TMG News

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MfP: Manufacturing for Performance

Erik Foltz

"When we try to pick out anything by itself, we find it hitched to everything else in the Universe." – *John Muir*

The increased use of plastics and composites in demanding, high-performance applications has highlighted many of the benefits of these materials. These materials have allowed many companies, around the world, to manufacture highly intricate parts, which have consolidated the number of parts required in an assembly while minimizing the overall weight. However, with the versatility and freedom these materials offer, the importance of taking a holistic approach in design and manufacturing is often overlooked. While resin suppliers have found good and efficient methods of synthesizing and compounding resins that have the potential of achieving properties that approach some metals, the ability of attaining those properties is often remote, and relies on proper processing of the resin. The schematic in **Figure 1** shows the distribution of tensile strength for 6061 T6 Aluminum and a 60% long-glass fiber nylon 6/6. Notice that the distribution of strength of the aluminum is very narrow, suggesting that the properties of that material are relatively consistent and less sensitive to how the material is stressed or formed into the part. Meanwhile, the long-glass fiber nylon material has the ability to achieve lower, but similar strength as the aluminum. However, the probability of achieving that strength is very low, and is more sensitive to the loading and manufacturing conditions used for the part. This article will look at important manufacturing factors that designers, toolmakers and molders need to consider to optimize performance of their polymeric materials.

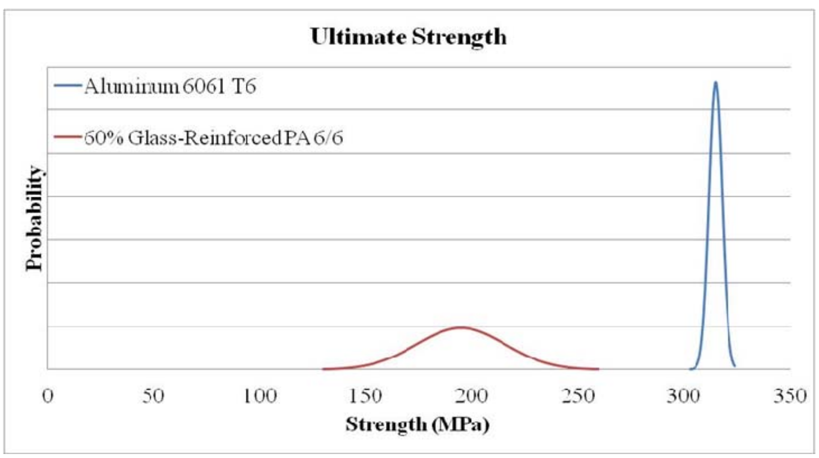

Figure 1: Schematic highlighting the expected ultimate strength of a glass-reinforced nylon 6/6 (PA 6/6) resin is much more variable than for a specimen of aluminum.

Proper Material Handling and Preparation

One of the most important factors in attaining the desired properties of a plastic resin is to maintain the natural attributes of the resin during processing. A significant amount of time is invested by companies in selecting the correct resin for the application. However, as the schematic in **Figure 1** suggests, the ability to attain those properties may be dependent on how the material is processed and how it is loaded. Maintaining the molecular weight of the polymer for unfilled materials or minimizing fiber breakage in fiber-filled resins is critical for achieving the desired properties. Performance factors such as tensile strength, toughness, abrasion resistance, and chemical resistance often are highly dependent on the length of the polymer chains or reinforcing fibers. Additionally, many of the factors that often lead to degradation of these materials occur while the material is being handled and prepared for the processing method. Ensuring the

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material is dried to the correct moisture level with the proper type of dryer, and is not simply dried for a certain amount of time at a certain temperature, is critical for some plastic resins. Additionally, minimizing the time spent being exposed to ambient conditions after exiting the dryer is also critical. Some resins can pick up enough moisture to cause molecular degradation during processing in only 10 minutes. Using a closed system from the dryer to the hopper can be a good option to minimize the potential for any degradation due to this moisture.

After ensuring the material is properly dried and has entered the barrel, it is also important to consider the conditions used to prepare and melt the polymer pellets. Resin suppliers provide general recommendations for melt temperature during processing. However, controlling the temperature of the polymer melt is not as simple as setting the barrel and nozzle heater bands to these temperatures. Examining the speed of the screw, the applied back pressure, and even the screw design itself, are critical for maintaining the natural attributes of the resin. Also, ensuring that the size of the barrel is correct for the application and the material is important. Some materials, such as polycarbonate, can be very thermally stable if properly dried and handled. However, other materials, such as poly(butylene terephthalate) (PBT), are much more sensitive to the amount of time spent in the barrel. Even using "recommended" processing conditions, PBT can experience molecular degradation because it remained in the barrel for too long.

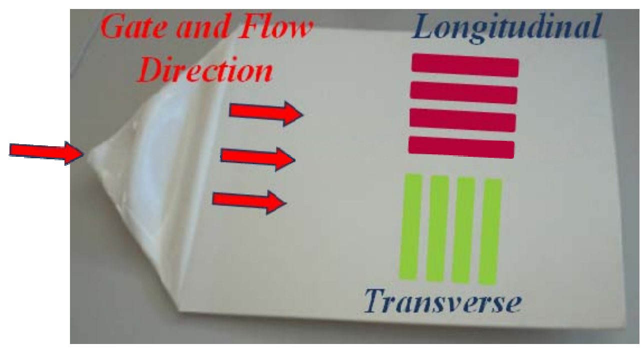

Figure 2: Tensile stress-strain graphs highlighting how the orientation of the molecules and fibers influences the performance of the material for a 60% glass-fiber filled nylon 6 material.

Proper Gate Location and Sizing

Another factor that is critical to part performance is the design and sizing of the feed system. The importance of the feed system is often minimized by processors and designers, because it is typically removed from the part prior to being placed in service. It is simply viewed as the path the material takes to get from the injection barrel into the cavity. However, the feed system design influences the final temperature of the molten polymer and often influences the settings used in the injection barrel. Of particular importance is the design and positioning of the gate. The gate is the location where the polymer is injected into the cavity and starts to form the part. It is typically a restrictive area of the mold, and can result in high deformation rates of the polymer melt. These high-stress conditions can lead to breaking of the long molecular chains, and a higher degree of molecular or fiber orientation in the part.

The gate location also influences where weld lines or knit lines form in the part, and how fiber reinforcements align in the part. Having weld lines or undesirable fiber orientation relative to the loading of the part, can result in a weakened part that is susceptible to failure. Allowing the molecular or fiber orientation in a part to align with the direction of loading, generally, will result in a stronger more durable part. **Figure 2** shows the tensile stress strain curves when the load is applied in the same direction as the fibers, and when it is aligned 90° to the fibers. Therefore, the same material will exhibit a very different performance based on the gate location. It is important to identify a gate location that pushes the polymer flow to align the fibers in the direction of high stress.

In addition to controlling the molecular and fiber orientation in a molded part, the gate also controls the stress distribution in the part. Typically, the areas near the gate exhibit higher molded-in stresses. Therefore, it is preferable to place the gate in non-critical regions, where the stress in service is minimized. Additionally, placing the gate in the thickest area of the part allows for a larger range of gate designs, and can help minimize the influence of any molded-in stress or molding defects. While in practice this sounds simplistic, the gate location is often decided after the design has been finalized, and is restricted in placement. Considering the influence of manufacturing, early on in the design process, can help to increase the chance for product performance success.

Proper Cooling and Cycling

Another factor that is often overlooked in manufacturing is of how the part is cooled. In the drive for efficiency and maximizing profits, one of the main objectives is to make a dimensionally stable part as quickly as possible. However, in addition to helping control how fast the parts can be manufactured, and the dimensional stability of the part, the cooling rate of the molten polymer also influences performance factors like appearance, chemical resistance, and molded-in stress. **Figures 3 and 4** show data collected by molding an unreinforced grade of nylon 6 at different mold temperatures. **Figure 3** highlights that while running a hotter mold will result in more shrinkage, it also suggests that molding the part at a higher mold temperature will result in less post-mold shrinkage. This will result in a more dimensionally stable part after ejection. **Figure 4** shows how increasing the mold surface temperature influences the crystallinity of the same resin (unreinforced nylon 6). As the mold temperature is increased, the crystallinity is also increased. Increasing the crystallinity of the resin can improve the chemical resistance of a resin and influence the mechanical properties. Therefore, while the short-term goal is to manufacture the parts as efficiently as possible, it needs to be considered that decisions in terms of short-term

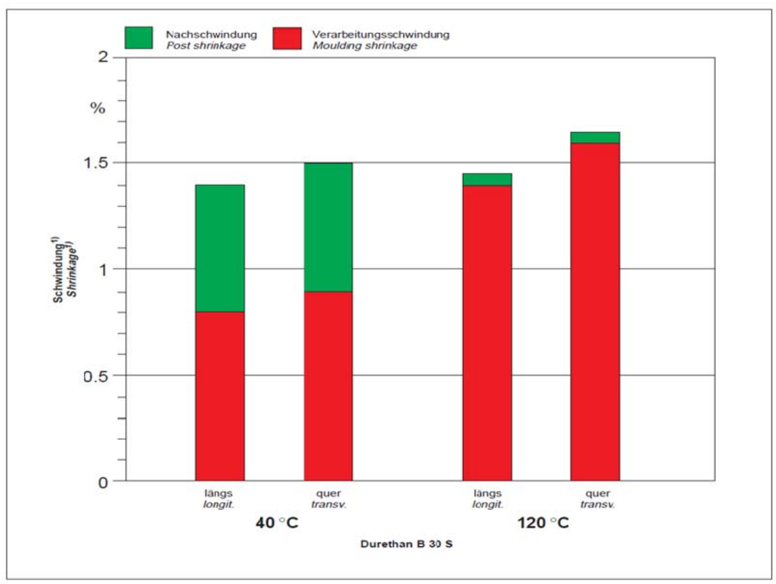

Figure 3: Graph highlighting how shrinkage of a plastic part changes in and out of the mold by altering the mold surface temperature. (Image source Bayer/Covestro)

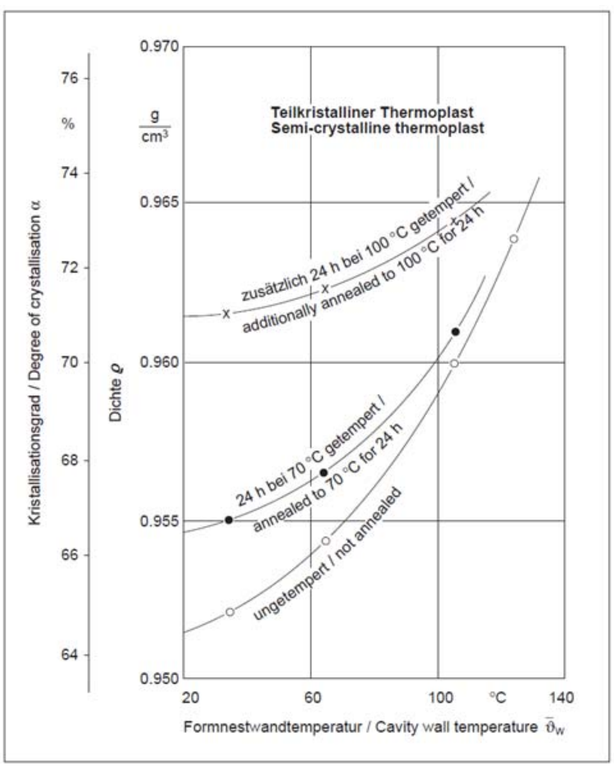

Figure 4: Graph highlighting how crystallinity of a part is increased by varying the mold surface temperature. (Image source Bayer/Covestro)

efficiency of molding can adversely affect the molded products' performance while in service. In addition to efficiently molding a dimensionally stable part, the molder and designer should consider what impact those cooling conditions will have on the final molded part, in both the long-term and short-term performance.

In today's manufacturing environment, the drive for efficiency sometimes overshadows the importance of manufacturing plastic products, and hinders the team's ability to effectively communicate possible downstream issues. Whether it is a reinforced grade or unfilled plastics decisions, the nature of these materials require that engineers and designers understand how processing is going to affect the end product. While the versatility of these resins provide design freedoms that bring about many benefits, it also requires even more attention to the details of how we make these great products.

To learn more look at these articles or contact Erik Foltz (erik@madisongroup.com):

Getting the Most from your prototype mold https://www.madisongroup.com/publications/Final%20-%20April%202016%20-%20TMG%20News.pdf

Simulate your way to a better mold https://www.madisongroup.com/publications/Simulate-Your-Way-To-A-Better-Mold.pdf

Upcoming Educational Webinars

Webinars provide a cost-effective way to expand your knowledge of plastics. Below is a list of the upcoming webinars presented by TMG Engineers:

Tuesday, February 14, 2017 - *Paul A. Gramann, Ph.D.*
National Association of Subrogation Professionals (NASP)
12:00 pm CST
Let's Get Tanked: Investigating Acrylic Aquarium Failures—Webinar
http://www.subrogation.org/event/lets-get-tanked-investigating-acrylic-aquarium-failures/

With reality television series such as "Tanked" on Animal Planet and "Fish Tank Kings" on National Geographic, the popularity of large acrylic aquariums has never been greater. Large-scale acrylic aquariums can be found in restaurants, airports, sporting venues, casinos, and retail outlets. Acrylic tanks are capable of holding thousands of gallons of water. Therefore, catastrophic failures can lead to significant property damage, and in many cases, substantial business loss.

Thursday, February 16, 2017 - *Jeffrey A. Jansen*—Society of Plastics Engineers
10:00 am CST
Introduction to Plastics - Webinar
For more information, contact ***Scott Marko at smarko@4spe.org.***

Plastics are the most versatile materials ever invented, and have become a universal material that is used for everything from water bottles to wings on combat aircraft. Plastic materials display properties that are unique when compared to other materials, and have contributed greatly to the quality of our everyday life. At this moment, you are almost certain to be touching plastic. Yet, while plastics play such an important role, we do not always understand the fundamental concepts of their production, compounding, end properties, and use.

If words such as polymer, thermoplastic, creep, amorphous, and modulus are outside your normal vocabulary, this presentation is for you.

This webinar will provide people not extensively familiar with plastics, an understanding of the basics.

Importance of Clear Specifications When Outsourcing Manufacturing

Antoine Rios, Ph.D.

It is very common to investigate failures where the cause is the use of an "inferior" material. As an example, the client wants to perform a failure analysis of a widget that exhibits cracking. After performing the analysis we conclude that the mode of failure is a stress overload event, or that the widget cracked due to chemical degradation. Then, the questions are: Did it fail due to an inferior design while it was used in its expected environment and service conditions? Or did it fail because it was misused/abused? The answers to these questions could be quite complex in some situations due to the unknowns of the service life for the widget. However, for simplicity, let us assume that the widget was used in a controlled environment where the customer was certain it was not misused. Then the next question is; Was the widget under designed? Without reviewing the geometry and material of the widget, this is yet another unanswered question. In this case, design refers to the combination of geometry and material selection. Is this a problem of material or geometry? Eventually, it can be both, since you could have a widget designed with the best geometry, but it failed due to the use of a poor material. Conversely, you could have a widget manufactured from a great material, but still have a faulty geometry that can lead to failure. You would design the geometry for the material or select the material for the geometry, but eventually the process must be concurrent.

A different situation arises when the customer tells you that this widget has been in the field for five years with no failures. Once you start investigating, you discover changes in the customer's supply chain, such as a new resin supplier or molder. Material testing of good and bad parts quickly shows that the new material is inferior, or a geometry checkup reveals that it has changed at the failure location. Once this conclusion is reached, it is easy to point the fingers at the manufacturer. However, in many occasions the problem is a deficiency in specifications. In this particular example, even further investigation reveals that the prints, drawings and documents used to specify the widget refers to materials or geometry details in generic terms. As an example, the drawing indicates that the material of the widget is polypropylene (PP). The problem is that there are hundreds of PP resins available in the market. Your overseas manufacturer assures your purchasing department that they can mold this widget at 30% off the cost of the previous manufacturer. Unbeknownst to you, their quote assumed a PP resin with inferior properties than the current PP used to mold the widget. From the new manufacturer's perspective, they have met your specifications. Remember, that the drawing specifies "polypropylene." The type of PP resin to be used was not properly specified. The new manufacturer quoted the widgets assuming the cheapest PP in the market, which ended up being inferior in quality, and produced widgets that underperformed.

The above material specification examples can be extended to geometrical specifications. A typical specification as shown in drawings is "Round all corners to 0.04." The designer should be careful with this general statement. First, critical regions of the part that are exposed to elevated and continuous stress may need a radius much larger than 0.04" to avoid premature failure. Second, just because this statement is there, you should not assume that it will be followed. It only takes one edge to not be rounded for premature cracking and failure to occur. Therefore, the final geometry of the part should be double checked. This should also be accomplished every time the mold is replaced or refurbished.

These are just a few examples of problems arising from insufficient specifications in a drawing or documentation. The designer would be in a better position to be as specific and detailed in the drawing as possible to reduce the chances of future problems. Especially, when years later any of the suppliers in the supply chain could be replaced. In an ideal situation, when specifying a material, the designer should detail the resins(s) to be used. This is the same resin that was used throughout testing and validation of the widget. Many times a resin callout is followed by the expression "… or equivalent." However, what does an equivalent material mean? Since the meaning of equivalent is vague, this is another specification that could cause future problems. Another method commonly used is to specify a material based on one or two short-term properties. If you have been a reader of this newsletter, you are familiar with long-term properties, creep failure and environmental resistance of plastics. Materials with comparable short-term mechanical properties can have dramatically, different long-term behavior. By the same token, the chemical resistance of the widget would be unrelated to short-term properties. Therefore, beware of specifying materials solely based on short-term properties.

In summary, communication along the supply chain is of extreme importance. Language and cultural barriers need to be managed to assure effective communication. The details about material and design should be specific in the prints and documentation. If more details are needed, a callout to a quality control document can be made where approved specific requirements, material resins and suppliers are listed.

For more information on how The Madison Group can help with material selection, geometry verification and manufacturing feel free to contact Dr. Antoine Rios at antoine@madisongroup.com.

Upcoming Educational Webinars

Thursday, February 23, 2017— *Jeffrey A. Jansen* - Audio Solutionz
Molecular Degradation Failure of Plastics—Webinar
12:00 pm CST
https://www.audiosolutionz.com/chemicals/plastic-failures-through-molecular-degradation.html

Plastic materials offer a unique balance of strength and ductility associated with their inherent viscoelastic nature. However, they are susceptible to molecular degradation through a variety of exposures. Molecular degradation is a permanent change in molecular weight that reduces the mechanical properties and integrity of the plastic material. This degradation can occur during compounding, processing, storage, or while in service. Such degradation mechanisms include:

- Thermal Oxidation
- Hydrolysis
- Ultraviolet Radiation
- Chain Scission
- Destructive Crosslinking

Wednesday—March 22, 2107—*Jeffrey A. Jansen*—Society of Plastics Engineers
Plastic Pipe Failure - Webinar
10:00 am CST
For more information, contact ***Scott Marko at smarko@4spe.org.***

Plastic piping systems are an important commercial product used in a wide variety of applications. Because of the diversity of applications and wide range of material used to produce pipes, many different types of failures can result in service. Evaluating these failures through a systematic analysis program allows an assessment of how and why the pipes failed. An essential portion of the failure analysis process is the fractographic examination, which provides information about the crack origin location, and the crack initiation and extension modes. The focus of this investigation was to characterize the surfaces of intentionally cracked laboratory samples in order to gain a more thorough understanding of pipe fracture mechanisms. This paper will document some of the key fracture features associated with overload of various materials used to produce commercial piping systems.

Information regarding upcoming educational opportunities can also be found at:

http://www.madisongroup.com/events.html

Upcoming Educational Conferences

Medical & Analytical Plastic Product & Part Design - Conference
Boston, MA

Tuesday/Wednesday—March 28 - 29, 2017—*Jeffrey A. Jansen*—Society of Plastics Engineers
Plastic Failure and Prevention: Creep and Environmental Stress Cracking
http://www.4spe.org/Events/event.aspx?EventID=70457#content

WCX™ 17: SAE 2017 World Congress—Conference
Detroit, MI

Wednesday, April 4, 2017 *Antoine Rios, Ph.D. – SAE*
8:00—8:30 am EST
Failures of Short Fiber-Reinforced Plastics in Automotive Applications
SAE 2017 World Congress, http://www.sae.org/congress/
Session M107 : Failure Analysis of Materials, Components, and Systems (Part 1 of 2)

It is common for designers to look at the datasheet of fiber reinforced plastics and select the material solely based on the property values. Some designers know that these materials can be highly anisotropic due to the final fiber orientation. There is abundant knowledge in regards to how fiber orientation affects the short-term behavior of plastics. However, there are often forgotten issues caused by long-term stress, weldlines, volumetric shrinkage and residual stresses. This presentation uses case studies where parts failed as the result of these less obvious issues.

ASM Minnesota Chapter Meeting
Minneapolis, MN

Wednesday, February 22, 2017 – *Jeffrey A. Jansen – ASM*
9:15 am CST
Session 2 - Creep Rupture Failure of Plastics
http://chapter.mnasm.org/index.php/jevents/eventdetail/8/-/full-day-seminar

Creep is the tendency of a polymeric material to deform permanently under the influence of constant stress, as applied through tensile, compressive, shear, or flexural loading. It occurs as a function of time through extended exposure to levels of stress that are below the yield strength of the material. Given sufficient time, this can lead to creep rupture, the failure within a material as a result of continuously applied stress at a level below the tensile strength. Plastic materials are particularly prone to creep rupture through exposure to static stresses, and a recent study indicates that 22% of plastic failures are associated with creep.

The relatively high frequency of creep failure is linked to the widespread lack of awareness and understanding of the effects of time on polymeric materials, particularly at the design stage; the unique difference in time dependence between polymeric materials and metals; and the increasing use of plastic materials in diverse applications with longer time demands.

- Introduction to plastic molecular degradation, including the various mechanisms
- Material susceptibility to degradation
- Stabilizers to prevent degradation
- Testing to assess the level of degradation

Information regarding upcoming educational opportunities can also be found at:

http://www.madisongroup.com/events.html