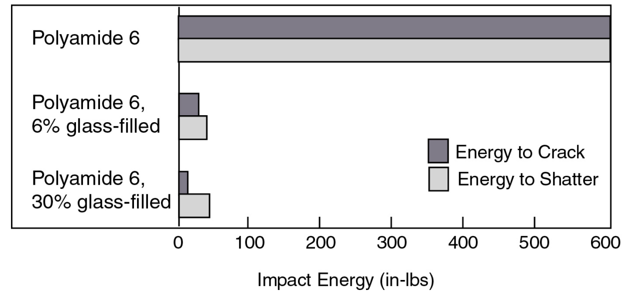

Figure 4 – Effect of glass fiber on energy to crack and shatter for polyamide 6 [2}.

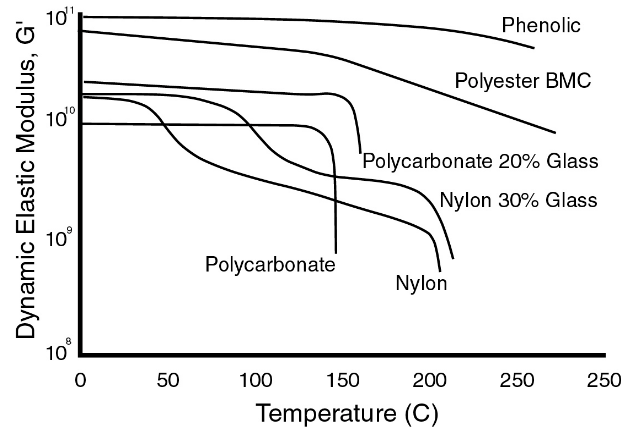

Figure 5- Modulus versus temperature for various thermoset and thermoplastics.

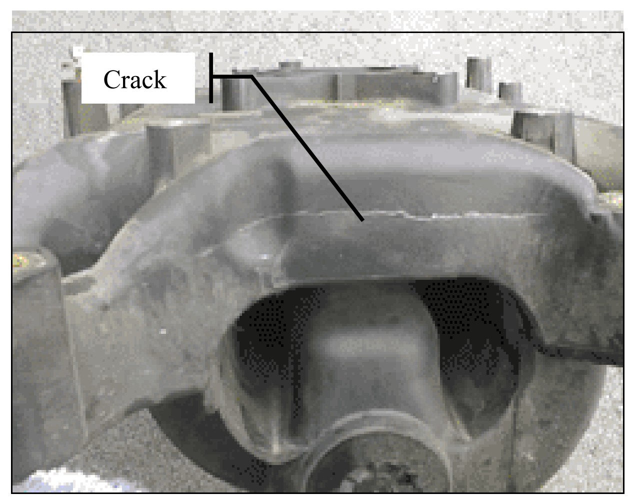

Figure 6- Failure of a Nylon 4.6 liter Crown Victor intake manifold [4].