TMG News

September 2017

The Madison Group
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The Benefits of a Non-Destructive Visual Analysis– Part 2 : *A Case Study*

Jack DeSousa

The Benefits of a Non-Destructive Visual Analysis—Part 2

(This article is a continuation of the article titled "The Benefits of a Non-Destructive Visual Analysis: *A Case Study*" appearing in the TMG News for June 2017.)

There are many benefits to performing a non-destructive, visual analysis prior to destructively testing a part. In some cases, non-destructive testing could completely solve your problem. In other cases, it will provide a springboard to destructive testing. The first article in this two-part series focused on conducting a non-destructive, visual analysis of a failed travel mug. The goal of this article is to verify the conclusions of the non-destructive analysis with destructive testing of the travel mug. In addition to this goal, we would also like to further determine if destructive/analytical tests can answer some questions left inconclusive.

If you have not read the first article, you can link to it here: The Benefits of a Non-Destructive Visual Analysis: A Case Study. For reference, here is a brief table of what we *did know* from the non-destructive analysis:

What was failure?	Cracking on exterior of cup and the interior threaded section.
Cracking characteristics?	Brittle mode, rapid propagation, and high-energy driving cracking.
What caused cracking?	A short-term, high-energy event.
Chemical influences?	None observed.
Thermal influences?	None observed.

Here is a table of things left *inconclusive* after the non-destructive analysis:

Crack Initiation point?	INCONCLUSIVE.
Use beyond parameters?	INCONCLUSIVE.
Design/Material contributions?	INCONCLUSIVE.

Destructive Sectioning of the Travel Mug

The first goal of destructive testing was to expose both of the cracks in the travel mug (a flowchart is shown in **Figure 1**. The transverse crack and axial crack surfaces were both exposed for visual, microscopic, and SEM analysis. In addition to exposing the fracture surfaces, a section of the mug with an intact weld was longitudinally cross-sectioned and potted in order to view the weld and internal geometries of the travel mug.

Inside This Issue:

The Benefits of a Non-Destructive Visual Analysis: - Part 2 : *A Case Study* (cont.)

Jack DeSousa

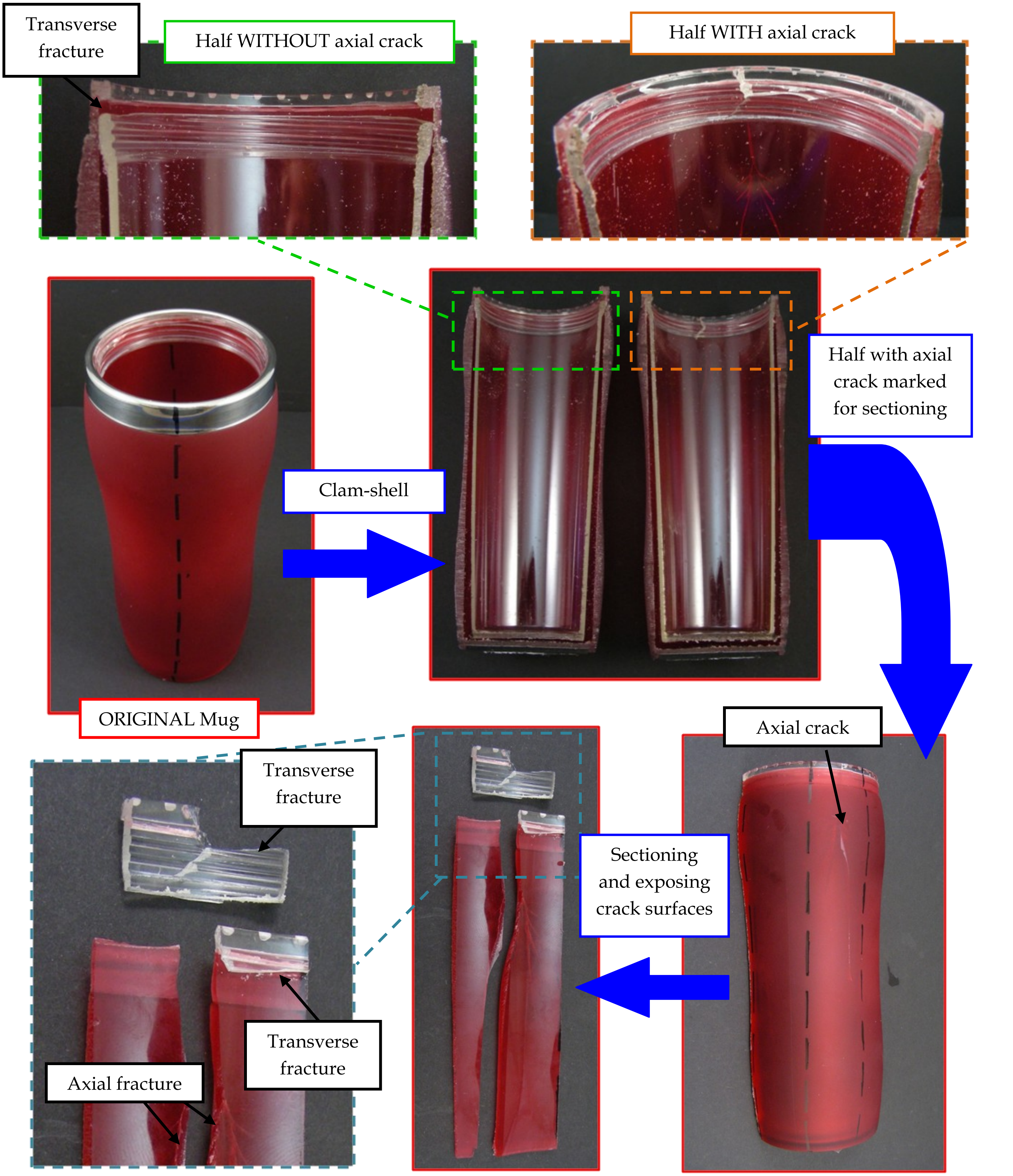


Figure 1 - Flowchart of the destructive sectioning for the travel mug.

The Benefits of a Non-Destructive Visual Analysis—Part 2: *A Case Study* (cont.)

Jack DeSousa

Viewing the Transverse Crack Surface

The transverse crack in the clam-shelled half without the axial crack was viewed with a digital microscope (**Figure 2**). There are two distinct sections within the transverse fracture. The sections on the cut ends of the clam-shelled half showed a jagged/sporadic fracture surface, while the middle section was relatively flat and appeared to follow the transition below the weld. The fracture in the cut end sections was evidently brittle in nature with little ductility. This fracture surface showed some relatively large river and hackle marks, which are indicative of a rapid fracture that has high energy. In the middle section, the fracture surface appeared brittle in nature with light ductility in some fracture features. At first, the features looked similar to banding, which is typically associated with slow crack growth. However, at higher magnifications with the digital microscope, the surface showed numerous fracture planes and rapid fracture features. In contrast, slow crack growth would most likely leave significantly, more smooth and fine features. Therefore, this showed that while the middle section was a rapid fracture, it could have had slightly less energy than in the cut ends of the transverse fracture.

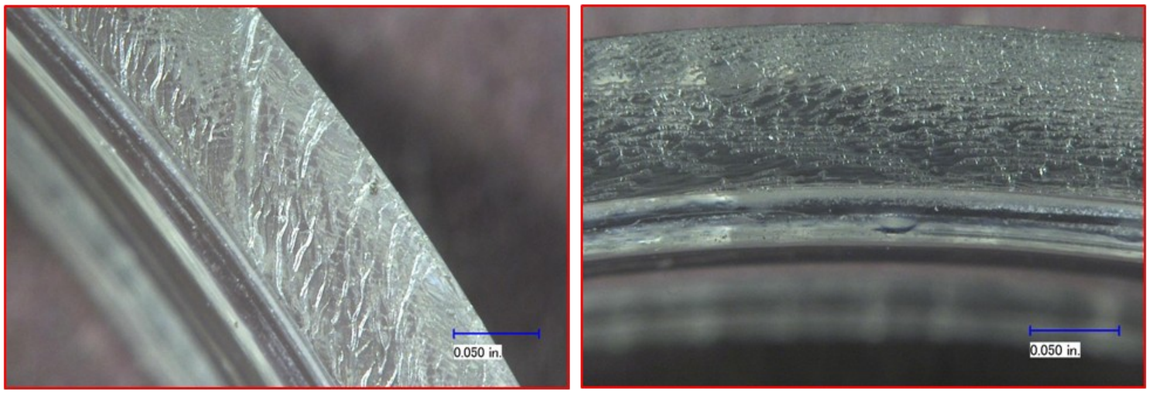


Figure 2– Micrograph views of a cut end section (left) and the middle section (right).

Both distinct sections of the transverse crack were viewed with a scanning electron microscope (SEM). The end sections showed a fracture surface that was characteristic of a rapid and high-energy fracture (**Figure 3**). There were river markings and hackle marks showing the fracture moving from the bottom right to upper left -hand corner of the image. While there was some micro ductility in the crack unions, there were little to no signs of any macro ductile stretching of the polymer during cracking. When viewed with an SEM, the "relatively flat" section of the transverse crack showed a fracture similar to the end sections in the sample. There were slightly larger areas between fracture features, but the features were similar in nature. In both sections, there were no signs of any adverse chemical/environmental effects that had contributed to cracking in the mug. Overall, the transverse crack showed a brittle and high-energy failure with rapid fracture features. This was observed with both the digital microscope and SEM. This confirms the conclusions in the non-destructive analysis regarding the transverse crack. There was nothing observed in the transverse fracture that showed it was not due to a short-term, high-energy event.

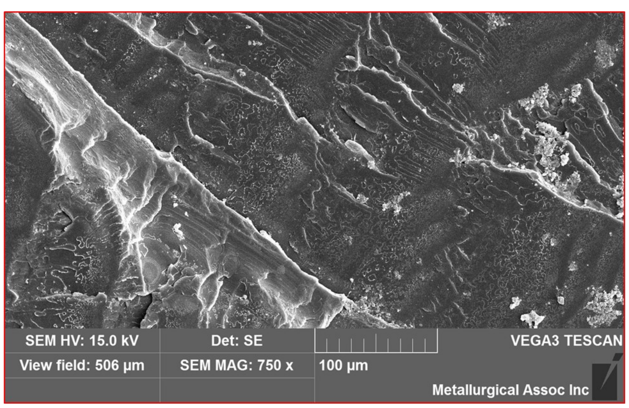


Figure 3—SEM view of a cut end section of the transverse fracture.

Viewing the Axial Crack Surface

Due to the metal ring around the top of the travel mug, it was difficult to tell during the non-destructive analysis whether the axial crack in the internal cup was the same crack as in the outer housing. After

The Benefits of a Non-Destructive Visual Analysis—Part 2: *A Case Study* (cont.)

Jack DeSousa

exposing the axial fracture surface, it was evident that the internal cup and outer housing shared the same axial crack. The half of the axial crack with an intact weld was examined to observe the features near the weld area.

The axial crack surface in the outer housing showed features that were characteristic of a short-term, high-energy failure (**Figure 4**). Much like the transverse crack, the fracture surface appeared to be brittle in nature with rapid fracture features such as hackle marks. The fracture features appeared to propagate from the top of the outer housing down to the bottom of the crack. When viewing the axial crack near the weld with a digital microscope, it appeared that the crack initiated within the internal cup very near to the weld between the two parts. This was observed as the fracture features in the outer housing appeared to extend from a single point right over the weld (this was overturned when viewed with an SEM.) At that point in the analysis, it was thought that the crack was likely initiating from around the weld in the part, but the part was viewed with an SEM to confirm the crack initiation area.

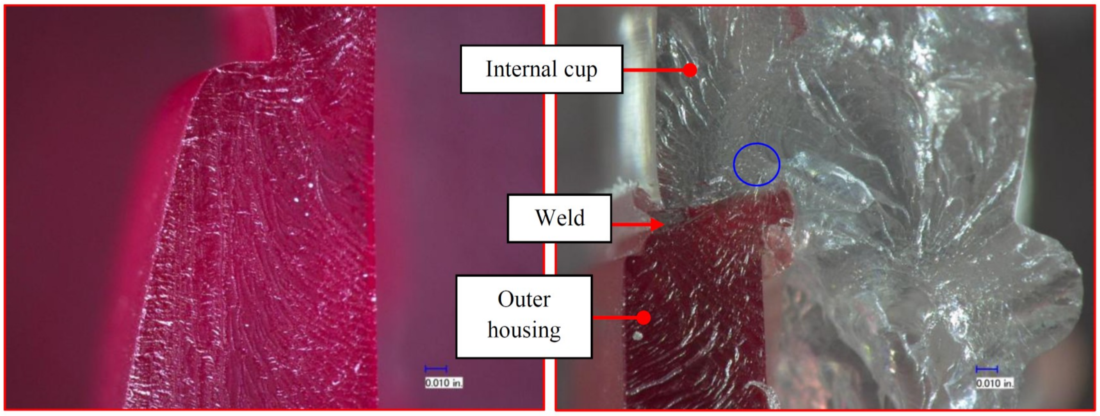


Figure 4- Micrograph views of the axial crack near the weld (left) and in the outer housing (right). The "secondary initiation" point is marked with the blue circle.

While it appeared that the axial crack initiated at/near the weld with a digital microscope, it was obvious with an SEM that this "secondary initiation" grew out of a fracture propagating from the internal cup. Upon further searching, the approximate area of crack initiation was observed in the internal cup adjacent to the transverse crack (**Figure 5**). From the crack initiation area, the crack propagated up and around the internal cup, crossed through the weld, and propagated down the outer housing. It is pertinent to note that due to the location of the approximate crack initiation area, the sample would have to be further sectioned to directly view that area with higher magnifications.

Exposing the axial crack surface confirmed the conclusions from the non-destructive analysis about the axial crack. Additionally, it gave a more precise area of crack initiation.

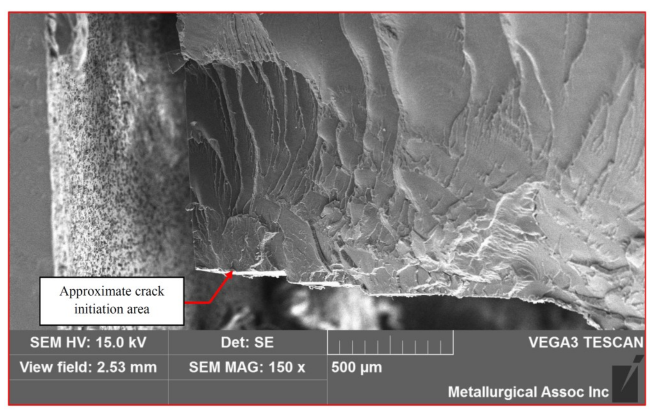


Figure 5—SEM view of approximate crack initiation area.

<u>Cross-Sectioning of the Travel Mug</u>

The potted portion of the mug was cross-sectioned and polished in order to view the weld area and threaded section (**Figure 6**). While the weld between the two parts appeared to have decent mixing of the materials, the intentional air gap between the sidewalls of the parts would have likely decreased the overall strength of the weld area. This shows that the travel mug contained a less-than-optimal design near the weld. The transverse crack in the internal cup occurred completely below the weld in the internal cup. It is possible that the weld

The Benefits of a Non-Destructive Visual Analysis—Part 2: *A Case Study* (cont.)

Jack DeSousa

Cross-Sectioning of the Travel Mug (cont.)

geometry decreased the strength of the part. Furthermore, the top of the gap between the parts could have acted as a stress concentration in the part, and increased the local stress in that area.

FTIR Analysis

The polymeric material for both the red outer housing and the clear internal cup were subjected to Fourier transform infrared spectroscopy (FTIR). As observed, there is a good match between the spectra for both the outer housing and internal cup (**Figure 7**). The absorption bands are characteristic with those for a styrene/acrylonitrile (SAN) copolymer resin. The soft coating on the exterior of the red outer housing was also tested with FTIR. It showed absorption bands indicative of a thermoplastic elastomer material with ester and acrylic functionality. Overall, the FTIR analysis fits with what has been observed in the other tests. While there was nothing unusual found from the test in this case, FTIR can provide you with helpful information. Knowing what material you are working with can give you a better understanding of where to go with other tests, especially any thermal tests. Furthermore, it could also help to shed light on the observed behavior of the material during cracking/failure.

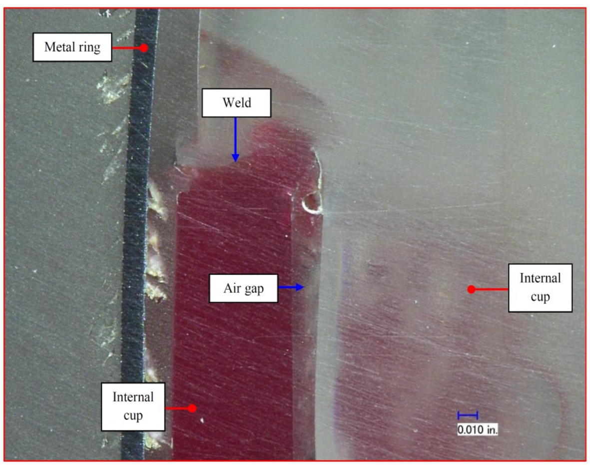


Figure 6-Micrograph view of the cross-sectioned travel mug.

Conclusion

The destructive testing of the travel mug confirmed all the conclusions of the non-destructive analysis. The SEM examination confirmed that both cracks were rapid and high-energy, and nothing observed disproved that this failure was due to a short-term, high-energy event (impact/drop). As far as answering the *inconclusive* questions, we were able to determine a more precise location for the crack initiation area. We also learned that the cross-section of the travel mug showed a less-than-optimal weld area, and that the SAN material of the mug correlates with what we observed in the fractography. At this point, we can definitively conclude whether the mug was subjected to a drop/impact beyond its design parameters, or the design/material of the mug contributed to failure. Extensive exemplar testing would likely need to be performed in order to have conclusive evidence answering those questions.

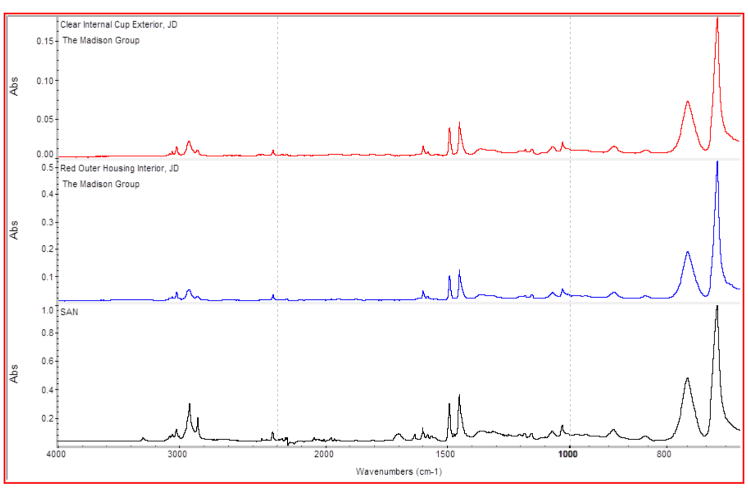


Figure 7—View of the spectra for both the internal cup (top), the outer housing (middle) and their shared library match.

If there is one thing to take away from this series, it is that non-destructive analysis of a part is a powerful tool. While we learned more information about the failure and part when we included the destructive testing, we were able to figure out the destructively confirmed mode and manner of failure before cutting into the part. All in all, you cannot go wrong by taking the time to look at a failure non-destructively, before jumping into destructive tests.

Information regarding additional case studies can also be found at: https://www.madisongroup.com/case-studies.html

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:

Wednesday, September 20, 2017—*Jeffrey A. Jansen* – Society of Plastics Engineers
An Introduction to Dynamic Mechanical Analysis — 10:00 am CST

Dynamic Mechanical Analysis (DMA) is a thermoanalytical technique that measures the stiffness (modulus) and damping (tan delta) of polymeric materials to assess the viscoelastic properties as a function of time, temperature, and frequency. Polymeric materials display both elastic and viscous behavior simultaneously, and DMA can separate these responses. Polymers, composed of long molecular chains, have unique viscoelastic properties, which combine the characteristics of elastic solids and Newtonian fluids.

As part of the DMA evaluation, a small deformation is applied to a sample in a cyclic manner. This allows the material's response to stress, temperature, and frequency to be studied. The analysis can be in several modes, including tension, shear, compression, torsion, and flexure. DMA is a very powerful tool for the analysis of plastics and can provide information regarding:

- Modulus
- Damping
- Glass Transition
- Softening Temperature
- Creep Behavior
- Stress Relaxation
- Degree of Cure

This webinar will provide an introductory look into DMA and how it can be applied to better understand plastic behavior, both long-term and short-term.

Contact **Scott Marko** at SPE, smarko@4SPE.ORG.

Tuesday, September 26, 2017—*Jeffrey A. Jansen*—AudioSolutionz
Ultraviolet (UV) Effects on Plastic Materials—Noon CST

If you work with plastic components that have outdoor exposure, you need an advanced understanding of the interaction between UV radiation-based weathering and plastic resins, and your goal is to prevent premature failure. Material engineers and others in the industry need to understand the mechanism of UV degradation, and which materials are most affected by it. They also must know the effects of UV degradation on plastic materials, and how using stabilizers can improve resistance to UV rays. There are also ways of testing the susceptibility of plastic materials to UV degradation.

This session will include an introduction to UV degradation and an explanation of the failure mechanism characteristic of UV radiation and plastic interaction. Case studies associated with UV radiation exposure will be presented and an explanation of how ultraviolet radiation can affect plastic materials will be included. You will also gain a better understanding of how to anticipate whether plastic materials used in their various applications may be at risk. In this webinar, Jeffrey will further discuss how to prevent UV and weathering failures through proper material selection, as well as the use of stabilizing additives.

For more information:
https://www.audiosolutionz.com/chemicals/ultraviolet-resistance-for-plastics.html

Upcoming Educational Webinars (cont.)

Wednesday, October 11, 2017 *- Paul Gramann, Ph.D., P.E. –* CLM Group
Why and how Large Aquariums can Crack— 11:00 am CST

Aquariums are a huge attraction with many of them throughout the world that hold millions of gallons of water. The size of aquariums continue to increase in size, which is possible by using extremely large plastic panels. Though it is not common for these tanks to fail, there have been many high profile aquarium failures. This presentation will review how and why these aquariums failed.

Upcoming Educational Conference

CAMX 2017 Conference: Monday—Thursday—September 11—14, 2017
Orange County Convention Center, Orlando, FL

Wednesday, September 13, 2017—*Dr. Antoine Rios*
Understanding Failure of Discontinuous Fiber Reinforced Plastics Through Predictive Analysis of Static Fatigue—8:00 am EST

It is common for designers to look at the datasheet of fiber-reinforced plastics and select the material solely based on the printed property values. However, care has to be taken to understand the anisotropic property effects caused by fiber orientation, fiber breakage, and weld lines. There is abundant knowledge in regards to how these material anisotropies affects the short-term behavior of plastics. However, less attention is paid to how these anisotropies can affect the long-term behavior of the part. This presentation shows examples of failures caused by long-term exposure to stress (static fatigue), and techniques utilized to predict long-term performance.

For more information:
http://camx17.mapyourshow.com/7_0/sessions/session-details.cfm?ScheduleID=49

Upcoming Educational Seminar

ICIPC Headquarters
Medellin, Columbia
Failure Analysis of Polymer Products and Materials

Monday—Tuesday, October 9-10, 2017— *Dr. Antoine Rios*
Presentations:

- Degradation Failures in Polymer Products and Materials
- Designing to Prevent Failure in Plastics
- Failure Analysis in Fiber-Reinforced Composite Materials

For more information:
https://www.icipc.org/site/en/news/item/227-failure-analysis-seminar
http://www.icipc.org/comunicaciones/sem-analisisfalla-2017/sem-failureanalysis-newdate.pdf

Information regarding upcoming educational opportunities can also be found at:
http://www.madisongroup.com/events.html

What Does it (or Does not) Mean if a Plastic Material has a Flammability Rating?

Paul Gramann, Ph.D., P.E.

Most plastic materials are made from the same raw ingredient that powers the majority of our vehicles — petroleum. It is not surprising that most plastics will be extremely flammable if given the chance. In essence, the plastics that surround us can be viewed as a solid fuel. To reduce the risk of a plastic part from catching fire and spreading a flame, additives are commonly blended into the plastic. These additives are referred to as flame retardants. Some plastics are inherently more flame resistant than others, such as poly(vinyl chloride) (PVC), and require little-to-no additional flame retardants. To provide the engineer or designer with some knowledge of the plastic's propensity to ignite and spread a flame, it is commonly given a flammability rating. What does (or does not) this rating actually mean? This article will attempt to provide some insight to this commonly misunderstood rating.

Misconception of the UL 94 Rating

Have you heard or read the phrase "The plastic is UL 94 rated" and understood this to mean that the plastic will not burn? You are not alone. This is a common misunderstanding by many engineers that specify plastics for the parts they are molding or using in assemblies. The UL 94 test standard does not provide definitive guidance on whether the material will burn or not. What the standard does provide is some insight into the ignition characteristic of the plastic material. The UL 94 tests are performed under controlled laboratory conditions on bar or plaque shaped specimens. The conditions rarely emulate actual field conditions. Further, since the geometry of the actual part can play a critical role on whether a part will ignite and/or spread a flame, the test geometry can overstate, or more likely, understate the resistance to igniting and spreading a flame.

The UL 94 Test

The UL 94 test involves the lighting of specimens with a controlled flame under controlled conditions. Following the horizontal burn (HB) test, a 5 in. x 1/2 in. x 0.118 in. specimen is exposed to a flame for 30 seconds while in a horizontal configuration. The plastic material will receive an HB rating if the flame self-extinguishes before or has a burn rate that is less than 3" per minute. The HB rating is considered the easiest UL 94 test to pass. Note, the plastic can get an HB rating if it ignites and spreads a flame.

A more difficult rating to achieve, places the sample in a vertical (V) orientation during the testing procedure. The 5 in. x 0.5 in. specimen, with a thickness that is typically 1/32 in., 1/16 in. or 1/8 in., is exposed to a flame for 10 seconds. If the sample does not ignite or the flame self-extinguishes, the sample is exposed to the flame for another 10 seconds. Igniting the vertical sample at its bottom, allows the flame to burn the plastic material above it and feed the flame. This makes it a more aggressive test than the horizontal burn test. A cotton ball is placed below the vertical specimen, which will burn if it comes in contact with any flaming drips of plastic.

The plastic gets a rating if the following results are met:

V-0:
If the sample self-extinguishes within 10 seconds and has no flaming drips.

V-1:
If the sample self-extinguishes within 30 seconds and has no flaming drips.

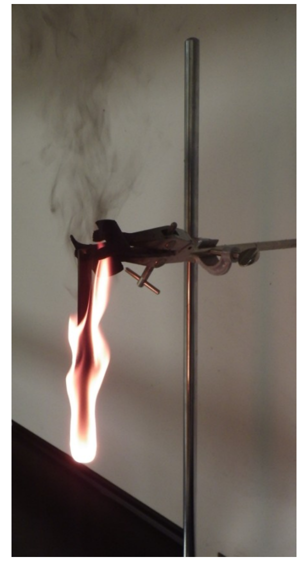
V-2:
If the sample self-extinguishes within 30 seconds, but flaming drips that light the cotton, are allowed.

What Does it Mean (or Does not) if a Plastic Material has a Flammability Rating? (cont.)

It is important to note that a plastic material can get a "V" UL rating, even if does not self-extinguish immediately or has flaming drips that can start another material on fire.

Why UL 94 is an Important Test/Rating

Though the UL 94 test does not indicate if the plastic material will burn or not, it does provide a relative measure on how flammable it can be. It also provides insight to how quickly a flame will spread. In many instances, the goal is not to necessarily stop the flame, but to reduce how quickly it will advance. This allows time for people to exit a structure where a fire may have started. Further, many flame events in electrical appliances are brief, lasting less than several seconds. A material with a UL 94 rating may never ignite under these conditions, whereas, a material that is not rated may ignite and spread the flame quickly and aggressively.



Summary

In summary, plastic materials are hydrocarbons that are commonly filled with additives to improve flammability resistance. Perhaps it is most important to understand that a plastic material that has an UL 94 rating can ignite, spread a flame, and contribute to a fire event. It is wrong to assume that if the plastic materials are UL 94 rated, there are no combustible materials in the assembly. This is not to say that the UL 94 rating is not important. On the contrary. The UL 94 rating provides an important metric for the engineer or designer on the plastic material's propensity to ignite and spread a flame. It is also important to know that there are other test methods (e.g. ASTM, IEC, FMVSS, FAR) used to measure or rate how a plastic material will behave during a fire event.

Announcements:

The Madison Group Adds Engineering Staff

The Madison Group is Pleased to Welcome Patrick Mabry

The Madison Group announces the addition of Patrick Mabry to its engineering team. Patrick earned his M.S. in Mechanical Engineering in 2015 from the University of Wisconsin–Madison's Polymer Engineering Center, and joined The Madison Group in May of 2017. His primary responsibility is performing Moldflow simulation for injection and compression molded parts. Patrick's background is rooted in the design and processing of composite materials, with these skills having been developed in working for Trek Bicycle Corporation and HEAD Sports. Through his previous work he has gained knowledge of lean manufacturing techniques, mold design, and composite part design.

"We are pleased to have Patrick join our growing team of engineers at The Madison Group. He brings excellent composite manufacturing knowledge that will bolster our capabilities at The Madison Group," said Bruce Davis (CEO).

The Madison Group Teaches Failure Analysis, Design & Prevention

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: material, design, processing, installation, and service
- 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
- Methods and techniques to avoid future failures
- Failure prevention through improved part and tool design

Course Outline:

- Overview of Plastic
- Composition
- Properties
- Plastic Part Failure
- Failure Correction and Prevention
    - Part Design
    - Mold Design
    - Material Selection
    - Processing
    - Validation Testing
- Failure of Plastics Overview
- Failure Mechanisms
- The Roles of Multiple Factor Concurrency and Statistical Distribution in Plastic Part Failure
- Failure Analysis
    - Problem Solving / Investigation Techniques – FA and RCA
    - Failure Analysis Test Methods
    - Case Studies

Plastic Part Failure: Analysis, Design & Prevention
Monday through Wednesday, October 16-18, 2017
8:30 am to 4:30 pm
Location: University of Wisconsin – Milwaukee School of Continuing Education
CEUs: 2.0/PDHs: 20
Program No. 4830-9922

For more information: http://uwm.edu/sce/courses/plastic-part-failure-analysis-design-prevention/

For more information, contact:
Marcia Gabriel, gabrielm@uwm.edu, 414-227-3378