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TMG News

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The Benefits of a Non-Destructive Visual Analysis: *A Case Study*

Jack DeSousa

People are creatures of habit. When faced with a problem, a mathematician might neatly write out all known variables, or a physicist may immediately draw a free body diagram in order to get a better grasp of a certain situation. While these are good first steps to answering a question, one might have an equally unhelpful impulse often in the interest of saving time. Skipping foundational steps to solve a problem could lead to a dead-end without being any closer to an answer. In the same way, jumping prematurely to destructive testing of a failed part could lead down a wrong path with no way of returning to "square one." Taking the time to perform a non-destructive, visual analysis at the forefront of a problem will always be helpful. In some cases, it could completely solve the problem. In other cases, it will provide a springboard to destructive testing and eliminate certain destructive tests (**Figure 1**).

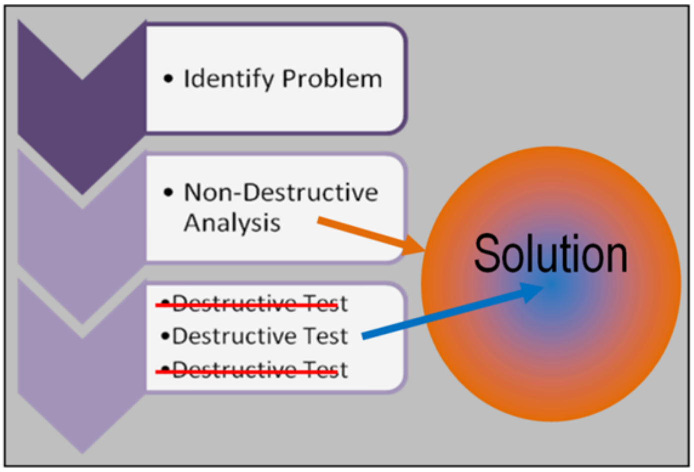

Figure 1 *– Elimination of destructive tests.*

Let us take a look at a case study of a travel mug.

A Non-Destructive Testing Case Study: Travel Mug

Problem Identification. The only background information I was provided is that the mug failed in the field, and I do not have access to the lid. In this case, the failure is obvious to anyone who would pick up the mug to use it. There is a large longitudinal crack running down from the metal lip at the top of the mug. A quick survey of the interior shows a little less obvious cracking in the threaded section of the travel mug (**Figure 2**).

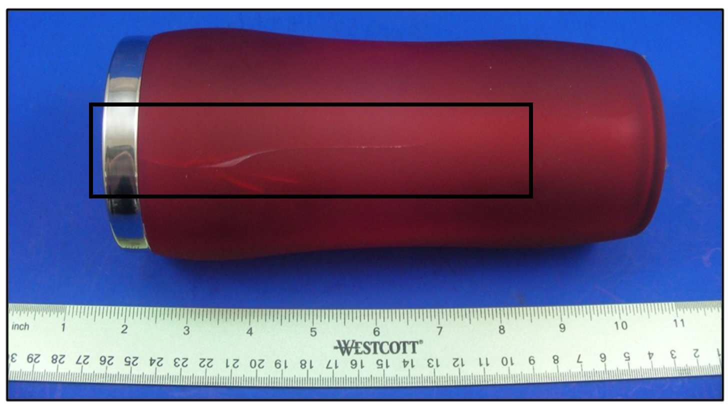

Figure 2 *– Overview of the failed travel mug. (Black box shows axial crack).*

Before we get too far, I want to identify two questions (and a possible third) regarding this failure:

1. *How* and *why* did cracking occur?
2. *Who* is responsible for the failure?
3. If failure is due to design/manufacturing, *what* can be done to prevent future failures?

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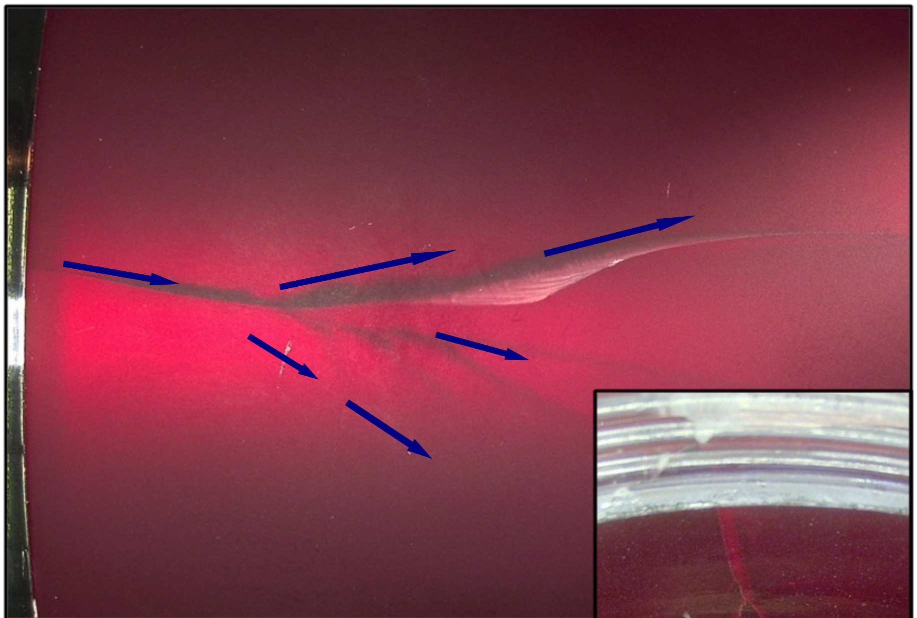
- **Exterior Analysis**

A closer examination of the visible fracture on the side of the mug (**Figure 3**) shows me three things right away: it is *high energy*, it is *rapid*, and it started at the *top*. All three of these characteristics stem from the fact that there are bifurcations in the main crack. When a single crack cannot dissipate energy in a part quickly enough, it will branch into multiple cracks. Because of this, true bifurcations typically occur in rapid fractures. Finally, if you think of the crack as a tree branch, the bifurcations grow out of the main crack; not the other way around. This shows that the crack progressed from the top to the bottom of the mug for the bifurcation to branch off in that way.



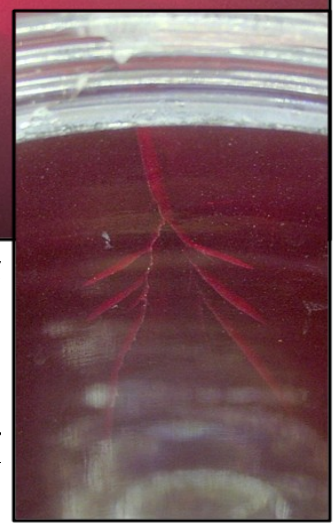


Figure 3 *– Exterior micrograph view of the axial crack (Top), and a view of the axial crack in the outer housing through the internal cup (Right).*

Now I have talked about what *is* on the exterior, it is equally important to look at what *is not* on the exterior of the mug. Even though the cracking is rapid and high-energy, there is not much damage on the exterior of the mug. There is some superficial scratching and marks likely from normal wear and use, but nothing that would correlate with the rapid, high-energy cracking on the side of the mug. While this could be due to multiple factors, I think that the separated lid of the travel mug would likely show damage from an impact or drop.

- **Interior Analysis**

Moving to the interior examination of the mug, I can see cracking that extends around the internal circumference of the threads (**Figure 4**). Although this crack is more difficult to interpret than the one on the exterior, there are some key elements about the crack that can be observed. First of all, the cracking is *brittle* in nature. Plastics are visco-elastic materials that can sometimes behave in a ductile manner and sometimes behave in a brittle manner. Typically, brittle cracking in plastics occur when the crack is moving either very quickly in the part or very slowly over a long period of time. In this case, the cracking occurred without stretching or deforming the material, thus, it is *brittle*.

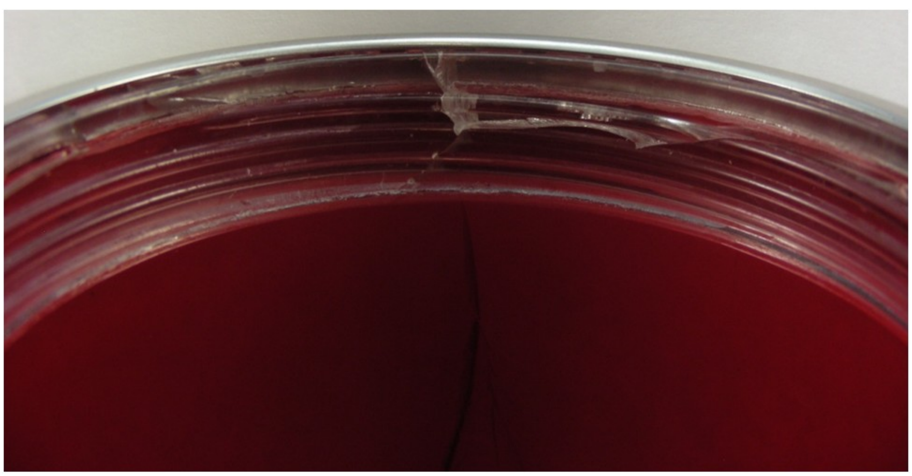


Figure 4 *– View of the cracking in the threaded section of the travel mug.*

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- **Interior Analysis (cont.)**

The other observations show that the crack was *rapid* and *high-energy*. The crack does not coincide with abrupt transitions in the threaded section. When it was propagating around the threaded section, it jumped between two different thread roots, and did not follow the root of the threads where the stress concentration would have been the sharpest. This shows me that the crack had energy behind it, and quickly propagated through the part to release energy in the path of least resistance.

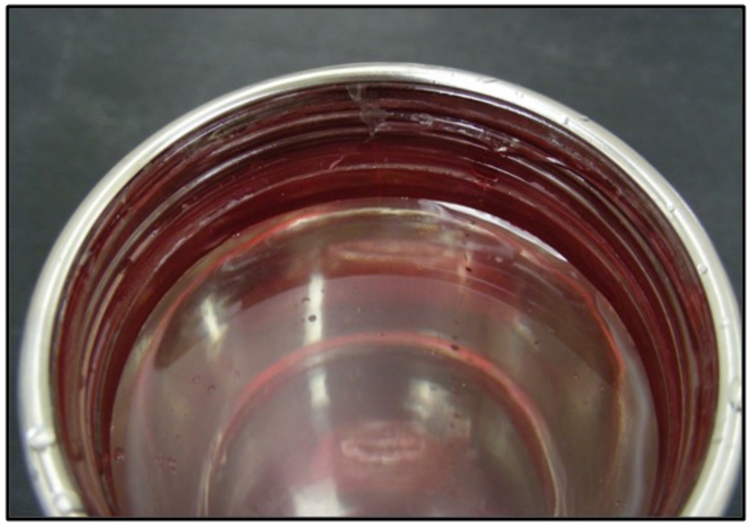

Figure 5 *– View of the water placed in the travel mug.*

I want to do the same thing for the interior of the mug and look for what *is not* there. First, I was surprised to find that the interior of the travel mug does not have any cracking below the threaded section. In order to confirm, I filled the internal cup with water and did not find any cracks or leaking up to the threads (**Figure 5**). If the heat from a hot liquid had caused or contributed to failure, I would expect cracking to occur in the internal cup since this would be nearest to the heat source. Therefore, this can eliminate thermal influences from a liquid placed in the travel mug. Furthermore, if frozen water had expanded in the mug to crack the threads and outer housing, the internal cup would definitely be cracked as well. The other major thing I do not see on the interior of the mug is adverse chemical or environmental effects. This would typically result in much more pervasive and global cracking on the interior of the travel mug.

After our exterior and interior analysis, the following findings can be made:

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

Here are some things that we *do not* know about the failure:

Use beyond parameters?	INCONCLUSIVE
Design/Material contributions?	INCONCLUSIVE

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- **Conclusion**

From our non-destructive, visual analysis, we can conclude the following: **failure was due to a high-energy event, which caused rapid and brittle cracking in the travel mug.** This conclusion is within a reasonable degree of engineering certainty. Even though this technically answers our first question, I think we can use critical thinking and logic to figure out what *more-likely-than-not* caused the short-term, high-energy event driving failure.

First of all, we will think about typical conditions that would place stress on the mug and its components. I will list some common ones out in a table for clarity:

· Weight of a liquid in the mug	· Tightening of the lid	· External compression
· Residual/manufacturing stresses	· Dropping the mug	· Impacting the mug with/on something.
· Freezing water in the mug	· Cross-threading lid	· Differing thermal expansion in mug

While there are other more extreme situations that could place high amounts of stress on the mug, I think that these are fairly typical stresses that a travel mug would see in its lifetime. First of all, since we know that failure was due to a short-term, high-energy event, the weight of a liquid in the mug and the tightening of the lid would not fit this situation. Also, we already eliminated cross-threading of the lid, differing thermal expansion, and freezing a liquid inside the mug during the interior analysis. It is possible that residual stresses or stresses from assembly could cause this failure. However, this mug did not fail directly after manufacturing. We know that this mug failed in the field. Additionally, if a very heavy object compressed the mug quickly enough to cause rapid and brittle cracking, I think we would see more gross deformation of the entire mug. The two situations that make sense are either a *drop* or *impact* of the mug (**Figure 6**). In both of these situations, high stress would very quickly be applied to a small local area, which is consistent with the failure.

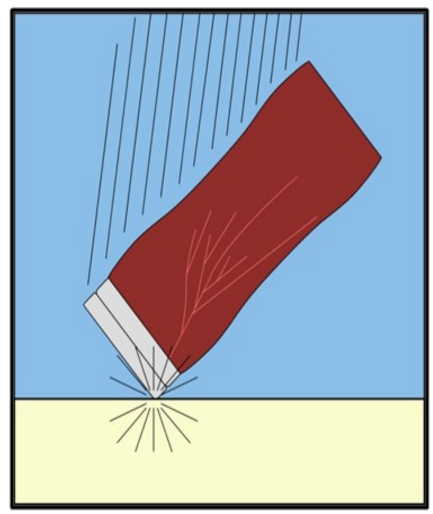


Figure 6 *– Impact of travel mug.*

Let us look at how we did with answering our questions. Ultimately, we were able to figure out *how* and *why* failure occurred without destructive testing. This is a big strength of non-destructive, visual analyses. In this specific case, there are too many unknowns after our non-destructive analysis to attribute full blame for the failure on the user or on the manufacturer. However, if we wish to know *who* was responsible for the failure, we now have knowledge about the failure to head in the right direction. For example, impact testing of exemplar travel mugs could be much more beneficial to answering that question than a standard thermal analysis test. You can never go wrong by taking the time to look at the failure rather than jumping into destructive tests that lead you nowhere closer to answering your questions.

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

Upcoming Educational Webinar

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

Thursday, May 25, 2017—*Jeffrey A. Jansen* – Society of Plastics Engineers
Prevent Failure by Understanding Why Plastic Parts Crack — 10:00 am CST

For more information:
https://www.eiseverywhere.com/ehome/248701

This webinar will cover:
Topics that are essential to understanding plastic failure. Knowledge on how and why plastics fail is imperative in preventing failure. By avoiding common mistakes it is possible to produce plastic parts that have a superior chance to perform successfully. A number of the most common causes of plastic failure will be reviewed in order to illustrate this point. The webinar will stress practical techniques to avoid future failures applications and will utilize case studies to illustrate key aspects of plastic failure and prevention.

Upcoming Educational Conferences

Autodesk Moldflow Summit 2017
Troy, MI
Wednesday and Thursday, June 7-8, 2017
Including:
Bend, Don't Break When Processing Long-Fiber Thermoplastic Resins—*Erik Foltz, The Madison Group*

The use of long-fiber composite parts has allowed engineers and designers integrate plastic components into performance critical applications. However, the end performance of those parts is heavily dependent on how the resin is processed. This presentation will highlight the new fiber breakage model implemented in Autodesk Moldflow Insight, and how the simulation can be used to help identify potential areas of concern in a mold design. The presentation will include correlation studies in which fiber length measurements were made and compared between simulation and physical parts.

For More Information:
https://www.autodesk.com/campaigns/moldflow-summit/overview

Successful Plastic Part Design
For Medical and Analytical Products
Northeast 2017—Boston, MA
Tuesday and Wednesday, June 20-21, 2017
Including:
Failure Prevention and Analysis—*Jeffrey A. Jansen*, The Madison Group
For More Information: http://www.spe-pd3.org/

IMTech Conference:
Oak Brook, IL
Tuesday—Thursday, August 1-3, 2017
Including: **Let's Talk About Right-Weighting, Not Light-Weighting**—*Erik Foltz,* The Madison Group
Registration Information Coming Soon!

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

From the TMG Solutions Archives:

Rain Barrel Analysis

Keywords - Failure, Creep, FEA, Design Evaluation

What Went Wrong?

A plastic rain barrel was cracking at the bottom of a stiffening rib after approximately two weeks in service, which resulted in leakage of water. The rain barrel was injection molded from a high-density polyethylene material.

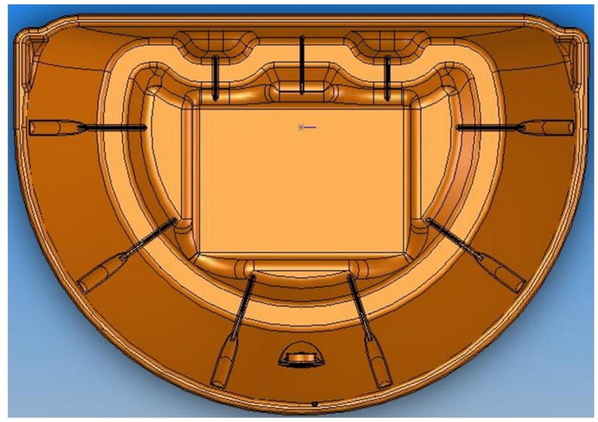
Evaluation

A visual examination of the failure revealed a smooth fracture surface that initiated at the base of the rib. The fracture surface was characteristic of a brittle fracture mechanism known as creep. Creep is a material response mechanism, commonly experienced by plastics and composites, in which the molecules of the plastic separate under the influence of a constant stress that is below the yield stress of the material.

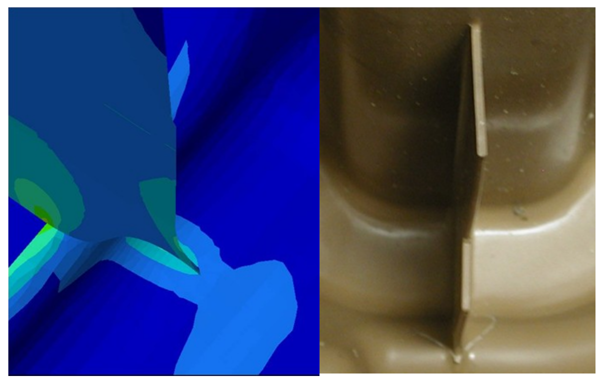
The design integrity of the rain barrel was evaluated by performing a series of material tests and structural finite element analysis (FEA). The material testing used dynamic mechanical analysis (DMA) to characterize the long-term mechanical properties of the resin while under load. The FEA was used to determine the stress distribution in the rain barrel when the barrel was filled with water. The FEA confirmed the area of high stress coincided with the failure location, and the stress remained below the yield point of the plastic material. Combining the results of the material testing and the FEA allowed for a prediction to be made regarding the amount of time until the rain barrel would fail. With the stress levels predicted in the FEA, the rain barrel was predicted to fail after approximately two weeks of service.

Conclusion

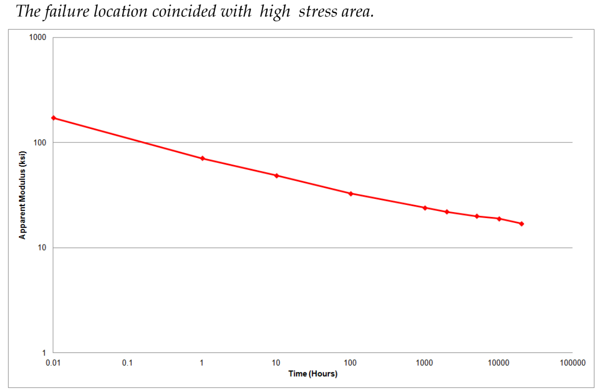
It was the conclusion of the evaluation that the rain barrel failed through a brittle fracture mechanism known as creep. The combination of the rain barrel design and material selected resulted in a stress level that left the rain barrel susceptible to premature failure when filled with water. It was recommended that a either the design of the rain barrel be modified or the plastic should be changed to a more creep resistant material.



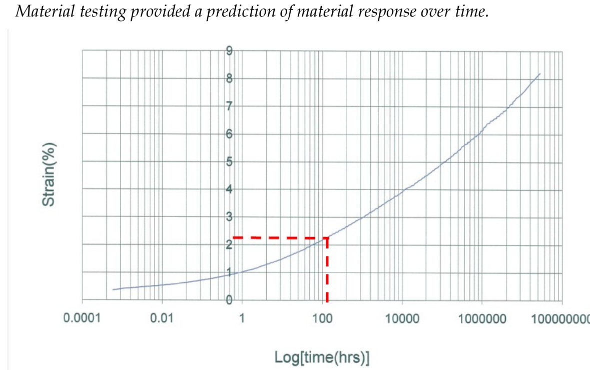
Top view of rain barrel design.



The failure location coincided with high stress area.



Material testing provided a prediction of material response over time.



Failure was predicted to occur after two weeks of service.

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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:
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