TMG News – November, 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. We also believe that it is our responsibility to help educate our clients.

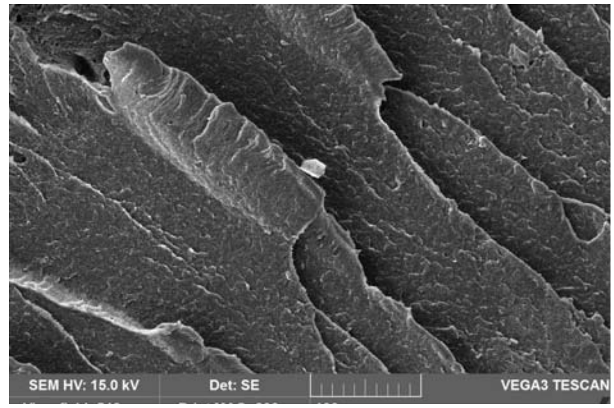
Working with plastic parts, whether in part design, manufacturing, or material or failure analysis, presents some unique challenges. The molecular structure and the resulting viscoelastic properties requires special knowledge.

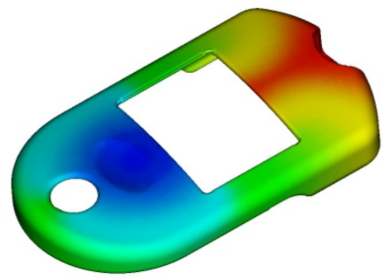
This issue of the newsletter features articles that address non-destructive plastic part evaluation and the prediction of part warpage through simulation. Both of the techniques previewed in this issue serve as invaluable tools to prevent field failures.

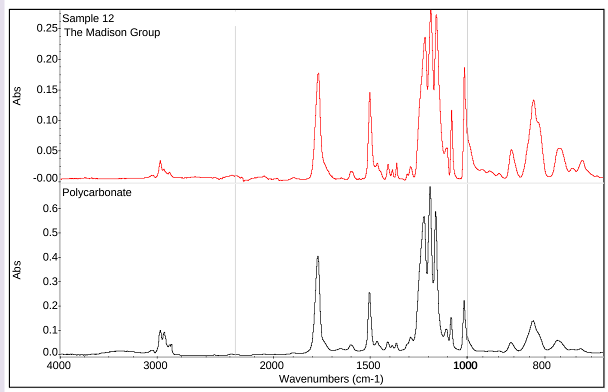
I hope that you find this issue interesting and helpful. I also encourage you to contact me if you have ideas for future issues.

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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Non-Destructive Analysis of Plastic Parts Using CT Imaging

Paul Gramann, Ph.D.

Analyzing the inside of an enclosed assembled plastic part is a formidable task without the use of invasive or destructive methods. Invasive and destructive analysis can alter the part by deforming walls or seals and still may not reveal the true state of the part prior to sectioning. Computed Tomography (CT) imaging has been used in the medical field for many years to analyze the fine details of the internal structure of the human body. This article will review the advantages and limitations of CT imaging and how The Madison Group is using this technology to analyze plastic parts.

What is CT Imaging?

CT imaging delivers a full 3D image of a part that can be electronically sliced and oriented at any location. To do this, thousands of X-rays are taken of the part as it is rotated. The X-rays penetrate the part as a digital detector receives the image. Software reassembles the images into a full 3D model that is very similar to a solid "CAD" model. The engineer now has a digital model of the actual assembly that shows extraordinary detail.

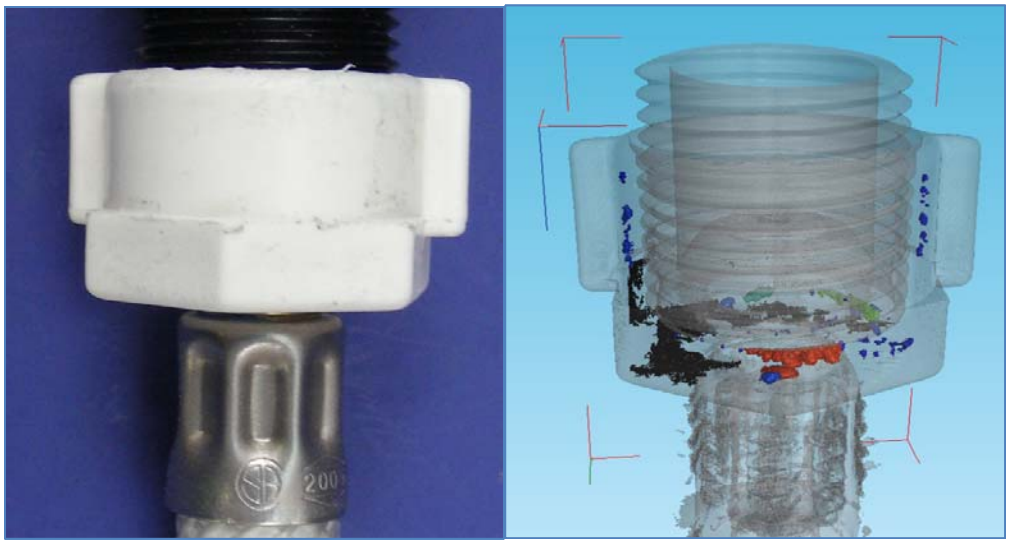

Figure 1 – Assembly of a plastic coupling and threaded stem. (left) actual part. (right) CT image.

Benefits of CT Imaging

The Madison Group uses CT imaging for the many benefits it provides when analyzing a plastic part/assembly. Perhaps most importantly, it does not require the part to be disassembled or sectioned. In almost all cases no preparation is required. The part is simply held in place using standard polystyrene foam during the scanning process.

Once scanned, the 3D model can be cross-sectioned at any angle at any location on the part. With digital slicing the actual assembled state can be viewed. The internal geometry, properly seated gaskets, engaged gears, even internal parts that have become loose, can be examined. CT imaging assists with metrology and reverse engineer a part/assembly. It is an accurate tool to help investigate the cause and origin of failure.

At The Madison Group, we frequently see internal manufacturing defects such as voids during destructive testing. Voids in the plastic can be easily detected with CT imaging. Because the part is not altered, the size and number of voids is quantifiable. Figure 1a shows an assembly of a plastic threaded coupling nut to a male threaded stem. Figure 1 right image shows the CT image of the assembly with the parts shown in a transparent mode. The colored spherical regions represent voids in the coupling that are automatically detected by the imaging software. The voids in this part are numerous and occupy a significant area of the part indicating possible processing issues and structural deficiencies.

Part-to-part or part-to-CAD model comparison is becoming increasing popular as a quality control technique. This allows one to determine if a part is changing over time from manufacturing or in service in its intended environment.

Limitations of CT Imaging

Though CT imaging continues to evolve at a dramatic rate, there are a number of limitations. CT imaging essentially works on differences in density. Materials that are extremely dense, i.e. fasteners made of heavier metals, can be difficult to scan when incorporated into plastic parts. These materials can create a "sunning effect" which produces a bright spot in the image. Since the amount of metal used in plastic parts is typically low, this effect is usually minor. Nevertheless, advances in technology are allowing metal and plastics to be scanned with increasingly better results.

Depending on the system being used, there is a size limit to the part. Currently, parts/assemblies up to approximately 15 inches long and 10 inches in diameter can be scanned. However, the resolution of the scan decreases as the area of interest increases. Thus, a balance needs to be maintained by the engineer on resolution and size of region to be scanned.

The cost of CT imaging can create limitations on what and how many parts to scan. However, the cost of CT imaging continues to decrease as this technique becomes more popular. Perhaps one can equate the cost of CT imaging to that of analysis by scanning electron microscopy (SEM), which has decreased significantly as it has become increasingly common for analyzing parts.

Analysis of a Toilet Valve

Perhaps one of the more complex parts in your house is the valve that controls the water flow into your toilet basin. This valve has very fine channels that must be molded properly and free of debris to work correctly. Figure 2a shows a common toilet valve and Figure 2b shows a cross-section/mount. The valve contains numerous parts including various rubber seals and a metal pin that must precisely assembled to work properly. The mount gives a 2-dimensional cross-sectional view of the complexity that is involved. To view another location a different part and mount would need to be created.

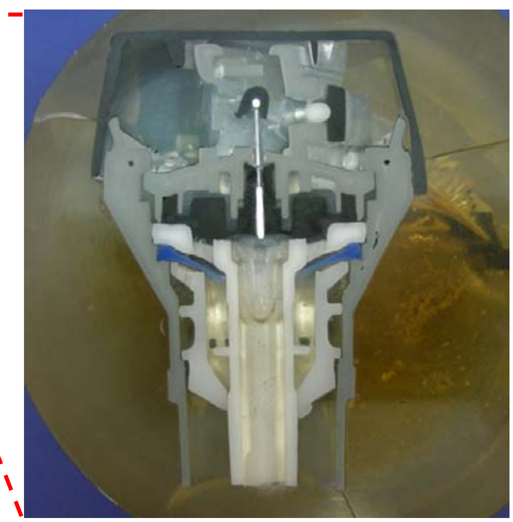

Figure 2 – Assembly of a toilet valve. (left) Assembly. (right) Cross-section.

Using CT imaging this valve could be scanned without alteration. Once scanned, any 2-dimensional cross-section can be made, Figure 3. The location of the gaskets and other components can be examined very easily. Measurements can be made. Voids can be located and counted. The resolution of CT imaging is even high enough to detect part serial numbers or company logos, Figure 4. One caveat is the lack of color differentiation between parts that one would get with a cross-section and mount.

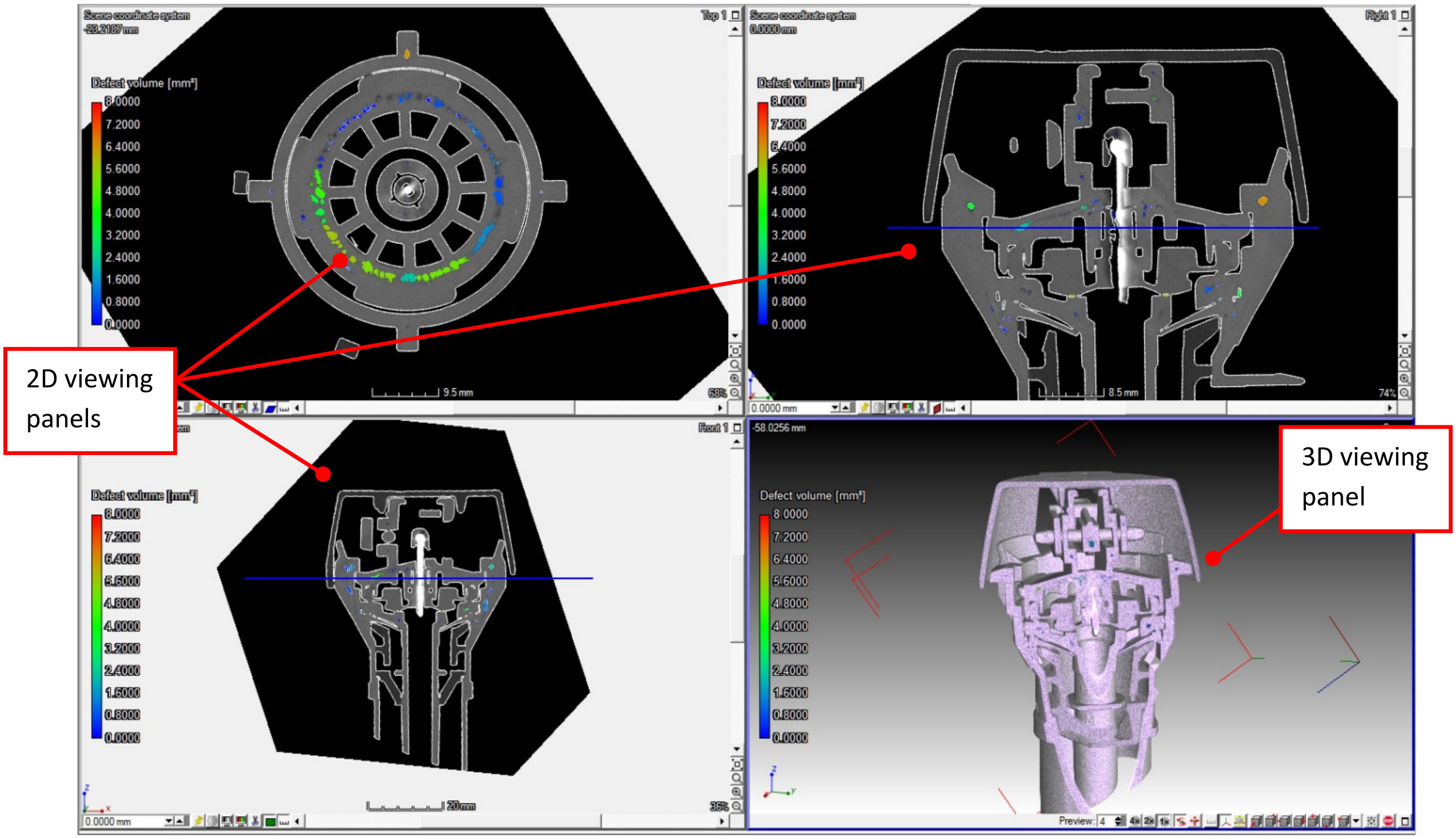

Figure 3 – CT images of toilet valve shown in 2D and 3D panels.

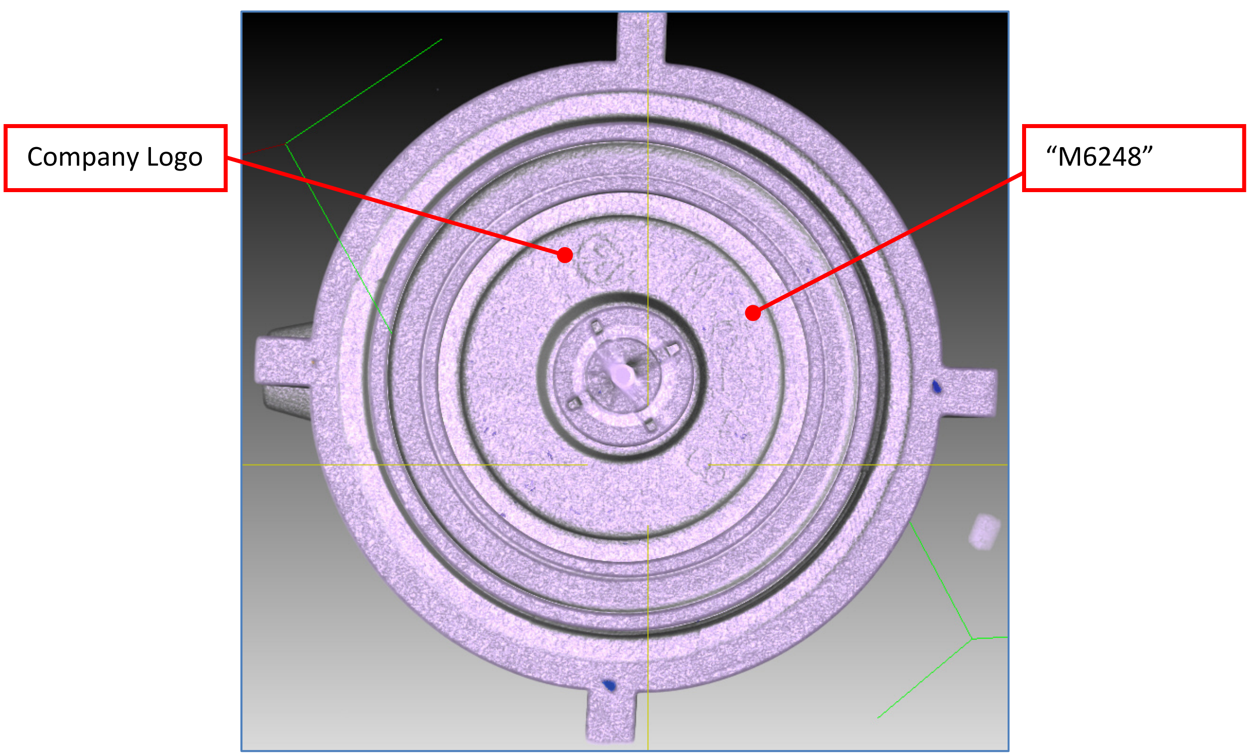

Figure 4 – Detection of part serial number and company logo internal to assembly.

Figure 5 – CPVC plastic pipe assembly that was discovered leaking.

Analyzing the Assembly of Plastic Pipes

The assembly of poly(vinyl chloride) (PVC) or chlorinated poly(vinyl chloride) (CPVC) pipes and joints commonly includes a cement that solvates the two surfaces to be assembled. If done correctly, once the solvent evaporates, a strong homogenous joint is created. Figure 5 shows a CPVC pipe and elbow that were part of a larger water distribution system. Water was discovered leaking from the joint. Using CT imaging the extent of cracking and the amount of cement were examined. Figure 6 shows the assembly with a portion of the elbow digitally removed. Numerous cracks in the pipe and the quantity of cement can be seen in Figure 7.

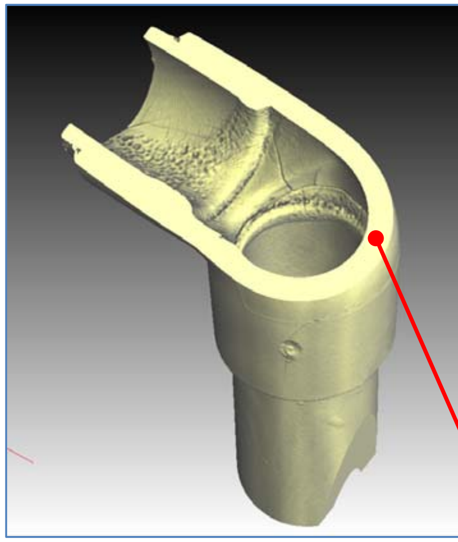

Figure 6 – CT image of a plastic pipe assembly with the digital slicing of the plastic elbow.

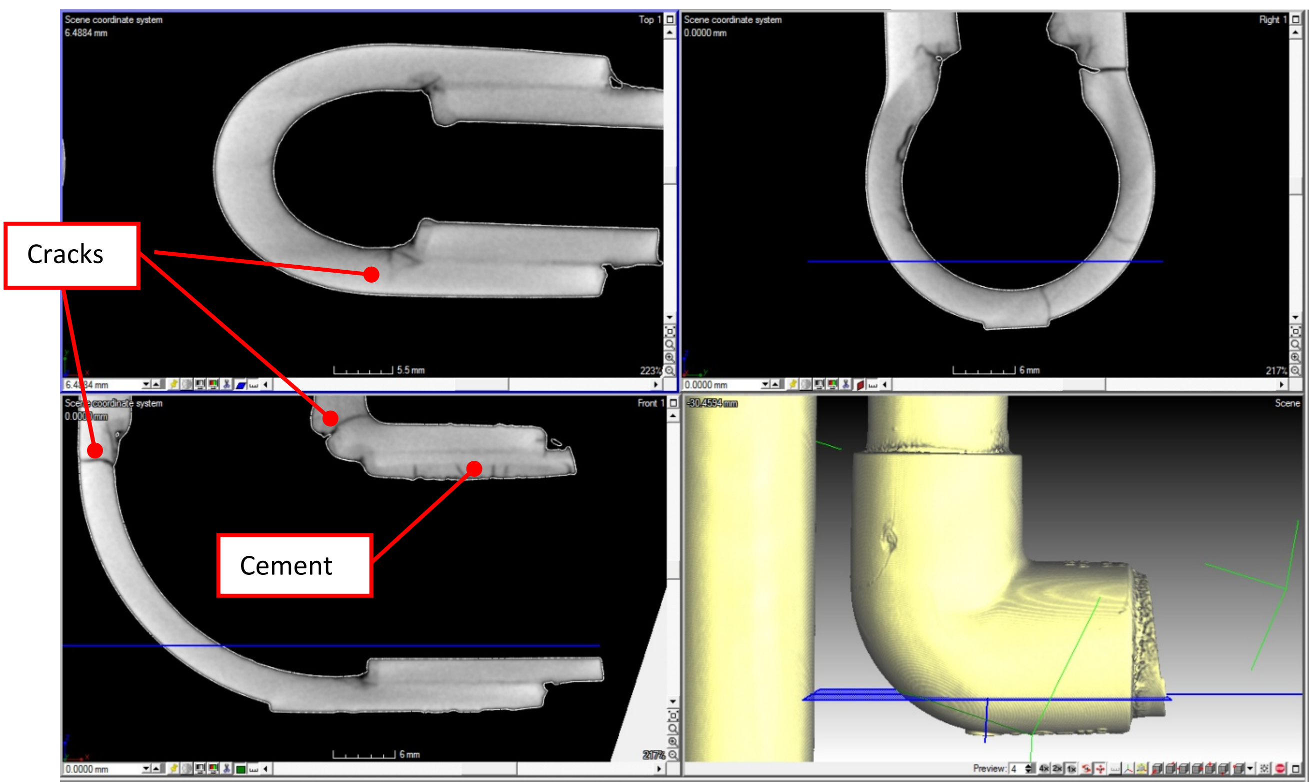

Figure 7 – CT images of plastic pipe assembly shown in 2D and 3D panels.

Conclusion

CT imaging is a powerful tool for analyzing the internal geometry without the need to modify the part. After an initial scan, the engineer has a 3D model that can be digitally sliced at any location allowing for metrology, void detection, form and fit of internal parts, among many other capabilities. The technique is being used successfully at The Madison Group for design verification, failure analysis and quality control. It is predicted that CT imaging will become as common as the scanning electron microscope when analyzing plastic parts.

If you would like more information regarding CT Imaging, or other plastics failure analysis techniques, please contact The Madison Group at 608-231-1907, or email at paul@madisongroup.com.

For further information regarding plastic part failure read the following papers 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

"Characterization of Plastics in Failure Analysis", Jeffrey A. Jansen, ASM Handbook Volume 11, ASM
http://www.madisongroup.com/publications/Jansen_ASM_Chapte_TMG2011.pdf

"Using DSC to Determine the Quality of PVC", Paul Gramann and Javier Cruz, ANTEC
http://www.madisongroup.com/publications/UsingDSCtoDeterminetheQualityofPVC1.pdf

TMG Tidbits

The Madison Group Presents Failure Analysis Seminar at NASA

When the engineers at NASA's Kennedy Space Center wanted to expand their knowledge in the area of plastics failure analysis they contacted The Madison Group for an onsite training seminar. Based upon the request, TMG's Jeff Jansen developed a specialized 8-hour program entitled **Plastic Component Failure Analysis: Methodology, Mechanisms, and Case Studies**. Approximately 25 engineers from the Kennedy Space Center participated in the training seminar and walked away with a much better understanding of the essential factors in plastic part performance, the key plastic failure mechanisms, and the failure process and techniques used to determine how and why a plastic part has failed.

To obtain more information about cost effective plastics training at your facility, contact Jeff Jansen of The Madison Group at 608-231-1907 or at jeff@madisongroup.com.

7 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. Below is a list of the upcoming webinars:

Environmental Stress Cracking of Plastics Jeffrey A. Jansen
November 15, 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.

Introduction to Failure Analysis of Plastics (2 sessions) Jeffrey A. Jansen
January 17 & 24, 2013 10:00 AM Central Time
The most efficient and effective approach to plastic component failure is performing a systematic failure analysis following scientific method. Someone once said, "if you don't know how something broke, you can't fix it", and this certainly highlights the importance of a thorough understanding of how and why a product has failed. As part of the course the attendees will gain insight into:

- The five factors effecting plastic part performance
- The primary plastic failure mechanisms
- The process of conducting a failure investigation
- The importance of ductile-to-brittle transitions and their role in plastic component failure
- The types of analytical tools used to evaluate a failed plastic part

An Introduction to Plastics Jeffrey A. Jansen
March 6, 2013 10:00 AM Central Time

The Effects of Impact and Other Rapid Loading Mechanisms on Plastics Jeffrey A. Jansen
May 1, 2013 10:00 AM Central Time

Basic Rubber Technology Jeffrey A. Jansen
July 16, 2013 10:00 AM Central Time

Thermal Analysis in Failure and Compositional Analysis Jeffrey A. Jansen
September 12, 2013 10:00 AM Central Time

Multi-factor Failure of Plastics Jeffrey A. Jansen
November 6, 2013 10:00 AM Central Time

For more information on the courses or to register, contact SPE's Barbara Spain at 203-740-5418 or bspain@4SPE.ORG.

The Influence of Material Characterization for Warpage Prediction

Erik Foltz

Many articles have been written highlighting the benefits of simulating the injection molding process early in the design process. Many potential design or processing issues can be identified and addressed before any physical prototypes have been manufactured. This can save time and money, which allows companies to bring products to market faster, at a lower cost. However, the accuracy of the simulation results is largely dependent on the material properties used during the simulation. The accuracy of the material data becomes especially important when the objective of the analysis is to provide a prediction of part shrinkage and warpage after ejection from the mold. Determining the dimensional stability of the part and the influence of processing on the final part geometry are the most common objectives for injection molding simulations. When performing this type of analysis (i.e. warpage analysis) the question invariably becomes does the material need to be CRIMS® characterized. This article attempts to explain what CRIMS® data is and when it is used for an analysis.

What is CRIMS®?

Plastics warp as a result of non-uniform shrinkage throughout the part. There are many factors that influence how uniformly a plastic may shrink, but it is the variation of shrinkage throughout the part that causes a plastic part to warp. As a result of the variation in shrinkage an internal stress develops throughout the plastic part. When the part is ejected out of the mold these stresses are released, which causes the part to deform or warp. This internal stress is often referred to as a residual stress.

Most injection molding simulation packages use a residual stress model when calculating the internal stresses in the part. This model calculated a residual stress distribution in each element of the model. This method then calculates a stress distribution across the thickness of the part in both the material flow and cross-flow direction. The calculated stress field is then used as an input for a structural analysis to determine how the part will deform and deflect to relieve the stress after it has been ejected from the mold.

The main factors influencing the validity of the predicted results of the residual stress model are:

1) Sensitivity of material shrinkage on the transition temperature (no-flow temperature) and PvT data which cannot represent the behavior under actual molding conditions;
2) Inability to calculate anisotropic shrinkage of non-fiber-filled materials;
3) Inability to determine variation of material crystallinity;
4) Inability to account for the relation behavior of the visco-elastic plastic.

In an attempt to minimize the error due to the residual stress model assumptions, Moldflow developed a modified model called CRIMS®, which couples the residual stress models with measured shrinkage data.

CRIMS® stands for **C**orrected-**R**esidual-**I**n-**M**olded **S**tress. When a material has been CRIMS® characterized it is also said to be shrinkage characterized. This characterization process involves actually molding several end gated tags as shown in Figure 1.

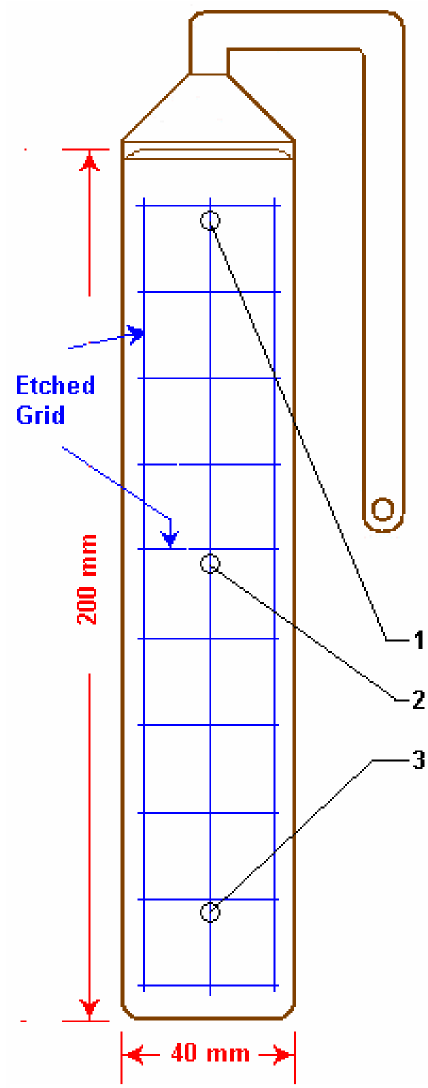

Figure 1 - Schematic showing the grid etched into the end gated tag geometry (Image Courtesy of Autodesk)

The 40mm X 200mm tags are injection-molded with an etched grid on the surface of the part, which is used for measuring the shrinkage of the part in both the flow and the cross-flow direction. Several specimens are molded with a matrix of 28 different conditions where the variables include:

A) Part thickness
B) Melt temperature
C) Mold temperature
D) Injection rate
E) Pack pressure
F) Pack time

These specimens are then allowed to cool for several days and the shrinkage measurements of the grid are recorded. This data is then fitted to the CRIMS® model and integrated into the material data file. By adding the CRIMS® model to the material file the predictions made by the solver are significantly improved. Figure 2 shows a graph that compares the predicted shrinkage of a plastic part under different process parameters to actual molded parts. The graph shows that when the simulation used the CRIMS® model the results correlated much better with measured outcomes.

When is CRIMS used?

CRIMS® data is never a requirement for performing an injection molding simulation. Therefore, if a material is characterized for Moldflow it does not necessarily mean it is CRIMS® characterized. CRIMS® is only used when the material is shrinkage characterized and a warpage analysis is being performed on a midplane or Dual Domain mesh. 3D meshes do not require CRIMS data as they use a different shrinkage model than the previously mentioned models. While a 3D mesh can be used to calculate the shrink factor of a molded part it is generally agreed upon that the most reliable shrinkage prediction for thin-walled plastic parts is provided by a resin that has been CRIMS® characterized.

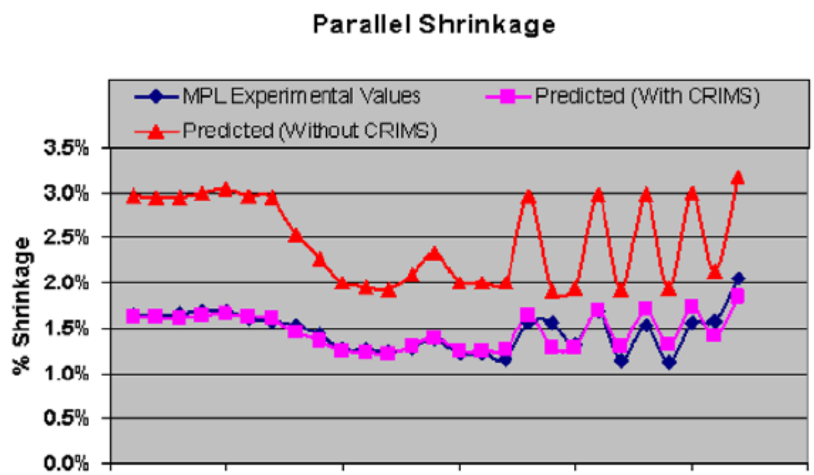

Figure 2 - This graph shows that the accuracy of a warpage analysis is significantly improved when the resin has been CRIMS characterized. (Image courtesy of Autodesk)

Injection molding simulation has become a great tool for designers and engineers to use when designing plastic products. However, the validity of the results is dependent on the input information the analyst uses. Having a highly-characterized resin helps improve the accuracy of the simulation, and can help an analyst find a solution faster. The addition of CRIMS® data can significantly improve the accuracy of the simulation when the objective of the analysis is to provide a prediction of the shrinkage and warpage the part will experience after being ejected out of the mold.

If you would like more information regarding CRIMS® or other molding simulation techniques, please contact The Madison Group at 608-231-1907, or email at erik@madisongroup.com.

For further information regarding molding simulation read these resources authored by the staff at The Madison Group.

"Simulate Your Way to a Better Mold" Erik Foltz, Moldmaking Technology, August 2011
http://www.madisongroup.com/publications/Simulate-Your-Way-To-A-Better-Mold.pdf

"Using Computer Simulation to Solve Warpage Problems" Erik Foltz, TMG News, January 2012
http://www.madisongroup.com/publications/TMG-News-January-2012.pdf

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Using Melt Flow Rate to Assess Molecular Weight

Jake Nemec

As professionals involved with plastic products on a daily basis, we are aware or should be aware that the molecular weight of a polymer is critical to its properties. The molecular weight of a polymer is essentially dictated by the length of the individual molecular chains and will directly affect its physical, chemical, and thermal properties. Additionally, molecular weight influences the processability of a material. In general, increasing the molecular weight of a polymer will improve its properties. However, this will increase the viscosity of the resin during processing, which must also be considered.

While there are many factors that impact the performance of molded thermoplastic parts, one of the common causes of part failure is a reduction in molecular weight caused by material degradation during processing. When the molecular weight of a thermoplastic resin is reduced during processing, the critical properties that the molded part was designed around will also be reduced. Thus, maintaining and understanding molecular weight throughout the part manufacturing process is instrumental in determining whether the final product will perform as intended.

One relatively basic, but important, test that can be done for thermoplastic materials to monitor relative changes in molecular weight is melt flow rate testing. This test provides an indirect assessment of the molecular weight of a material. The melt flow rate is dictated by the melt viscosity of the resin. Increases in melt flow rate represents decreasing melt viscosity and a reduction in average molecular weight of the resin. This testing can be conducted on both suspect neat resin as well as finished parts.

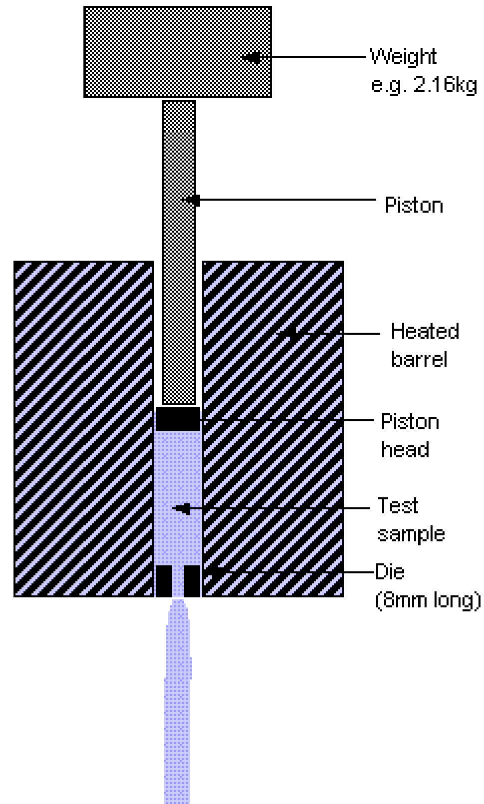

Figure 1 - Schematic showing the elements of the apparatus for melt flow rate testing.

The testing is conducted by placing a quantity of the material in a heated barrel where it resides for a set period of time until melted. It is then extruded through a standardized orifice, as illustrated in Figure 1. The industry standards for melt flow rate testing are ASTM D1238 and ISO 1133. The amount of material that extrudes in a set period of time is weighed, and the results are typically normalized to the units of grams per 10 minutes. This melt flow rate value is often what is referred to when a material is called a "10 melt" or "20 melt" resin. The melt flow rate increases with decreasing molecular weight and, as such, can be used to compare the average molecular weight of similar materials. Based on a comparison of the melt flow rate test results, it can be determined whether degradation has occurred or an incorrect/out-of-spec material was used.

Melt flow rate testing may not diagnose or solve all of the problems, and there are many complexities that must be taken into account, such as fillers/reinforcements and molecular weight distribution. However, as a front-end test during a product failure investigation or as a quality control measure, it can be extremely useful as a strong indicator that the molecular weight of a part/resin is not as it should be. When experiencing product failures, before altering or tweaking processing parameters, switching machines, or changing materials please consider whether a melt flow rate comparison might provide the missing piece of the puzzle that you are looking for.

If you would like more information regarding melt flow rate testing or other techniques used for plastic material evaluation, please contact The Madison Group at 608-231-1907, or email at jake@madisongroup.com.