TMG News
April 2021

The Madison Group
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Creating a Digital Twin of Your Mold

Part 1—Fill and Pack

Erik Foltz

To successfully design and manufacture a plastic component requires collaboration between a diverse team of designers, manufacturing engineers, material experts, and tooling engineers. Oftentimes when it is required to mass-produce complex, dimensionally stable parts, the team will turn to injection molding for their process of choice. While the team is critical for designing the feature, performance requirements, and tolerances, it comes down to the molders and toolmakers to determine how to fit all these desired features and performance criteria into a mold. Additionally, while significant time and resources are dedicated to getting the design of the part correct, it is usually a mad dash to get the mold designed and manufactured so the product can make it to the consumer. With the competitive global landscape for manufacturing, the need to quickly make decisions to get first-time right parts is critical. Many molders and toolmakers have turned to injection molding simulation to experiment with or "prove out" their mold designs, **Figure 1**. However, the question of "How accurate is the simulation?", often comes up. To help move this question forward, we will be writing a five-part series to help provide clarity on how simulation can best be utilized, and move the simulation activity from a check-the-box step to an optimization step that will in the end, reduce the cost and lead time for getting first parts. In this installment considerations for optimizing our mold filling and packing parameters, and how it might influence our runner and gate design, will be addressed.

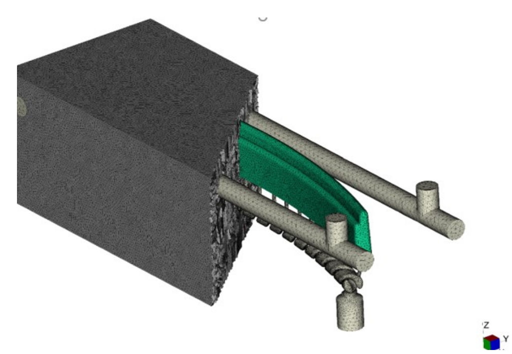

Figure 1. Injection molding simulation can model the entire mold design.

One of the first decisions for optimizing the filling process for injection molding is selecting the best gate location(s) to start forming the part. There have been numerous articles and books written about selecting the gate location. Additionally, many times the part designer puts restrictions on the gate location or amount of vestige that will force us to put the gate in a non-ideal location. Therefore, this article is going to discuss how we can move forward with replicating the mold performance **after** the gate location has been selected.

Step I: Define the Analysis Objective:

As with any tool, an analyst or designer should start any simulation project with defining the objective of the analysis. While simulation can simulate almost all stages of the injection molding process, it is not always necessary to simulate the entire mold design or have a finalized mold design to effectively utilize this tool. By defining the objective, the analyst can better define how much of the mold design is required to be defined. For mold filling, the objective of the analysis is to fill the mold, and be able to pack out the part to avoid issues like excessive sink without requiring excessive pressure. Therefore, to start creating a digital twin of how your mold will perform or how it is performing, the minimum requirement is to model in the parts and feed systems. While the feed system may never be seen by the customer or consumer, it will definitely influence factors like pressure to fill the mold, weld line location, and even dimension stability of the part.

Inside This Issue:

Creating a Digital Twin of Your Mold (cont.)

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Step II: Define Your Metrics:

Step II of creating your digital twin highlights one of the major issues within the plastics industry, and that is oftentimes the team we assemble to design and optimize our plastic part manufacturing, are not speaking the same language. In this case, language is not the tongues they speak, but rather it refers to the terminology the team members use. This disconnect in communication is also a common problem with transferring simulation results to the process development team. So, when it comes to determining how accurate a simulation is, it is critical to determine how we are measuring and defining our measurement metrics. As an example of this miscommunication, we look at the term, "gate seal." For most professionals within injection molding, this term refers to the time it takes for the gate to freeze off and prevent additional material from being injected into the mold cavity. However, a simulation analyst is often taught to use factors such as the frozen layer fraction to help determine when the gate freezes off. When the frozen layer fraction reaches 100%, that means that the entire cross-section of the gate has frozen, and no more material can be injected into the mold. Currently, there is not a commercial way for a process engineer to measure the frozen layer fraction at the gate. Rather, they use the measured part's weight vs. packing time to determine when the gate seal is achieved. Therefore, we are using different systems to measure this point in the process. As **Figure 2** shows, if these two different systems are plotted against one another, we come to two different conclusions for the gate seal time. This discrepancy does not indicate which system is right, but rather is an artifact of the inability to measure the same parameters. Therefore, we should not expect that we will always come to the same conclusion in every scenario. Additionally, it does not mean that analysts should not adjust their findings/ decision criteria to better guide the team and correlate their results to reality. A study should be done to determine which is more representative.

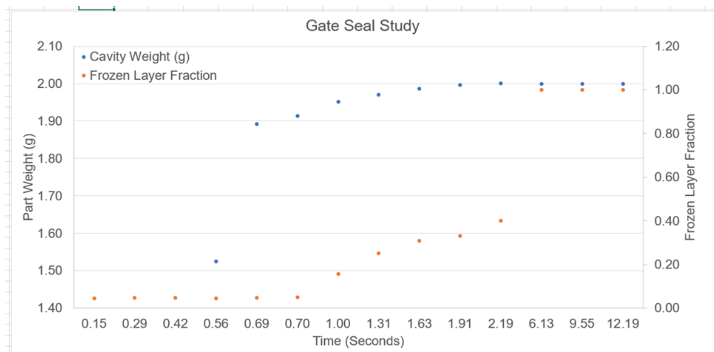

Figure 2: Graph shows that using different systems to determine the gate seal, can lead to different conclusions.

	Simulated	Actual
Fill time (second)	0.32	0.26
Pressure at Switchover (PSI)	9,952	11,450
Packing Time (seconds)	3.00	2.74
Cycle Time (seconds)	10.00	9.90

Table 1: A comparison of the fill and pack results between simulation and actual measured, showing good correlation.

With the initial mold filling parameters, oftentimes fill time and transfer position are the critical parameters identified to characterize the process. However, again, many times the exact fill time and transfer positions are determined by different system metrics. The analyst may use injection pressure to fill, melt temperature variation at the flow front, shear rates through the gate, and frozen layer fraction to determine the fill time. Yet, a process engineer will use a "rheology curve," linearity study, part weight at transfer, and part cosmetics to help determine the fill time. Therefore, it can be difficult to determine the correlation since we are using different criteria. Still looking at the two different systems to evaluate the fill time, it is interesting to see that they can lead to very similar conclusions. **Table 1** shows a comparison of the fill time determination for a thin-walled polypropylene cap from a simulation and from a scientific molding fill study. Comparing the results suggest that the results are very comparable. Therefore, despite having different evaluation criteria, the two approaches can still come together to the "same" answer.

Creating a Digital Twin of Your Mold (cont.)

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Step III: Acquire the Appropriate Inputs:

Once the objective of the study has been established and the critical metrics are defined, it is important to ensure the appropriate simulation inputs are provided. It is an almost overused phrase of "garbage-in, garbage-out," but it is a very valid point. If the objective is to create a digital twin of our physical mold and process, it is important to make sure we are "asking" the digital mold to perform the same tasks as the real mold. This means we need to make sure our boundary conditions or inputs of the simulation, are similar to those we are subjecting on the physical mold.

Probably the most important input is to ensure the plastic material that we are actually molding with is characterized for our mold filling simulation. It is important that an analyst tries to gather as much measured data for the physical resin and develop the appropriate flow models. Simply finding a similar melt flow rate material in the same family, with similar fillers, is not acceptable. The boundary conditions of the melt flow rate test are not representative of those conditions experienced during injection molding. Injection molding often focuses on the shear behavior of thermoplastic materials, due to the shear thinning behavior of the material. This material behavior is one reason why injection molding generally uses faster fill speeds. As the material experiences more shear, the viscosity of the resin tends to decrease, **Figure 3.** However, shear deformation is only one of the deformation modes experienced in injection molding. There are also extensional deformation forces, where the material is stretched as it flows through changes in the cross-sections in the mold. These restrictions in flow often occur in the feed system in the mold, especially at the gate. So when a hot manifold system, tunnel gate, or pin gate is used to fill the cavity, it is important that we have a material that has this extensional viscosity characterized. **Figure 4** shows a comparison of an injection pressure curve during the initial mold filling stages, when the resin is characterized for shear and extensional viscosity, and when it is only characterized for shear viscosity. The difference is very clear. There is an underprediction of pressure to fill the mold when the extensional viscosity is ignored. The cost and time investments to characterize the extensional viscosity are minimal and can have a substantial influence on the design decisions that are made during the early-stage mold development process. Adjusting the mold design and allowing for a larger process window for the process engineer without needed modifications to the physical mold, easily justifies the time and financial investments.

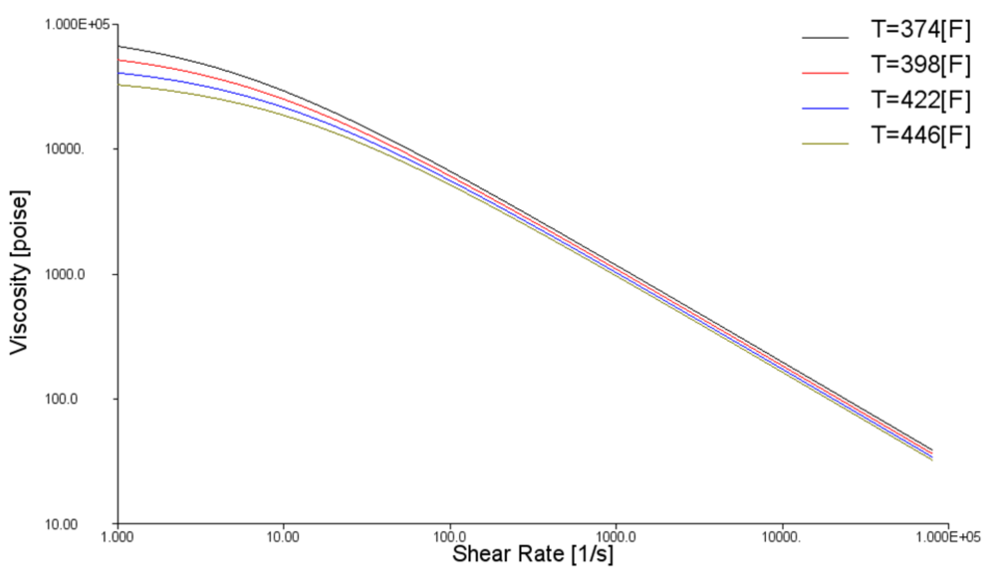

Figure 3: Plot showing how viscosity changes with increasing shear rates.

From a modeling-of-the-physical-mold perspective, to properly modeling the behavior of the melt during the initial mold filling stages, it is critical to have the feed system and mold cavities included in the model. The

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Step III: Acquire the Appropriate Inputs: (cont.)

feed system design should be designed to impart shear on the molten plastic that will heat the material up and allow for a lower viscosity in the mold cavity. However, this additional flow length and the characteristic cross-section of the feed system will add additional pressure loss during the mold filling process. If the feed system (runner and gates) is not included, any attempt at comparing pressures at the press to those simulated, are a waste of time since we are not measuring the pressure at the same locations. While this seems like an obvious statement, such a detail is often lost when comparing simulation to real life, and can raise concerns of the fidelity of the simulation results.

Finally, the last inputs that are critical for achieving high fidelity results are to ensure representative ¨plastic conditions¨ are used for setting the filling simulation. Ensuring a representative melt temperature and mold temperature are used for the simulation, as well as the proper flow rate of the polymer into the mold, are critical for properly capturing the shear and thermal conditions the resin experiences during the mold filling stage.

As **Figure 4** shows, when those conditions are properly modeled, not only can the maximum pressure to fill the mold be captured, but the entire injection pressure profile can be captured with good correlation during the entire mold filling stage.

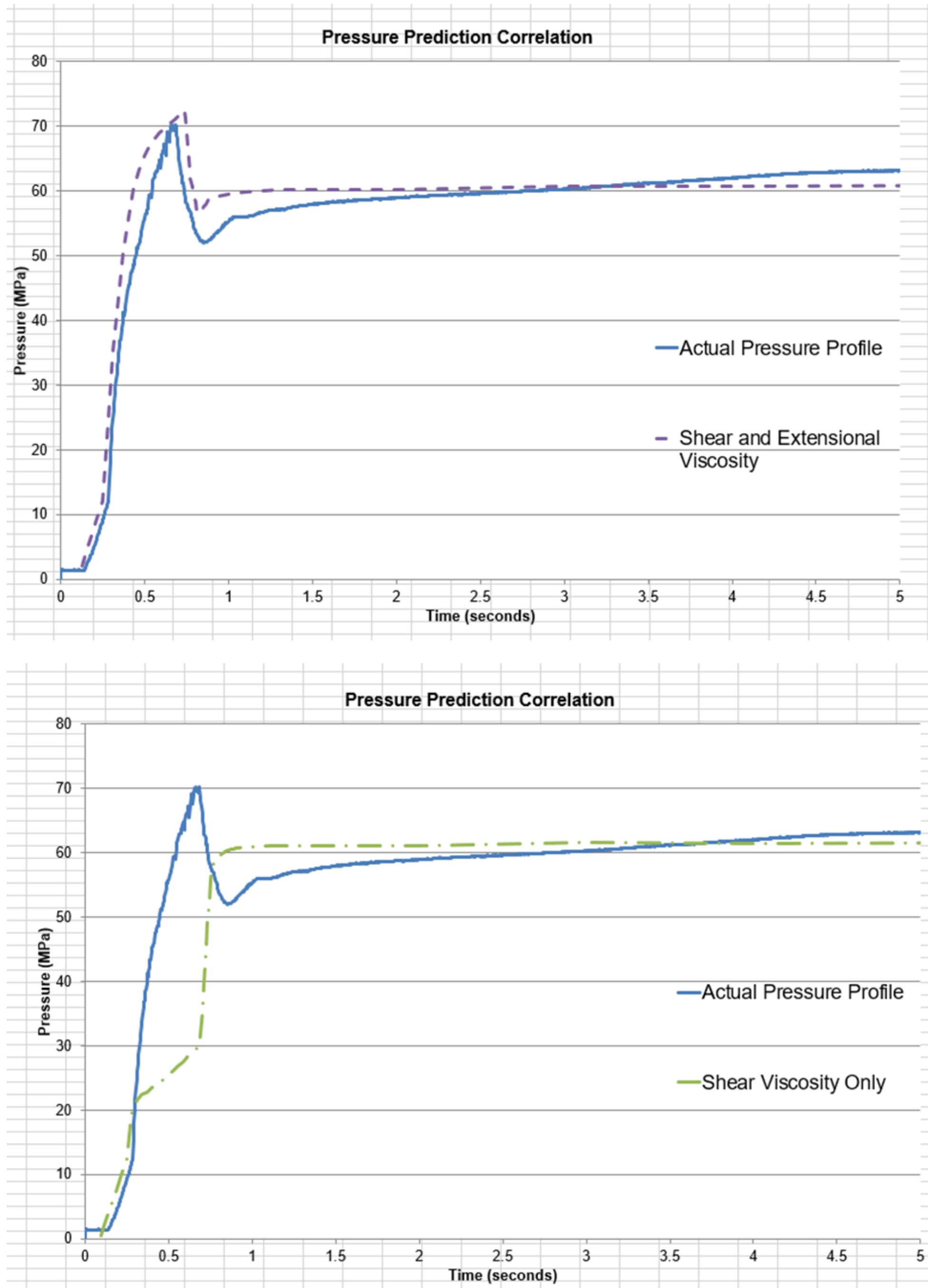

Figure 4: Graphs highlighting the importance of accounting for shear and extensional viscosity to accurately predict pressure to fill the mold.

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Step IV: Close the Loop and Correlate:

The last step of creating a digital twin of your mold is to close the loop. Too often, simulation is viewed as an early development process step and once the simulation step is complete, the report is filed away and never to be seen by the process engineer. However, this is doing a disservice to the investment that was initially made by performing the simulation. By not sharing the simulation results with a process engineer, extra steps and time is required at the press to reestablish parameters that were already determined to be successful. Now, it is not to say that the process should be set up to match the simulation. However, the simulated results can help a process engineer narrow their initial scope and potentially find solutions to other issues that developed that were not initially defined in the simulation scope. Despite all the advances in in-mold sensors for injection molding, there is still limited information that a process engineer can gather to help them troubleshoot a process. Generally speaking, a process engineer will only have one-to-two physical sensors in the mold cavity to help them generate data. However, in a simulation there are thousands to millions of virtual sensors that can give the process engineer more information to quickly troubleshoot a process. Whether that is looking at cosmetic defects at the gate, end-of-fill, or difficulty packing out the part. The simulation results allow for an opportunity to empower the process engineer and provide them with more information to troubleshoot those issues. Additionally, the analyst can gain valuable feedback on what additional issues arose to start developing a more robust cosmetic process window for the part as well, **Figure 5**. The simulation should be an additional tool for the process engineer to further confirm their experience and intuition and help find solutions more quickly.

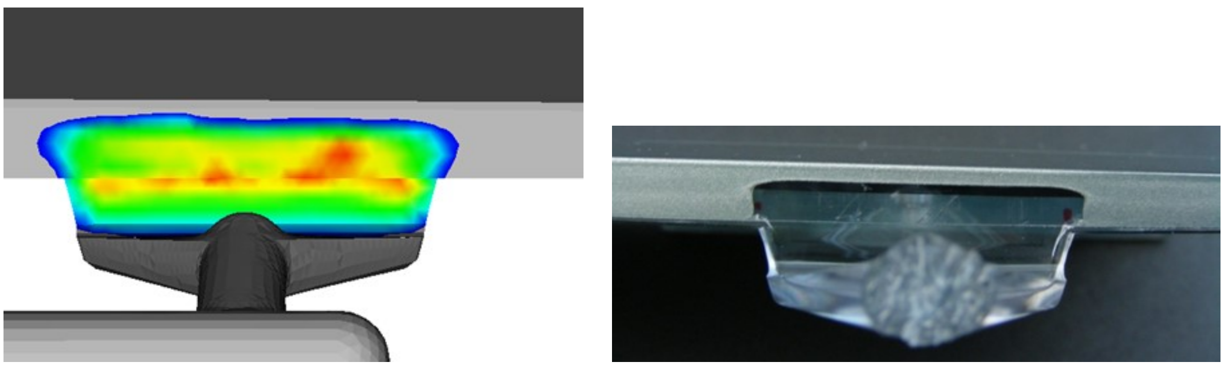

Figure 5: By closing the loop and providing process engineers simulation results even cosmetic defects can be predicted with simulation.

In the next several articles, we will discuss extending simulations to optimize the cooling line layout methodology for an injection mold, and achieving accurate part warpage predictions.

Stay tuned for the next installment.

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

Announcements

TMG—Industry News

The Madison Group is excited to offer our training for all Autodesk Moldflow products, both Insight and Advisor.

The need for optimizing our plastic part designs, processes and mold designs prior to first shots, is more critical than ever. Autodesk Moldflow has multiple products to help assist and optimize your project at any stage. Whether you are a part designer that is interested in better understanding your externally provided Moldflow reports, a user that is looking to take full advantage of the tools you already have, or explore what additional tools are available to take you to the next level, we have a training package that can help you accomplish just that.

The Madison Group has a training plan option for any circumstance and budget.

Choose any of the following options:

- **On-site Training**
- **Remote Instructor-Led Training**
- **Private Training**

Benefits of Investing in Moldflow Training

- Keep up to date on the newest solvers and simulation tools for all the Autodesk Moldflow Products designed to save you time.
- Improve your results interpretation skills and help optimize your design.
- Increase your internal knowledge quickly and economically to improve communication and create a culture of innovation.
- Explore additional simulation capabilities to improve overall customer satisfaction.

Benefits of Remote Instructor-Led Training Sessions:

- Allow any of your employees to gain the training without being out of the office.
- Eliminate travel costs so you can have more employees trained.
- Choose interactive, live, instructor-led classes for one-on-one assistance with solver set-up and results interpretation.
- Installation of software not needed prior to training opportunities.

Find a listing of all of our Upcoming Training Sessions here.

Material Characterization Tier II — (Part 2 of 3)

Richie Anfinsen

In the first part of this series, we discussed the different levels of material characterization that I see employed on a weekly basis and examined the testing and results expected from a Tier I material characterization. A Tier I characterization provided important information regarding the material family.

In this installment, we turn our attention to a Tier II material characterization. The information from this tier can be used for material selection, failure investigations (comparison to good materials), material deformulations, and also can provide some information on processing/thermal stability.

Figure 1. Tier II characterization allows for comparison to data sheets with similar compositions, which will provide you with a much better idea of the properties for the material.

Yes, understanding the material family of a product is extremely important in every application. The polymeric materials in use are by in large, not just pure polymer. The industry has introduced numerous additives, blended different polymers together, and varied the amounts of these alterations to achieve more desirable end properties. To further complicate things, within the same subset of material family there are a diverse portfolio of molecular weights utilized. This can have a great deal of influence on the performance. A Tier II characterization takes aim at understanding the composition or amounts of the various components of a material that will help to better pinpoint the major components of a resin. This tier will start to give a much clearer picture of the properties expected from the material and allow for comparison with the data sheets for existing grades of material, **Figure 1.**

The first technique for Tier II characterization is thermogravimetric analysis (TGA). TGA is a test method that subjects the sample to temperatures up to 1,000 °C and measures the weight change from additive volatilization and polymer decomposition. The data from this test provides a series of weight losses on a graph that can be quantified. Since polymers have variable thermal stabilities, this technique can be used to identify polymers, if there is reference information on how that material degrades under the test conditions, **Figure 2.** While this basic information is present, this technique can be further extended to examine complex material mixtures that include other polymeric additives (e.g., PTFE), inorganic additives (e.g., glass fiber, talc), plasticizers (in PVC or elastomeric/rubber materials), and carbon black content. In the case of the TPE material in **Figure 3,** we can identify how much plasticizer is used, how much of the material is polymeric, and then identify the filler and carbon black content.

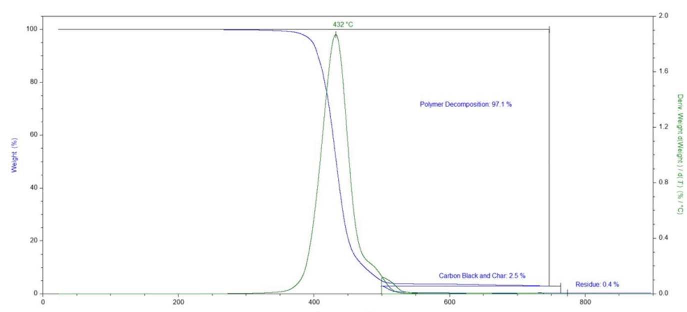

Figure 2. TGA provides a weight loss curve (blue) that is indicative of the thermal decomposition of the polymeric materials.

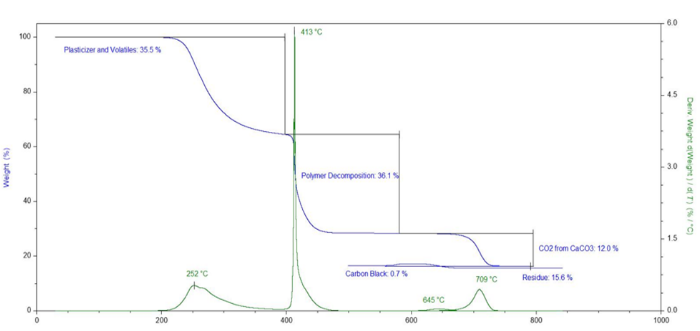

Figure 3. TGA analysis of a complex material shows with proper understanding, TGA can give a very good identification of the quantities of various components of an unknown material.

Another technique that is typically used in conjunction with TGA is energy dispersive X-ray spectroscopy (EDS). This test provides an elemental profile of the sample with concentrations of elements having an atomic weight of five or greater. In a

Material Characterization (cont.)
Tier II — (Part 2 of 3)

Richie Anfinsen

material characterization setting, this test is important for identifying the type of inorganic filler utilized in the material, cure system type for rubbers, and other elemental additives incorporated at higher concentrations (e.g., flame retardant systems). As an example, the data in **Table 1** was obtained from an analysis of the inorganic residue from the TGA analysis shown in **Figure 3**. The elemental profile including high levels of calcium and oxygen was consistent with calcium carbonate. This example shows the complimentary nature of these techniques in a material characterization.

Element	Relative Weight Percent
Calcium	56.1
Oxygen	42.1
Silicon	1.5
Sulfur	0.3

Table 1 – EDS analysis of the TGA residue showed an elemental profile that was consistent with a calcium carbonate filler.

The third technique that is typically required to reach a Tier II characterization is melt flow rate (MFR). This test method forces melted polymer through a controlled orifice that gives a relative measurement of viscosity of the resin. The results of this test give a comparative value of the molecular weight of the material. For example, polycarbonate materials are commercially available with average melt flow rates of 8 to over 30. The lower numbers correlate to higher molecular weight materials, which will have greater performance properties, but will be harder to fill into an injection mold, **Table 2.** It should be noted that this technique is typically tougher to interpret for mineral and fiber filled materials due to variable effects on the flow rate through the orifice. For these cases, a similar analysis is typically performed with solution viscosity test methods such as intrinsic viscosity (IV).

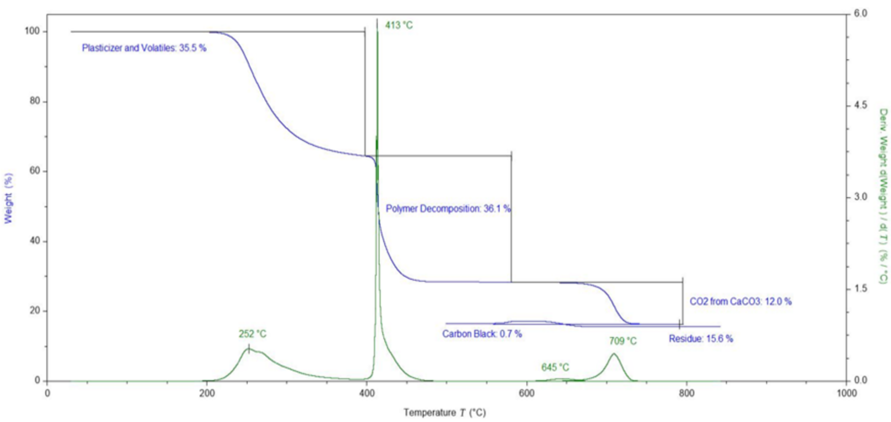

Figure 3. TGA analysis of a complex material shows with proper understanding that TGA can give a very good identification of the quantities of various components of an unknown material.

TGA, EDS, and MFR are the most commonly used techniques in a Tier II characterization. However, for some specific material families, there are other test methods that will be required to reach this level of characterization. For polyolefin materials such as polyethylene, the density of the material is extremely important to understand the properties of the material. Resins with higher densities are able to pack the polymer chains closer together, which increases the intramolecular forces. This leads to materials with greater strength, stiffness, chemical resistance, and heat resistance.

Material	Melt Flow Rate (g/10 min.)	Notched Izod Impact (23 °C)	Elongation at Break (%)
Polycarbonate A	7.0	910	140
Polycarbonate B	18.0	690	130

Table 2. Comparison of two polycarbonate grades with different melt flow rate values from the same supplier. The higher melt flow rate material has lower impact properties, which will extend to long-term properties such as creep, fatigue, and environmental stress crack resistance (ESC).

For elastomeric materials, shore hardness is an extremely important data point for a Tier II characterization. The reason for this is simple; most elastomer manufacturers will sell their material based on the hardness value. In the world of elastomers, hardness does not always equal to a certain set of mechanical properties.

Material Characterization Tier II—(Part 2 of 3)

Richie Anfinsen

However, it is a very important factor in the identification of elastomeric materials.

Other tests that are commonly provided on data sheets such as tensile and impact data can also be completed during a Tier II characterization. The reason for doing these tests, is while the data given from the thermal analysis techniques will get you from thousands of potential grades to dozens, the performance-related tests will provide you with another layer of certainty that we are selecting a similar material. In the case of failure analysis, the testing could show that we do not have the properties we expect from a molded component.

As you can see, the Tier II material characterization opens a lot of possibilities in terms of test methods utilized and the efficacy of the final results. At this level, a designer will have a much better chance of selecting a material based on data sheet values for their application. One word of caution, while these test methods do provide good information regarding a comparison to data sheet values, it is still vital to perform testing to ensure that long-term and chemical properties of the material are adequate for your application.

In the next installment we will be discussing the characterization of additives (heat stabilizers, flame retardants, UV protection, etc.) that are put into materials to modify their behavior and provide stability to expected environmental conditions.

Stay tuned for the next installment.

Click here to read Part 1.

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

If you are interested to have
The Madison Group
provide training to your team,
please feel free
to contact us at

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Training Topics

- Failure Analysis
- Plastic Material Selection
- Plastic Part Design
- Moldflow
- Other

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Upcoming Educational Webinars

#TMGPLASTICEDU

Tuesday, April 27th, 2021 — *Tom Hansen and Erik Foltz*
Optimizing Your Product Performance and Manufacturing Through Multi-Material Molding
10:00 AM (CST)

With the objective of improving part performance while simultaneously driving down cost, many designers turn to multi-material molding to produce their plastic components. Whether the end objective is to provide product differentiation, enhanced consumer experience or to improve product performance, a designer has many options to achieve their end goal. However, it is important that the designer take a holistic approach where the material selection, product design, and over-molding process are considered to help ensure what is designed in CAD will translate into physical parts at first shots. This webinar will focus on over-molding, insert molding, and in-mold labeling/decorating, and what are the design considerations to help ensure success during first shots.

At the end of this event, attendees will have a better understanding of:
- The difference between over-molding, insert molding and in-mold decorating, and their unique product offerings.
- Product design considerations to ensure proper molding of both the substrate and over-mold component.
- Material selection criteria for the promotion of adhesion between the two different substrates.
- Process conditions for optimal product integrity and desired aesthetics.

Click here for more information.

Tuesday, May 11th, 2021 - *William Aquite, Ph.D.*
"Plastics In" Series: Consumer Medical Device Applications
10:00 AM (CST)

Multiple considerations come into play for material selection in the manufacture of consumer medical devices. In the ever-evolving medical industry, plastic materials play a crucial role in the production of products meant to be used in non-clinical environments. Besides safety requirements to allow for their effective use, materials must also evolve to adapt to technology advancements and healthcare consumer expectations. Whether they are meant for single or long-term use, the availability of suitable plastic materials continue to grow.

At the end of this event, attendees will have a better understanding of:
- How plastics have impacted the consumer medical device industry.
- Critical plastic properties for material selection.
- Case studies, examples and recent developments in consumer medical devices and their associated plastics.

Click here for more information.

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

ANTEC Papers/ Presentations

ANTEC Papers/Presentations

Two engineers from The Madison Group will be present their work as part of The Society of Plastics Engineers Annual Technical Conference (ANTEC). The presentations will be in May 2021 as part of the two-week online conference.

Monday, May 17, 2021—*Jeffrey A. Jansen*
Comparative Creep Evaluation of Polyacetal and Polyketone Resins
1:20 pm (CST)

Failures occurred within threaded fasteners used in an outdoor industrial application. Specifically, cracking was observed within fasteners used to terminate a pipe conveying a gaseous chemical product. The parts had been installed leak free as verified through leak testing. However, failures occurred within some of the installations between four and five years, as identified by leakage of the gaseous product. A failure analysis identified that some of the fasteners had cracked through a mechanical short-term overload mechanism in which the stresses applied during installation, exceeded the short-term strength of the material. Other parts, however, cracked through creep rupture, whereby the applied service stress exceeded the long-term strength of the material. In both cases, crack propagation and ultimate rupture were associated with the creep properties of the material. A material conversion was considered to increase the creep performance of the fasteners. This paper will review the testing performed to characterize and compare the creep performance of the incumbent and proposed materials.

Click here for more information.

Friday, May 21, 2021, - Paul J. Gramann, Ph.D., P.E.
The Most Frequent Design Flaw That Leads to Part Failure
7:30 am (CST)

This paper and presentation will review why sharp geometric transitions should not be present in a plastic part. Though it has been known for decades that parts should not have sharp transitions, failures occurring at these features are still very common. In most cases, they can easily be avoided by simply removing metal from the mold to make a smooth transition. This paper will review where most of these transitions are being found, and why they are common in critical parts. A tensile testing study was performed to better understand the effect of geometric transitions. Case studies are given showing why the sharp corners can significantly reduce the lifetime of a plastic part.

Click here for more information.

Information regarding upcoming educational opportunities can also be found at:
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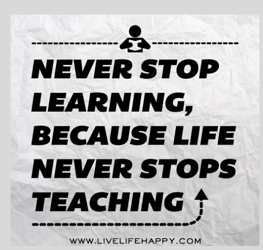
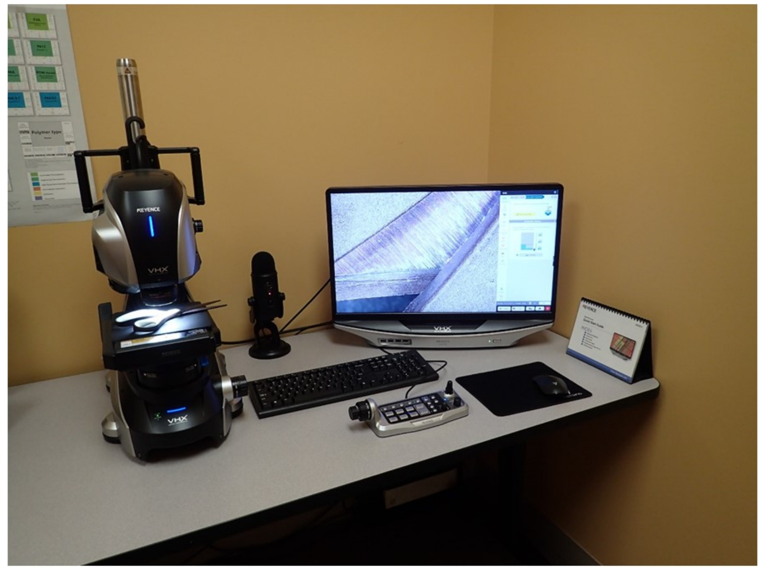


Through the Through the Lens of The Madison Group

The Madison Group has acquired a new state-of-the-art Keyence High Definition Digital Microscope VHX-7000. This microscope has greatly expanded our examination capabilities to the next level by:

- With automatic 3D technology it is possible to examine rough and deep fractures in one image.
- The magnification capabilities up to 2,500x makes it possible to measure the thickness of coatings and films.
- The new advanced illumination options allow for backlighting, multi-angled oblique lighting, polarization and an optical shadow effect mode that allows the visualization of crack features and textures not visible in a SEM microscope.
- Stitching of high magnification images allows for a large field of view to improve analysis and visualization.
- With remote capabilities, this microscope also opens the door for remote inspections for our customers.

NEW VHX-7000 at The Madison Group.



The image is of a cracked CPVC pipe that was experiencing environmental stress cracking. (ESC). The numerous crack initiation sites are present along the inner diameter of the pipe. The classical thumbnail features and crack propagation marks are clearly visible. As the individual cracks travel from the inner diameter outwards, they coalesce together, creating a protruding ridge.

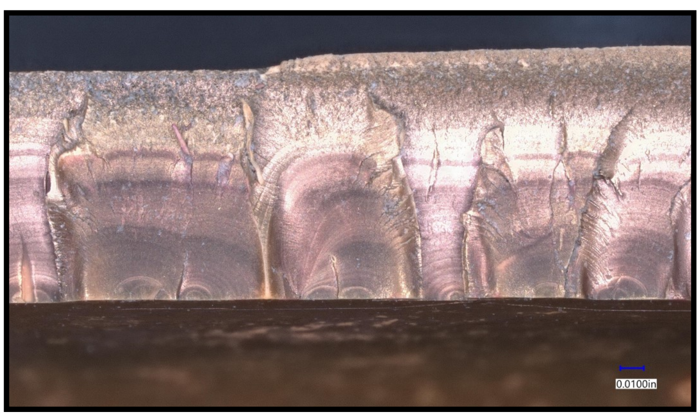


Image of cracked CPVC pipe.

The root cause of failure was the introduction of a foreign substance into the fire suppression system of the building this pipe was used.

The Keyence VHX 7000 provides excellent depth of field, while maintaining the color of the part being viewed. This microscope can go up to 2500x magnification and has numerous lighting options.

If you are interested to learn more about the capabilities that we have at The Madison Group, please feel free to contact us at [info@madisongroup.com.]

PLASTIC CONSULTING ENGINEERS THE MADISON GROUP

