TMG News – September, 2012

Welcome to TMG News

Welcome to TMG News, the newsletter brought to you by The Madison Group. This is a quarterly newsletter that contains plastics-related articles and information regarding educational opportunities. We enjoy working with our clients to help them solve their plastics problems. However, we also believe that it is our responsibility to help educate our clients as well.

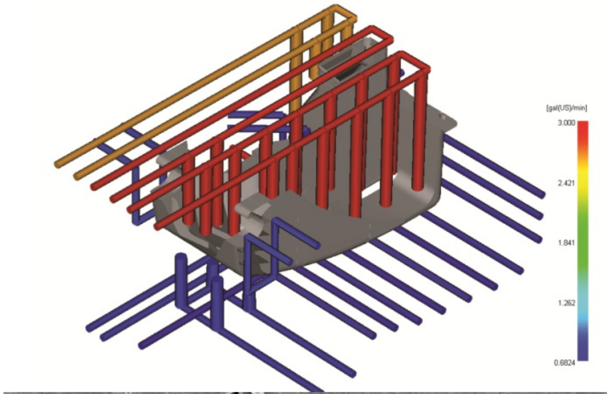
Working with plastic parts, whether in part design, manufacturing, or material or failure analysis, presents some unique challenges, particularly compared with metals. The molecular structure and the resulting viscoelastic properties requires special knowledge.

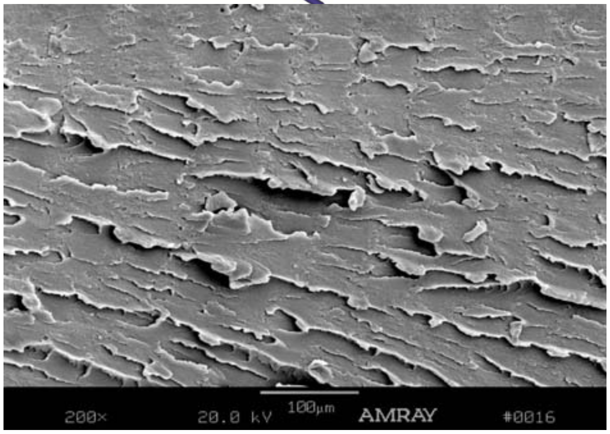
This issue of the newsletter features articles that address plastic part design and the failure analysis process. The first article covers thread design, a critical aspect of plastic part performance. The second article focuses on the interpretation of a plastic fracture surface, an essential element of a failure analysis.

I hope that you find this issue interesting and helpful. I also encourage you to contact me if you have ideas for future issues.

Jeff Jansen

If you do not wish to receive TMG News you can opt out by contacting me at jeff@madisongroup.com.





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Plastic Thread Design

Antoine Rios, Ph.D.

Threads in plastic parts are often necessary to assemble components. The thread geometry used for plastic threads is commonly inherited from existing specifications used in metals. In many cases there is little latitude given to change the thread geometry since the component must conform to existing standard threads. In these instances the designer may be limited to slight modifications of the geometry. However, a frequent problem with plastic threads is not always related to the thread geometry, but rather the design of the whole component.

Regardless of the thread standard used, an important design aspect is to avoid sharp edges, which create stress concentrations. A sharp geometrical transition is inherent to the root of the thread. Some standards allow rounding or truncating the thread root up to 1/8 of the thread pitch (Figure 1). For these, the thread root should be smoothly rounded to reduce the stress concentration. However, even after smoothing the thread root a stress concentration still exists. For this reason proper part design should consider the whole component, not just the geometry of the thread. Factors such as wall thickness and material selection play a crucial role. The role of wall thickness is more obvious because it directly affects the stress of the part; thus the stress at the threads. Conversely, wall thickness has a less obvious effect on processing. Thickness variations within the component can produce molded-in stresses that could further aggravate the stress concentrating effect of the threads. Therefore, the designer must consider the unintended consequences resulting from a specific design selection.

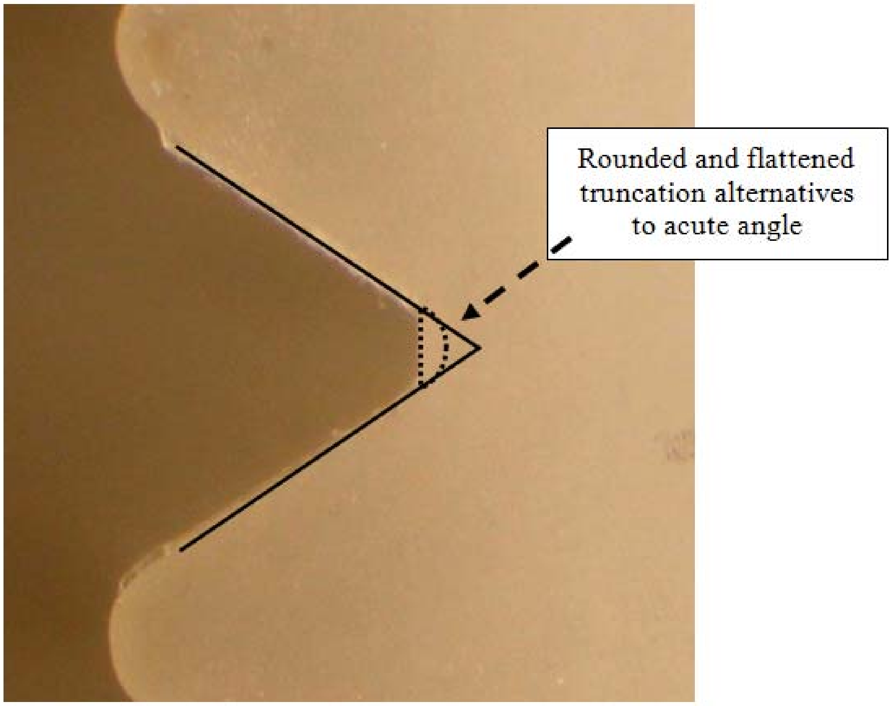


Figure 1 – An example of thread truncation is shown.

Another important design parameter is the plastic material selected. Some plastics are more sensitive to cracking due to stress concentrations. The notch sensitivity is an important property affecting the performance of the threads. Additionally, the long-term and creep properties of the material are crucial. The stress concentration created by the edge at the thread root would accelerate creep and eventual failure. The designer can choose not only different materials but different grades of the same material. For example, a material grade with higher molecular weight would generally be more resistant to creep; therefore, more resistant to long-term failure at the threads.

Another design issue is the integration of a thread stop that limits engagement between threads. A properly designed thread stop should effectively prevent engagement of the thread termination. In addition, the thread stop must limit the installation stress on the threads, especially when tapered threads are used. Thread tapering can be aggravated by the use of improper design and manufacturing parameters that lead to thread shrinkage.

Finally, the aspect of the thread termination is often ignored and left for the tool maker to determine. However, it is one of the most important features of the thread design. The thread termination often coincides with the region of the threads that is exposed to the highest stresses. When a threaded core insert is used to form the threads, it is common to create a sharp or feathered edge as the thread terminates. The sharp edge is created as the groove of the thread diminishes, which eliminates the truncation at the thread root to create an acute angle (Figure 2). To reduce this sharp thread termination special care has to be taken when selecting the threaded core insert. This insert should have a smooth transition at the last thread in order to mold a thread without sharp edges and unexpected stress concentrations beyond the inherent geometry of the thread.

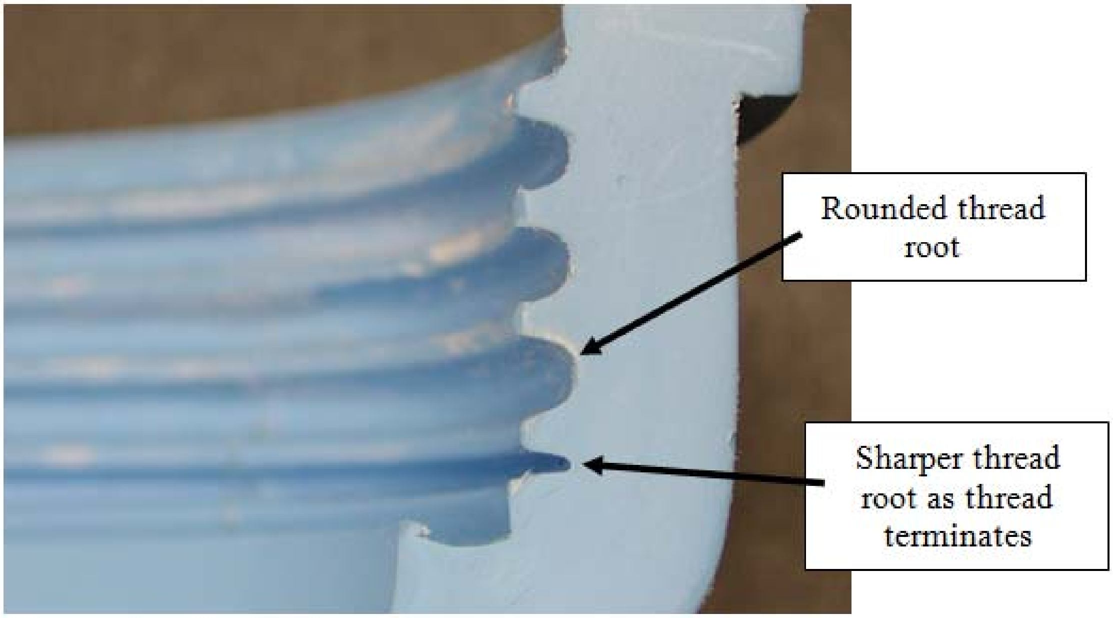


Figure 2 – An example of thread termination with sharp edge is shown.

The design of threads in plastic components must go beyond basic engineering standards and beyond replication of metal threads. The geometry of the thread is an important consideration, but the design should not stop there. The combination of wall thickness, material properties, thread geometry and thread termination should be considered concurrently. It is not only important to study the distribution of stresses along the threads, but also to consider the long-term creep effects of the plastic and the residual stresses from manufacturing.

If you would like more information regarding functional threads, plastic component design review, or failure analysis please contact The Madison Group at 608-231-1907, or email at antoine@madisongroup.com.

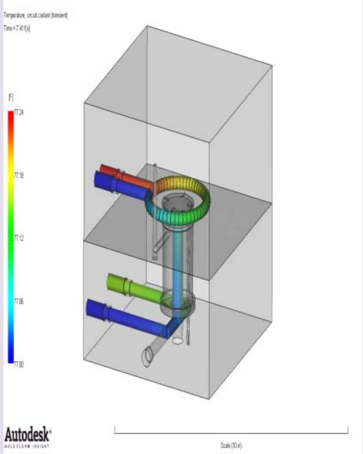
For further information regarding plastic plumbing part failure read this paper authored by the staff at The Madison Group.

“Failure of Plastic Plumbing Products”, Paul Gramann, Antoine Rios and Bruce Davis, ANTEC
http://www.madisongroup.com/publications/failure_plastic_plumbing_products.pdf

TMG Tidbits

Madison Group Now Offers Transient Cooling Analysis for Moldflow®

The Madison Group has expanded its Moldflow® services to include transient cooling analysis for the injection molding process. This new solver allows engineers and mold designers to learn how efficiently their proposed cooling line layout will cool the mold, and can provide more detailed information of the mold temperature throughout the cycle. By changing the solver to utilize the finite element method (FEM), the mold temperature can be calculated throughout the injection molding cycle. Also, the change in solver allows for a better representation of the effectiveness of conformal cooling lines. These advancements in solver technology should allow for a better cycle time prediction and can help improve the accuracy of warpage analysis.



If you would like more information regarding the capabilities of Moldflow® and the new transient cooling solver please contact Erik Foltz 608-231-1907 or erik@madisongroup.com.

Failure Analysis and Prevention – Plastic Parts Seminars

This summer, The Madison Group, endorsed by the Society of Plastics Engineers (SPE), together with the University of Wisconsin - Stout and Waukesha Country Technical College offered two sessions of a seminar entitled "Failure Analysis and Prevention - Plastic Parts." The course introduced the attendees to the concept of plastic failure and the analytical approach to evaluate failures. Additionally, the presentation highlighted how structural and processing simulation can be incorporated at any stage of the design process to help prevent or resolve any quality or performance issues. The seminar also covered key issues with plastics and plastic part design and showed how these concepts can be used to solve real-life problems. The seminar was presented as an educational outreach between The Madison Group and the UW-Stout SPE Student Chapter and the Industrial Division of WCTC. The seminar was taught by Jeff Jansen and Erik Foltz of The Madison Group, and Dr. Adam Kramschuster of the University of Wisconsin – Stout. A total of 127 people from Wisconsin, Minnesota, Illinois and Iowa attended the two seminars.

New sessions to be presented at both institutions are being planned for Summer, 2013. To obtain more information about the 2013 seminar, contact Jeff Jansen of The Madison Group at 608-231-1907 or jeff@madisongroup.com.

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Fractography – A Key Component of a Failure Analysis

Jeffrey Jansen

Cracking - the partial fracture of a solid material - occurs as a result of the exertion of stresses, both external and internal, on a component. Cracking is simply a stress relief mechanism in which the material is attempting to reach a lower energy state. Contrary to popular belief, mechanical stresses do not break the covalent polymer backbone bonds. Instead, the stresses overcome the intermolecular forces, such as Van der Waals forces and hydrogen bonding that keep the polymeric molecular structure intact. Plastics fail through a disentanglement mechanism in which polymer chains slide past each other. Given sufficient stress, the disentanglement leads to cracking, and catastrophic failure occurs if the cracking extends sufficiently through the material. Cracking can be generally categorized into ductile or brittle fracture. Ductile cracking occurs after significant deformation and yielding. Ductile fracture is a bulk molecular response through yielding (macro molecular rearrangement) followed by disentanglement. Brittle fracture is a localized molecular response where disentanglement is favored over yielding.

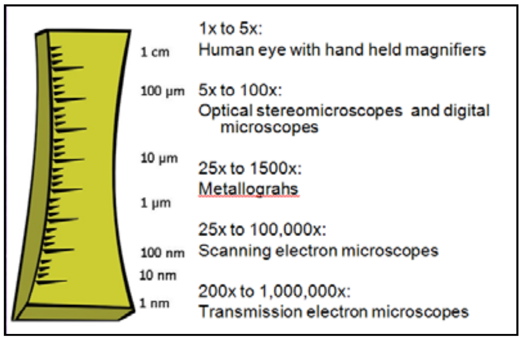

Figure 1 – Various techniques can be used to study a fracture surface.

The goal of a failure analysis is to ascertain the mechanism and cause of the failure; more simply, to determine how and why the part failed. Much of the information regarding the failure mechanism can be gleaned by interpreting the features found on the fracture surface. The examination and interpretation of the fracture surface is known as fractography. A fractographic examination begins with a thorough macroscopic inspection of all of the failed parts. This is typically followed by examination at increasing magnifications using a stereomicroscope, a digital microscope, and when necessary a scanning electron microscope (SEM). There are numerous tools that can be used to examine and evaluate the fracture surface, each offering different strengths and providing unique information (Figure1).

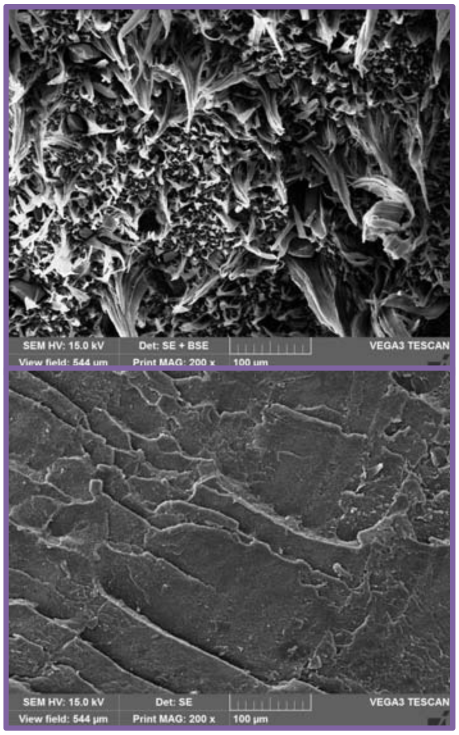

Figure 2 – SEM images showing ductile (upper) and brittle (lower) fracture surfaces.

Cracking produces two mating fracture surfaces. The features on the fracture surface are created based upon a number of parameters:

- Type of material and formulation constituents;
- Type of applied forces (tensile, compression, shear);
- Magnitude of forces;
- Frequency of forces (continuous, intermittent, rapidly applied);
- Environmental effects (temperature, presence of chemical).

The key to interpreting the fracture surface is to be able to recognize and interpret the features left from crack generation. The first generality to be made regarding the fracture surface is the nature of the cracking, ductile or brittle (Figure 2). As indicated previously, ductile failure takes place with substantial deformation associated with yielding. Macroscopically, ductile failure is often characterized by stress whitening and stretching. Microscopically, ductile fracture surfaces generally exhibit the formation of stretched fibrils. In contrast, brittle fracture takes place without yielding, and is characterized by minimal deformation or elongation. On a macro level, the mating fracture surfaces of a brittle fracture will exhibit little separation with little distortion within the surrounding material. Microscopically the fracture surface is generally characterized by a smooth morphology or the presence of sharp angular features.

A key piece of information found on the fracture surface is the crack origin. The fracture origin is the location of crack initiation and usually corresponds to the area of maximum stress and/or the location with minimal strength (Figure 3). A fracture may have a single origin or multiple origins depending on the type of stress, the environmental conditions, and the part configuration. The fracture origin holds important information regarding the magnitude and orientation of the stress, as well as the physical environment at the time of the failure.

The morphology of the fracture surface provides information regarding the speed of the crack. Cracks can propagate at a wide range of speeds, from 1 mm/year to 1000 m/sec[1]. Most often a smooth fracture surface morphology is associated with slow crack growth. In contrast, sharp distinct features most often signify rapid crack extension. In particular, crack bifurcation, the separation of a crack into multiple branches, occurs as the crack releases a high level of energy.

Beyond the origin and the overriding morphology of the fracture surface, there are many features that provide information to the failure investigator regarding how and why the part failed. These include:

Rib Markings: Also known as arrest markings, rib markings can be evident as faint indications or striations on the fracture surface (Figure 4). They are commonly formed when the moving crack front arrests. They can also be produced by dramatic transformations in crack propagation speed or changes in the environmental conditions.

Crack Bifurcation: Crack bifurcation is the splitting of a single propagating cracking into multiple cracks (Figure 5). This is usually associated with conditions of relatively high energy input under which the crack is attempting to dissipate the energy as rapidly as possible. Crack bifurcation is generally linked to crack extension at higher speed.

Secondary Cracking or Mud Cracking: Secondary cracks are cracks present on the fracture surface that are formed perpendicular to the primary fracture. They are commonly formed through molecular degradation of the polymeric material.

River Markings: Associated with relatively higher crack propagation speeds, river markings are formed as the material dissipates the increasing energy of the stress (Figure 5). They are a sign of a significant increase in the crack extension rate or a change in the stress state on the part.

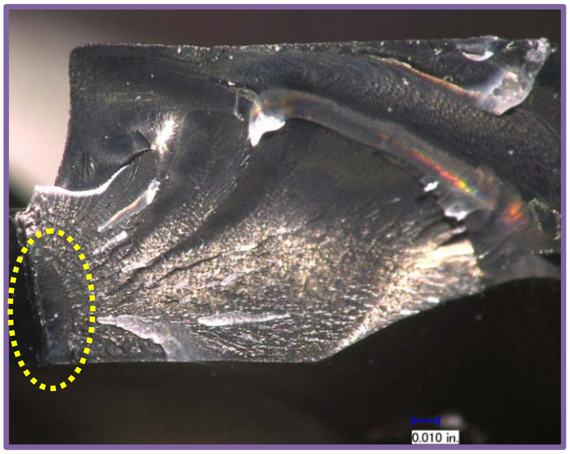

Figure 3 – Photomicrograph showing the origin are on a brittle fracture surface.

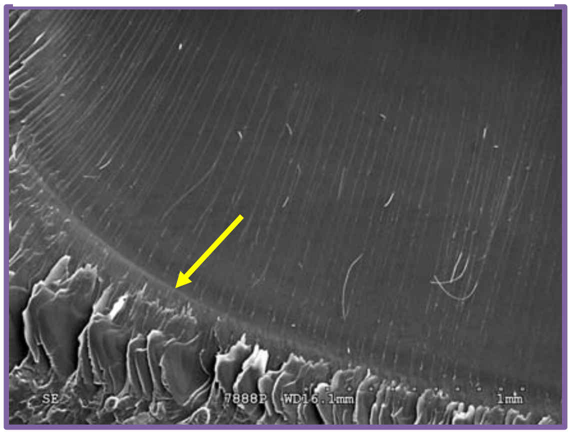

Figure 4 – Scanning electron micrograph showing a rib marking.

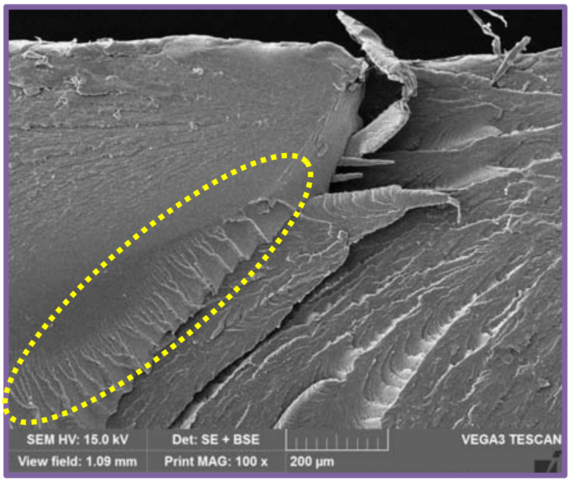

Figure 5 – Scanning electron micrograph showing crack bifurcation. River markings are also present (yellow dotted line).

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[1] Brostow and Corneliusses (ed.), Failure of Plastics, Hanser Publications, 1986, p. 171.

Crack Unions: The ridges formed by the unification of two separate cracks, crack unions, are usually oriented parallel to the crack propagation direction (Figure 6). The ridges often appear as steps and may exhibit more ductility in the form of stretching than the surrounding fracture surface.

Craze Remnants: Crazes are interpenetrating micro-voids with small fibrils bridging the two sides of the micro-voids. Crazing takes place under conditions of constant tension and are load-bearing. If the applied tensile load is sufficient, the bridging fibrils elongate and break, causing the micro-voids to grow and coalesce (Figure 7). Through coalescence of the micro-voids, cracks begin to form.

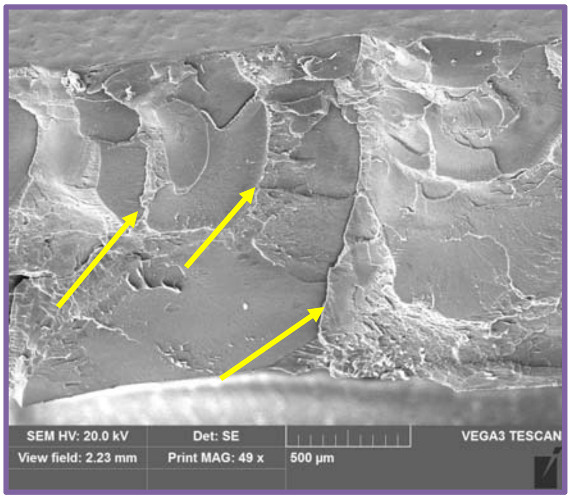

Figure 6 – Scanning electron micrograph showing multiple crack unions on the fracture surface.

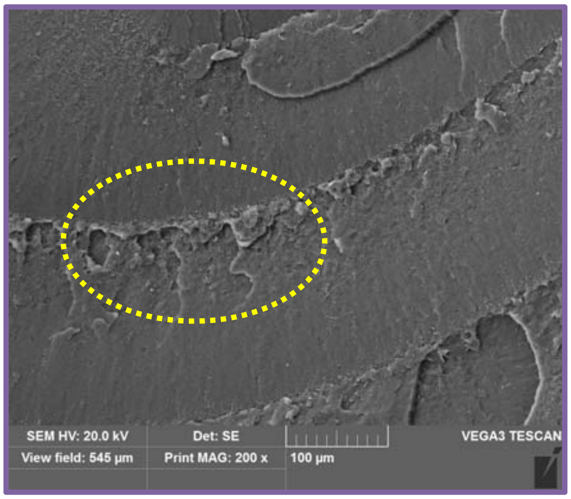

Figure 7 – Scanning electron micrograph showing remnants of an opened craze.

The challenging aspect of plastic material fractography is that some features will have divergent meanings in different materials and under disparate stress conditions. As such, it is important to understand and take into consideration the type of plastic being examined. A thorough understanding of the material properties and experience with the tell-tale features are essential for the proper interpretation of the fracture surface.

If you would like more information regarding fractography, failure analysis, or materials characterization please contact The Madison Group at 608-231-1907, or email at jeff@madisongroup.com.

For further information regarding fractography or failure analysis read these publications authored by the staff at The Madison Group.

"Fractographic Characterization of Pipe and Tubing Failures", Jansen, Jeffrey A.; Loken, Thomas G.; ANTEC, 2011
http://www.madisongroup.com/publications/Fractography-of-Pipe-Failures.pdf

"Fractographic Characterization of Polycarbonate Failure Modes", Jansen, Jeffrey A.; ANTEC, 2004.
http://www.madisongroup.com/publications/Jansen_ANTEC_2004_TMG2011.pdf

"Characterization of Plastics in Failure Analysis", Jansen, Jeffrey A.; ASM Handbook Volume 11 – Failure Analysis and Prevention, ASM International, December 2002, pg. 437-459.
http://www.madisongroup.com/publications/Jansen_ASM_Chapte_TMG2011.pdf

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 experts within The Madison Group. Here is an upcoming webinar:

Environmental Stress Cracking of Plastics

Jeffrey A. Jansen

November 7, 2012 10:00 AM Central Time

If you deal with plastic components, then this webinar will provide you with information that will enhance your understanding of the interaction between chemicals and plastic resins and help prevent premature failure. Environmental stress cracking (ESC) is a phenomenon in which a plastic resin is degraded by a chemical agent while under stress, and it is a leading cause of plastic component failure. It is a solvent-induced failure mode, in which the synergistic effects of the chemical agent and mechanical stresses result in cracking. A recent study showed that 25% of plastic part failures are related to ESC.

Previous webinars sponsored by SPE have been recorded and are available for viewing by contacting Barbara Spain at 203-740-5418 or bspain@4SPE.ORG. These include:

Degradation Failure of Plastics

Jeffrey A. Jansen

Originally Presented May 17, 2012

Polymeric materials are susceptible to several molecular degradation mechanisms, including oxidation, hydrolysis, thermal degradation, and UV attack. While diverse in their processes, all forms of degradation result in a reduction in the molecular weight of the base polymer. This molecular reduction is accompanied by a deterioration of physical properties, rendering the plastic part prone to failure. Degradation represents an important failure mechanism for plastics, with a study indicating that 17% of plastic failures are associated with degradation. This webinar will review the various degradation-related failure mechanisms.

Non-Destructive Analysis of Plastic Parts Using CT Imaging

Paul J. Gramann, Ph.D.

Originally Presented June 5, 2012

Visual inspection is the most powerful and important method when examining a part. In certain situations, however, the destructive sectioning and disassembly required for a comprehensive visual inspection is not possible. In those cases CT imaging can provide equivalent information. CT imaging is a technique that is relatively new to the non-medical industry that can provide a wealth of information. This webinar will review this powerful technique for analyzing plastic parts. Specifically, how CT imaging works, its advantages and limitations. Several examples of its use with plastic parts will be given.

Ductile to Brittle Transitions in Plastics Parts 1 and 2

Jeffrey A. Jansen

Originally Presented September 6 and 13, 2012

Thermoplastic resins are utilized in many applications because of their unique property set, including their ductile response to applied stress. This ductility is associated with the viscoelastic nature of polymers and is attributed to their unique molecular structure. In spite of that inherent ductility, most plastic components fail through one of the many brittle fracture modes. Experience has shown that most plastics failures occur as brittle fractures of normally ductile materials. Thus, within evaluations of plastic component failures, the focus of the investigation frequently turns to identifying the nature of the ductile to brittle transition.

TMG Adds Engineering Staff

Ben Malcheski

Ben received his B.S. from the Department of Composite Materials Engineering at Winona State University in the spring of 2012 and joined The Madison Group after graduation. He is responsible for performing failure analysis on thermoplastic and composite parts. Prior to joining The Madison Group, Ben worked in Winona State University's Composite Materials Technology Center (COMTEC). At COMTEC, Ben was responsible for manufacturing test specimens as well as performing destructive testing, non-destructive testing, rheometry, and thermal analysis. Outside of work Ben manufactures carbon fiber composite parts using autoclave processing and has built an FDM style 3D printer.

Ben is also an avid sailor, windsurfer, kiteboarder, and snowboarder. In 2006 Ben and his father were named to the US Sailing Team in the Tornado class.

"Ben has a lot of hands-on experience with plastics and understands plastic behavior very well. Both of these attributes are rare to find in an engineer," wrote Paul Gramann, President of The Madison Group, "Ben has fit-in very well and assisted on a number of projects that have used his unique skill set."

Richard Anfinsen

Richie received his B.S. from the Department of Composite Materials Engineering at Winona State University in the spring of 2012 and joined The Madison Group team after graduation. His responsibilities are performing failure analysis on thermoplastic and composite parts. While attending school, Richie worked for RTP Company in the Quality Assurance Lab. At RTP, Richie was responsible for performing various tests on specialty thermoplastic resins including rheometry, various strength properties, MFI, and many others. Richie is registered as an Engineer-in-Training with the National Council of Examiners for Engineering and Surveying and plans to earn a Professional Engineering license once the work experience criterion has been fulfilled.

"We are pleased to add Richie to our growing team of engineers. Richie brings excellent hands-on training and experience in the behavior of plastics that will bolster our capabilities to help solve our client's plastics problems," said Bruce Davis (CEO).