TMG News

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Why are a Limited Number of Parts Failing?

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When a plastic part fails, a tough question is often asked, "Why are a limited number of parts failing?" This is particularly true with seemingly random failures at significant, but low, failure rates. Two aspects are generally linked to such low failure rates – multiple factor concurrency and the statistical nature of plastic failures. Failure often only takes place when two or more factors take affect concurrently. Absent one of these factors, failure will most likely not occur. Plastic resins and the manufacturing processes produce parts with a statistical distribution of performance properties, such as strength and ductility. Likewise, environmental conditions, including stress and temperature, to which the resin is exposed through its life cycle, is also a statistical distribution. A simplistic approach is to assume failure occurs when a portion of the distribution of stress on the parts exceeds a portion of the distribution of strength of the parts.

While it might seem complex, it is important to remember that cracking is simply a response to stress. Cracking takes place as a stress relief mechanism when the stress overcomes the apparent strength of the part. However, the apparent strength varies depending on multiple factors including strain, rate of the applied stress (strain rate), duration of the applied stress, manufacturing-induced effects, chemical factors and molecular integrity of the material.

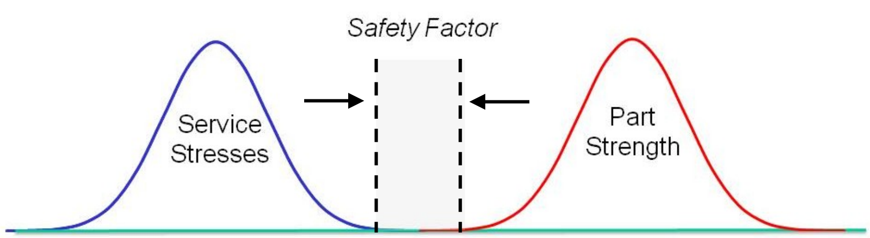

Figure 1: Stress and strength distribution separated by a design safety factor

Concurrent Factor and Statistical Distribution Considerations

The influences that affect the performance of a plastic component can be separated into five different factors covering the lifecycle of the part: material, design, processing, installation, and service. The cause of failure in plastic parts typically occurs as the result of several of these factors concurrently reducing the expected strength and/or increasing the expected in-service stresses of the part. The number of factors affecting part performance produces a broad statistical distribution of the material properties and service conditions. The overlap of these two statistical distributions leads to sporadic and seemingly random failures. When working to identify the cause of component failure, it is important to consider the interaction between the various factors and the inherent statistical distribution of the performance and service conditions.

In these cases a simplistic approach is to interpret the in-service conditions (stresses, etc.) and material properties (strength, etc.) on the part as statistical distributions. When the plastic part is designed, it is typical to review the material's property datasheet provided by the material supplier and use this data as an input to the design. However, the value in the datasheet is usually an average and typically no information is given in regards to the

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standard deviation of that value. In reality, the mechanical properties of the material follow a statistical distribution. Actually, some of the most common mechanical tests regulated by ASTM or ISO require reporting the average value and standard deviation of the measured property.

The statistical distribution of a property is important because if the distribution tail of such property overlaps that of the in-service conditions, failure could occur. As the material properties fall within a statistical distribution, the same occurs with the stresses, temperature and conditions existing during the service life of a part. Figure 1 shows a distribution of expected in-service stresses and a distribution of part strength. In this case, the separation between the two distributions is related to a statistical design safety factor. However, the stresses and strength of the part can vary due to unforeseen factors causing these two distributions to overlap (Figure 2). The overlap region of both distributions represents a small portion of the parts that would lead to failure. Here, for simplicity, failure is considered to occur when the stress on the part is greater than the strength of the part.

Figure 2: Stress and strength distributions overlapping leading to a failure probability

The distributions can shift or broaden due to one factor or multiple factors. If the shift or broadening is greater than the safety factor then there is an increased probability for failure to occur. Broadening a distribution of properties can occur when a material is substituted. It is not uncommon to specify materials by a property or a group of properties. Two materials can have similar datasheet property values, but different property distributions. This could be a problem if the tail of the property distribution is so broad that it overlaps the distribution of the in-service conditions.

It is also important to understand the variability introduced when measuring properties. As ASTM D638 for tensile properties shows, there would be differences in the measured average among testing laboratories. For example, the tensile break strength of LDPE shows a standard deviation of up to 5.9% of the reported average, 6.2% for LLDPE, 8.3% for acrylic and 2.9% for glass-reinforced nylon. Therefore, it is important to consider this variation as part of the safety factor. Of note is that ASTM D638 shows a standard deviation of 55% for tensile strength at break for polypropylene. This shows a substantial distribution of values for polypropylene due to the inconsistency of necking of the tensile bars. Figure 3 shows the inherent variability of tensile strength of polypropylene and acrylic polymers from round-robin data in ASTM D638.

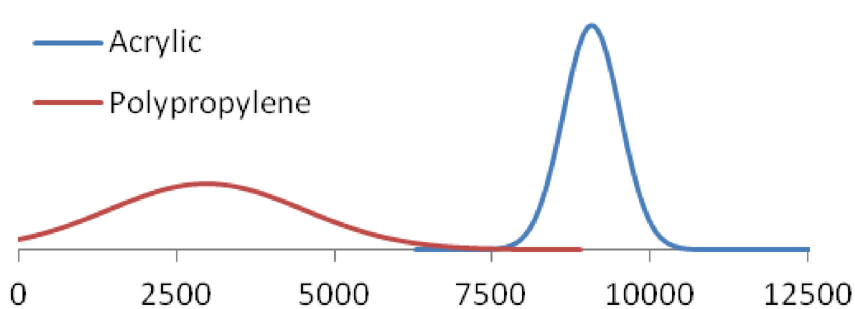

Figure 3: Tensile strength data is psi showing inherent variability of plastics (from ASTM D-638)

Look for the second installment of "Why are a Limited Number of Parts Failing?" in the next TMG News.

If you would like more information regarding plastic failure, or other plastics issues, please contact The Madison Group at 608-231-1907, or email at antoine@madisongroup.com.

Third Annual Educational Seminar

The Madison Group together with the University of Wisconsin - Stout and sponsored through the Society of Plastics Engineers will be offering a free half-day seminar entitled **"Back to Basics – Importance of Plastic Material Selection on Performance and Processing"**. Three separate topics exploring practical aspects of plastic materials will be covered.

Plastics Material Science Fundamentals
Dr. Adam Kramschuster University of Wisconsin – Stout
Ever wondered why some plastic materials behave differently than others? The materials science behind plastics behavior, including molecular structure, molecular weight, thermal transition temperatures (T_g and T_m), and crystallinity will be discussed. An overview of how these fundamental properties affect how plastics are processed and how they function in their environment will also be presented.

Plastics Versus Metal – Properties, Conversion, and Selection
Jeffrey Jansen The Madison Group
The conversion of a metal component to plastic may seem straightforward, but often presents significant challenges. The key to a successful metal-to-plastic conversion is understanding the inherent differences between these two classes of materials, including structure, physical properties, and sensitivities. The presentation will examine these differences and why they are important. Material selection and design aspects will be reviewed as they relate to a successful conversion.

Importance of Runner and Gate Design for Injection Molding Plastic Parts
Erik Foltz The Madison Group
Often seen as throwaway material, the design of the runner and gate scheme is often overlooked during the injection mold design process. However, the design of the runner and gate is critical to the manufacturing of quality parts. Not only do these features allow the melt to enter the molding cavity, but they also prepare the melt during injection. An improperly placed or incorrectly sized runner or gate can lead to cosmetic issues, extreme processing conditions, and excessive cycle times. This presentation will highlight the key design features and guidelines that should be considered during mold design, and how they influence the manufacturability of the part.

Attendees will come away from the presentation having a better understanding of the essential properties of plastics and how they affect manufacturing and the performance properties of the molded component.

An Educational Outreach Sponsored by:
- Society of Plastics Engineers
- UW-Stout SPE Student Chapter
- Waukesha County Technical College
- The Madison Group

The seminar is offered in two locations and is **free of charge**:

Tuesday - May 13, 2014	Thursday - May 15, 2014
University of Wisconsin – Stout Menominee, Wisconsin 9:00-12:20 Presentation 12:30-1:30 Tour of UW-Stout Plastics Facility	**Waukesha County Technical College** Waukesha, Wisconsin 9:00-12:20 Presentation 12:30-1:30 Tour of WCTC Plastics Facility

For more information or to register contact Jeff Jansen at jeff@madisongroup.com.

The Importance of Establishing a Nominal Wall for Plastic Part Design

Erik Foltz

The increasing push to integrate light-weight materials into performance demanding applications has made plastics a material of choice for designers. Additionally, once a product has been converted to plastic the desire to further minimize material and weight without sacrificing performance typically follows. These two trends of light-weighting and reducing material consumption have led many designers to ask the questions “How much material can be removed?” and “What should my wall thickness be?” The answer to both of these questions should start by revisiting the first rule of plastic part design. That rule states that every plastic part should maintain and establish a uniform nominal wall.

Establishing the nominal wall of a part is one of the more mundane details of product design, but it is also one of the most critical. The nominal wall establishes the overall size and dimensions of the part. The nominal wall will also dictate many decisions regarding the design and spacing of more interesting features such as stiffening ribs, louvers, mounting bosses, and snap-fit design. None of these features can operate optimally without establishing the correct nominal wall of the part.

What should the nominal wall be?

The preliminary decision of establishing a nominal wall should be dictated by the functional performance requirements of the part. Considerations of acceptable stress levels, and expected lifetime of the part should help guide the designer in establishing the nominal wall. Previous experience and the correct interpretation of structural finite element analysis (FEA) has made these decisions more reasonably attained during the preliminary design stages.

While performance dictates the minimum nominal wall of the part, manufacturing should also be considered. The designer must remember that injection molding is a pressure driven process. Thinner walls and longer flow lengths will require higher injection pressures to fill the mold. Most modern conventional injection molding equipment can achieve between 20,000-30,000 psi of plastic injection pressure. Specialized micro-molding machines can achieve higher pressures, but have other limitations such as shot size.

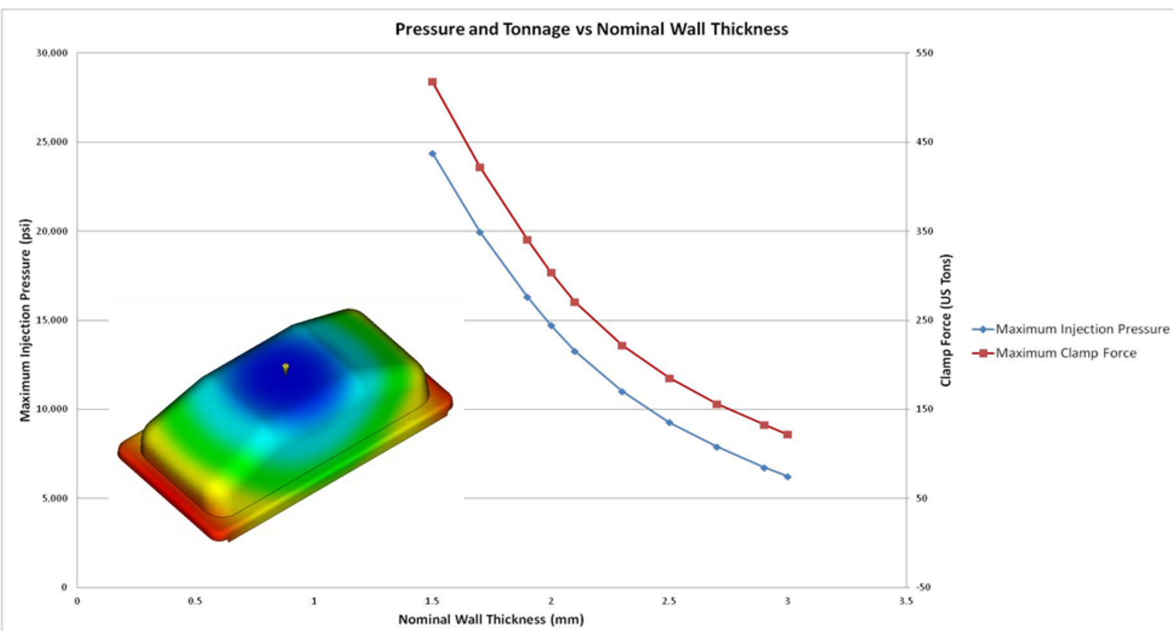

Figure 1: Graph showing the predicted injection pressure vs. nominal wall thickness for a plastic shroud. The analysis showed that the minimum wall thickness to maintain a reasonable injection pressure was 2.25 mm.

Injection molding simulation can be used to determine the feasibility of manufacturing a part at a given wall thickness. Figure 1 shows a graph of required injection pressure to fill a plastic shroud vs. the nominal wall thickness. During the preliminary design stages, the product designer determined the minimum wall thickness of the shroud to withstand the intended loads was 1.5 mm. However, a series of studies that simulated the injection molding process revealed that the part would require too high of injection pressures to fill at 1.5 mm, and the processing window would be small. The simulation also helped the designer determine that from a manufacturing perspective the minimum wall thickness was 2.25 mm.

Why is it important maintain a uniform wall thickness?

Once the nominal wall thickness is established it is important that the wall thickness remain constant. Maintaining a uniform thickness will allow for the best possible processing of the part, and will minimize any residual stress in the part. Plastics are inherently poor heat conductors. By maintaining a uniform wall thickness the part will cool as uniformly as possible. This also means, if packed properly, that the part should shrink as uniformly as possible. Equation 1 shows that the cooling time of a plastic part is directly proportional to the square of the wall thickness.

Eq 1.

$$t_{cooling} \propto \frac{t_{part}^2}{\rho}$$

This means that with a 2 mm wall the part will take 1.76 seconds to cool, but a 4 mm wall will take 8.00 seconds to cool. If these two wall sections are placed adjacent to one another the 4 mm wall will want to shrink significantly more than the 2 mm wall, Figure 2. As a result of this differential shrinkage, a stress develops that the part will want to relieve upon ejection, which results in part warpage. If the part design requires certain areas to act stiffer than others there are better options than simply thickening up the wall. The addition of ribs or profiling the part wall to achieve a stiffer part while maintaining the uniform wall thickness will allow for more success than selectively increasing the part wall thickness.

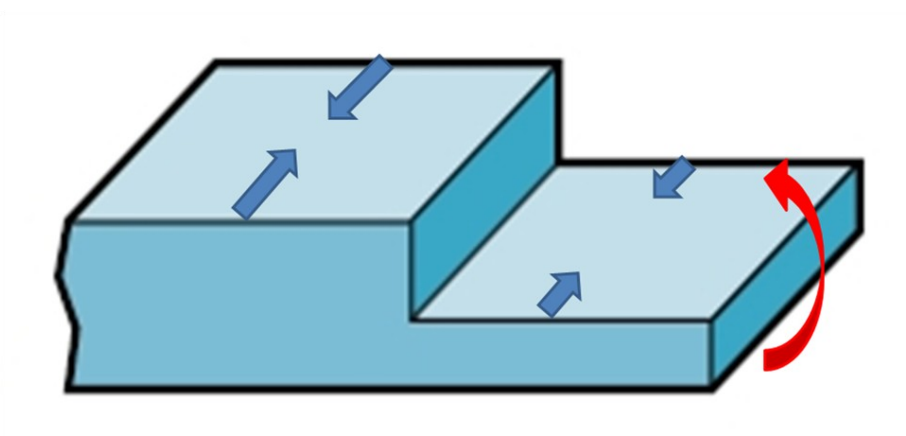

Figure 2: Schematic shows that varying the wall will result in differential shrinkage and excessive warpage of the part.

Plastics are a versatile material that allow a designer many advantages and freedoms. However, the designer must take a holistic view of the plastic part design and consider not only performance but also manufacturing during the design stage. Considering manufacturing and remembering to maintain and establish a nominal wall thickness will allow the most success in creating a high quality product.

If you would like more information regarding design and material validation please contact The Madison Group at 608-231-1907, or email erik@madisongroup.com.

For further information regarding design and material validation read the following papers authored by the staff at The Madison Group (click on the link to access the document).

Creep Failure of Plastics

Lifetime Predictions: Case Studies

Accounting for Non-linearity in Plastic Part Design Validation

Upcoming Society of Plastics Engineers Webinars

Educational Opportunities - SPE Webinars

Webinars provide a cost effective way to expand knowledge of plastics. The Society of Plastics Engineers (SPE) offers a wide selection of high quality webinars, many of which are taught by Jeffrey A. Jansen from The Madison Group. Below is a list of the upcoming webinars:

Plastic Material Selection
Date in May to be determined 10:00 a.m. Central Time

Plastic Failure - A 3-Part Series
September (Th) 11, (W) 17, and (Th) 25, 2014 10:00 a.m. Central Time

Understanding Plastic Failure Rate
Thursday, November 20, 2014 10:00 a.m. Central Time

For more information on the courses or to register, contact SPE's Scott Marko at 203-740-5442 or smarko@4spe.org.

Webinars that have been previously given are also available as a recorded DVD. Some that may be of interest are:

Basic Rubber Technology

Thermal Analysis in Failure and Compositional Analysis

Creep Rupture Failure of Plastics

For more information contact SPE's Scott Marko at 203-740-5442 or smarko@4spe.org.

The Madison Group Teaches Failure Analysis Course

The University of Wisconsin—Milwaukee School of Continuing Education is offering a 3-day course entitled, **"Plastic Part Failure: Analysis, Design & Prevention"** taught by The Madison Group Engineers Antoine Rios, Erik Foltz, Javier Cruz, and Jeffrey Jansen. The course will cover a broad range of topics essential to understanding and preventing plastic failure. Get introduced to the strategies behind analysis, design and prevention with course material that includes:

- Essential knowledge of why plastic components fail
- The five factors affecting plastic part performance
- The process of conducting a failure investigation
- The importance of ductile-to-brittle transitions and their role in plastic component failure
- Methods for understanding how and why a product has failed
- Approaches to more quickly respond to and resolve plastic component failure

For more information contact:
Murali Vedula UW-Milwaukee
mvedula@uwm.edu, 414-227-3121

Groundbreaking for The Madison Group's Corporate Headquarters

The Madison Group is pleased to announce groundbreaking for its new company headquarters in Madison, Wisconsin. The 13,000 square-foot facility will sit on approximately 2 acres and is expected to be completed by mid-October.

"We've been investigating this expansion for several years to keep pace with company growth, additional plastic engineers and more office and laboratory space. The larger facilities will allow us to satisfy our client's requests for expanded services," said Paul Gramann, Ph.D., President.

The planned single-story Class A building required re-zoning by the city, but also allows for expansion in the future. "The single-story design is critical to our team-oriented approach and will help ensure our culture and success," said Gramann. The custom building has been designed closely with architectural firm Eppstein Uhen and construction will be completed by J.H. Findorff.

Artist's rendering of the new TMG corporate headquarters.