



Good Vibrations – A Manufacturing Introduction to Ultrasonic Welding

Patrick Mabry and Paul Gramann, Ph.D.

In an era where innovation, lead times, and speed to market are critical to the successful launch of a product, any advantage is desirable. At The Madison Group, we pride ourselves in our knowledge and understanding of everything plastics from formulation, to processing, to product life cycle. We work to provide those advantages for you to reach your path critical goals. This article covers assembly processing of plastics via ultrasonic welding. It is intended to be an overview of the process, with future, more in-depth articles to follow.

There is no shortage of assembly methods when it comes to plastics. However, depending on the application, certain assembly methods will be more effective at helping ensure the longevity of the bond in the designed parts. Ultrasonic welding is an extremely popular process for joining plastics. Similar to most assembly methods, ultrasonic welding has positives and negatives. This process is mainly selected due to the following:

- Fast Cycle Times
- Easy to Automate
- Clean Process
- Localized Process

A wide range of polymers can be welded, but there are some restrictions in terms of which different ones can be welded together. Generally, stiffer materials provide a better medium for the welding process, including some fiber filled material. It is important to note that stiffer materials must also be able to provide an adequate amount of viscous heating to effectively weld polymers.

So how does it work? Ultrasonic welding bonds two plastics (similar or dissimilar polymers) via concentrated ultrasonic motion. A transducer translates electrical energy input to physical motion. The overall physical distance traveled in one stroke of this motion is the amplitude of the process. A typical amplitude range for ultrasonic welding is 10-250 μm . This motion can be amplified through a booster if higher frequencies are required to weld the polymers. The ultrasonic motion is then concentrated again through a horn. The horn is what contacts and delivers the ultrasonic motion to the material and begins the welding process. This is shown in Figure 1.

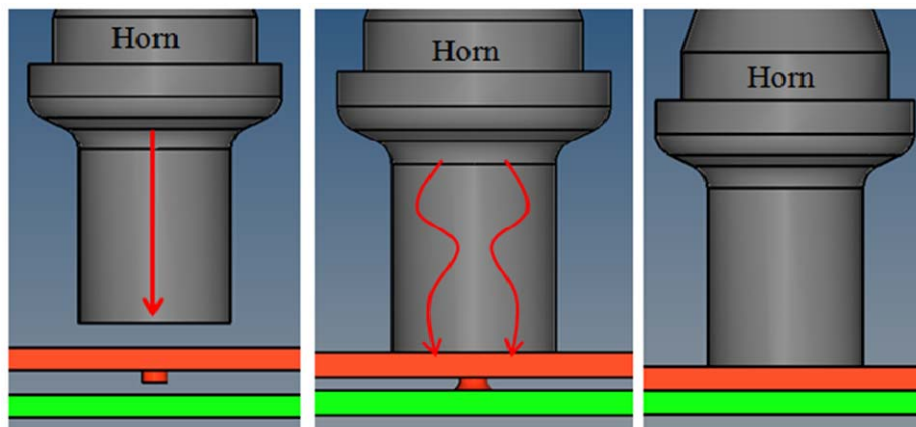


Figure 1: A horn makes contact with two materials. The energy director promotes the start of the polymer melt at the weld interface.

This is shown in Figure 1.

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The cyclical energy is converted into heat, within the thermoplastic polymer, through intermolecular friction [1]. At the weld interface, polymer chains from both parts of the assembly become diffused and entangled once they have reached a melt state. When the welding process is complete, the resulting part should have a strong, clean, and predictable bond between the materials. This process is highlighted in Figure 2. The time for the part to cool down from the welding process is extremely short because the heating of the materials at the weld interface is highly localized.

Let Us Talk Physics: The driving physics behind the ultrasonic welding process can be explained in terms of

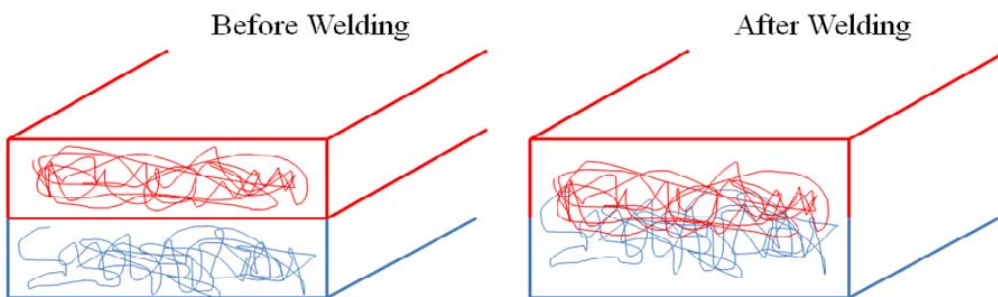


Figure 2: Molecular interface before and after the welding process.

material properties and dynamics. The amount of heat generation at the weld interface is directly proportional to the loss modulus of the material, along with the frequency of vibration and strain amplitude of the process [2]. The loss modulus is the amount of energy a material will dissipate as heat from dynamic input. Its value can change based upon testing conditions such as temperature, strain amplitude, and frequency. This material response can be measured with Dynamic Mechanical Analysis (DMA). Characterizing the loss modulus via DMA is done with a frequency sweep analysis. An example of this type of analysis is shown in Figure 3. The sample is oscillated from lower to higher frequencies and the material response is recorded. As the frequency increases, the polymer has less time to recover the stress input and begins to dissipate the input energy as heat. Some DMA analysis can be performed to predict the dynamic material behavior at higher frequencies. This is done by time-temperature superposition analysis [1].

The loss modulus is one of the only material behavior factors in determining the amount of viscous heating and may be a good way to characterize whether a material is suitable for specific ultrasonic welding processes or not. A robust ultrasonic welding process will produce enough heat generation to drive the weld interface to a melt state. Typical frequencies used in ultrasonic welding range from 20-40 kHz and the process can be limited by several different factors (Time, power, distance, force, etc...).

Are these two polymers weld-compatible? For example, polycarbonate is a widely used material for ultrasonic welding due to it being amorphous and relatively stiff. Amorphous polymers require less energy to weld than semi-crystalline polymers. A quick way of determining polymer compatibility is to check the melt flow rate (MFR) of a material. This should give a good indication of how quickly each material can reach the melt state during the welding process.

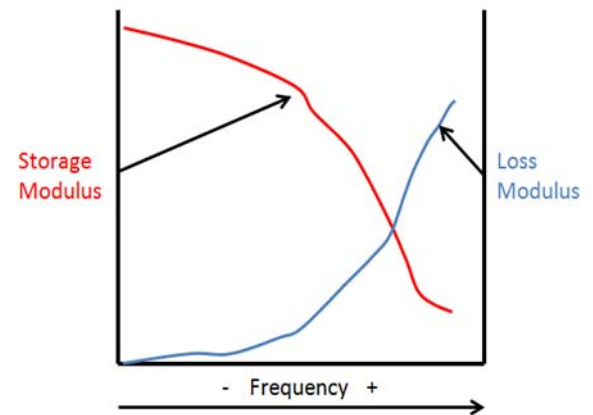


Figure 3: In general, most polymers will see a decrease in storage modulus and an increase in loss modulus as the testing frequency increases.

Good Vibrations – A Manufacturing Introduction to Ultrasonic Welding (cont.)

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Are the materials that are being welded too soft? Recall, the appropriate material choice for the ultrasonic welding process should be relatively stiff. The material must also be able to translate the ultrasonic motion from the horn to the weld interface by viscous dissipation. A material that is both stiff and can dissipate the energy through the part will ensure that the assembly being welded can generate heat at the weld interface.

Some materials may have a naturally higher loss modulus, and may dissipate energy locally, but not through the part. Not being able to effectively translate the energy through the part, may result in a poor weld interface. This phenomenon can be seen in **Figure 4**. The higher loss modulus material will heat up at the point of contact with the horn, whereas the lower loss modulus material will translate the ultrasonic motion and energy to the weld interface and begin to heat up there. Adding a filler material, such as glass fiber, may stiffen the polymer enough to better transfer energy and create a quality bond interface. It is also important to know if the material needs to be dried prior to welding. For example, polyamides are very hygroscopic. Because the moisture will effectively reduce the stiffness of the polyamide, they generally need to be dried before welding.

Does the part design allow for ease of welding? The more available area that the horn can enter the process, the more freedom there will be in creating the weld. If the area is limited where the horn can contact the material, inconsistencies in the process may occur. Limited areas of horn contact can also make the part difficult to fixture securely. Near field welding should be used whenever possible and should be taken into consideration when designing the parts for assembly. Near field indicates that the horn contacts the material at or less than 6 mm away from the welding interface. Wall thicknesses should also be a primary design consideration when investigating the use of ultrasonic welding. Wall thicknesses used in the welding process that are too thin may yield inconsistent bonds from part to part because of their ability to effectively transfer the ultrasonic motion.

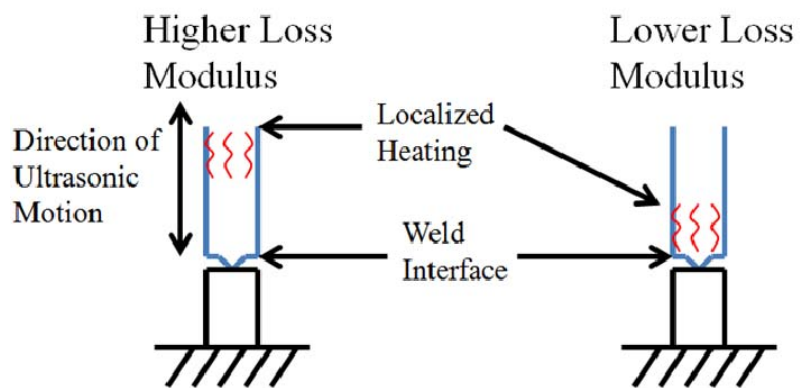


Figure 4: Behavior of a higher loss modulus polymer as compared to a lower loss modulus. An appropriate blend of loss modulus and welding frequency is required to place the localized heating from the welding process at the interface of the polymers.

Another key design concern is accounting for residual stress. If the two parts being welded need to be deformed in order to make contact, the magnitude of the force related to that deformation will be contained by the weld. Over time, a weld that contains residual stresses may fail due to creep. For example, take a thin walled cylinder such as a plastic drinking straw. If the end of the cylinder needs to be welded flat to create a hermetic seal, the plastic must deform to meet its new shape. The stress associated with that deformation will be stored at the weld interface and carried by the polymer bond. If the product is susceptible to creep, the cylinder may begin to fail and open at the weld location. Environmental conditions will also play a role in the strength of a weld which contains residual stresses.

Are there sharp radii in the part design that could break during welding? Sharp radii can result in part damage or full breaks at their location in the part once the ultrasonic motion is translated into it. A smaller radius promotes a larger stress concentration in the geometry as compared to a smoother radius. Low strain to failure materials may be susceptible to this.

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What kind of equipment is right for the project? The level of sophistication that is integrated into ultrasonic welding equipment has grown significantly as it has become more popular in manufacturing settings. Molded part assemblies that maintain strict dimensional tolerances (medical, automotive) may often require welding equipment that has built in quality and statistical process control (SPC) software. Ultrasonic processes such as spot welding may not require such advanced equipment. It is also important to understand the operating frequencies that the process will require. Typical welding machines have an operational range from 20-40 khz, but specialty machines can range from 10-70 khz.

These are general guidelines for product development for the intended use of ultrasonic welding. Each case will be different and present its own challenges. While keeping these suggestions in mind, a robust process can be developed that will result in a consistent product.

References:

- [1] Grewell, Benatar, Park, "Plastics and Composites Welding Handbook", (2003)
- [2] Marcus, Miranda, "Ultrasonic and Spin Welding" (2014)

Upcoming Educational Webinar

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

Wednesday, December 13, 2017 – Jeffrey A. Jansen – Society of Plastics Engineers
Fourier Transform Infrared Spectroscopy in Failure and Compositional Analysis
10:00 am CST



Fourier transform infrared spectroscopy (FTIR) is a fundamental analytical technique for the analysis of organic materials. It provides critical information in the evaluation of polymeric materials, including material identification, contamination, and degradation.

The webinar will present a fundamental understanding of the technique, and the following topics will be covered:

- Theory of Infrared Spectroscopy
- Test Result Interpretation
- Application to Polymeric Materials
 - Material Identification
 - Contamination
 - Degradation
- Sample Preparation
- Supplementing FTIR With Other Techniques
- Case Studies

For more information, please contact Scott Marko at 203.740.5442

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

The Madison Group-Two-Day Course – Failure Analysis of Plastics

GOLDEN GATE POLYMER FORUM



Announcing the Golden Gate Polymer Forum – Two-Day Short Course

Failure Analysis of Plastics

Monday-Tuesday/ March 5 and 6, 2018

Location: Michael's at Shoreline, Mountain View

Discounted advance registration ends February 9 (\$650)

Regular full-price registration ends February 23 (\$750)

This two-day day short course, presented by recognized experts from The Madison Group www.madisongroup.com, is based on their annual course "Plastic Part Failure: Analysis, Design and Prevention" given at the University of Wisconsin-Milwaukee. Attendees will gain a better understanding of basic principles that affect the durability and failure of plastic parts. As these speakers like to say "if you don't know how something broke, you can't fix it," highlighting the importance of a thorough understanding of how and why a product has failed. With emphasis on practical problem-solving techniques, the course will utilize case studies to comprehend key aspects of plastic failure and prevention, gain a better understanding of why plastic components fail, and how to avoid future failures by applying the knowledge learned. The combination of excellent speakers, a convenient location in the Bay Area, an affordable price, and focus on practical applications makes this an exceptional opportunity.

Course Outline:

Monday, March 5, 2018

- Plastics Composition and Properties
- Plastic Part Failure
 - Overview
 - Failure Mechanisms (e.g. overload, creep, fatigue, ESC, molecular degradation)
 - The Roles of Multiple Factor Concurrency and Statistical Distribution
- General Failure Analysis Methodology
 - Problem Solving/Investigation Techniques - FA and RCA
 - Failure Analysis Test Methods
 - Physical Property Testing, Analytical Chemistry - GPC, GC/MS, HPLC, Thermal Analysis, Spectroscopy, Microscopy/Fractography

Tuesday, March 6, 2018

- Failure Prevention (e.g., Processing and Design Considerations, Materials Selection, Screening Tests)
- Failure Correction and Prevention
 - Part Design
 - Mold Design
 - Materials Selection
 - Processing
 - Validation
- Case Studies

See details above and on the web page, www.ggpf.org.

Information regarding upcoming educational opportunities can also be found at:

<http://www.madisongroup.com/events.html>

How Glass Fibers Affect the Long-Term Properties of a Composite Material and the Importance of the Glass Fiber Measurement

Dayton S. Ramirez

Today, the plastics industry is utilizing fiber reinforcements to create composite materials that are lighter and stronger. Some of the most common types of fiber reinforcements utilized for composite materials are glass and carbon fibers. By combining reinforcements, such as glass fibers or carbon fibers with the polymer, the material can be modified to match the specific properties required for the application. For example, reinforcements such as glass fibers will improve the strength and stiffness, while providing a benefit of being lightweight. Although this article will focus on how glass fiber lengths can affect the part properties, the information is valid across other fiber reinforced composites.

When a load is applied to the composite material, the weaker polymer structure will transfer the loading to the fiber reinforcement. To completely transfer the loading from the polymer to the fibers, an adequate fiber length must be maintained. This value is referred to as the critical fiber length, which is dependent on the adhesion between the polymer and glass fiber. For a perfect adhesion case, the critical fiber length can be calculated as:

$$L_c = D \frac{\sigma_f}{2\tau_{fm}}$$

In this article, we will focus on long fiber filled polypropylene. Assuming 17 micron fiber with a tensile strength of 2000 MPa and a shear strength of 39.37 MPa for polypropylene, the perfect fiber adhesion case will result in a critical fiber length of 0.432 mm. However, polypropylene does not readily adhere to glass fibers, **Figure 1**. Therefore, critical fiber length values for polypropylene for uncoupled polypropylene can range from 1 to 3 mm in length. This length is 300% to 700% higher than the perfect adhesion case. To promote adhesion between the polymer and glass fibers, a coupling agent is added to the composite material, **Figure 2**.

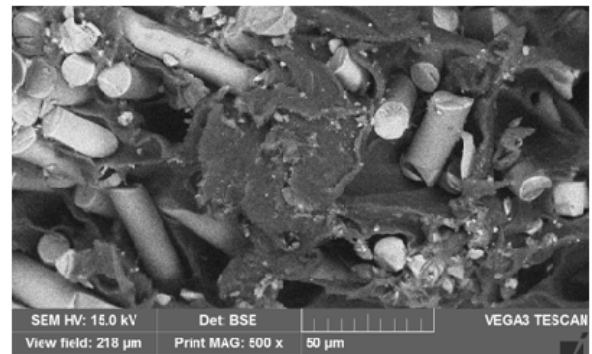


Figure 1: View showing poor fiber adhesion.

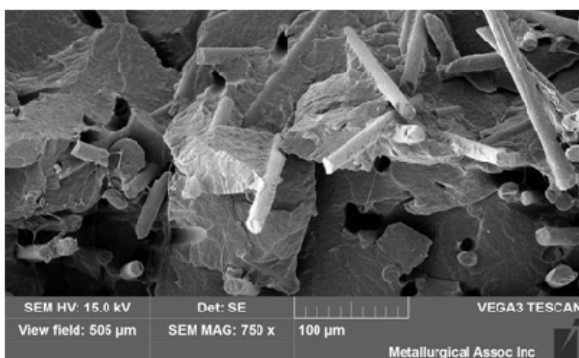


Figure 2: View showing chemically coupled PP.

When adding reinforcements such as glass fibers to the polymer, there are different sizes of fibers that can be utilized. A broad categorization of fiber lengths is short glass fiber and long glass fiber. Short glass fiber materials typically start with fiber lengths less than 1 mm, while long glass fiber filled composites start with a glass fiber length above 10 mm. During compounding and processing of the material, the fiber length will become reduced due to the expected manufacturing conditions. The more aggressive the compounding and processing conditions are, the higher the fiber attrition will be. Although guidelines may be followed during processing of the material, screw geometry will have a significant influence on the amount of fiber attrition. Specifically, in our case, the use of a general purpose screw results in a 15% reduction in short glass fiber lengths. In long fiber filled materials, the fiber length was reduced by 95%.

During the following study, material testing was performed to evaluate the influence of glass fiber length on the mechanical properties of the composite material. The initial fiber length of the long glass fiber polypropylene was 11 mm. While using recommended conditions for injection unit parameters, the fiber attrition

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during screw recovery resulted in an average fiber length of 1.386 mm. As a substantial degree of fiber breakage occurs during screw recovery, back pressure and screw rpms were varied to study the influence. This resulted in average glass fiber lengths ranging from 1.386 mm to 0.879 mm with varying back pressure and average glass fiber lengths ranging from 1.155 mm to 0.879 mm with varying screw rpm. These are only a few parameters that can have an influence over glass fiber breakage. Other influences during processing include mold temperature, melt temperature, injection speed, and hold pressure. However, processing is not the only influence on the amount of fiber breakage. Part design can have a significant influence over fiber attrition, which includes runner geometry and size, gate geometry and size, wall thickness, corners and overall geometry.

In today's industry, short-term testing such as a tensile pull, is performed to evaluate the strength of a composite material. As shown in **Figure 3**, a 6% change in tensile properties is observed with fiber lengths of 1.386 mm and 0.879 mm.

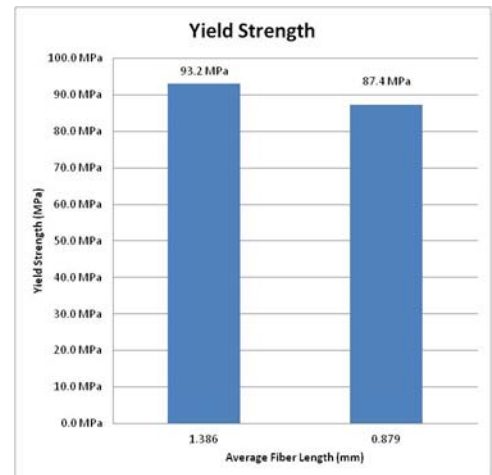


Figure 3: Yield strength data.

Although there was a small shift in the tensile data, it is unknown how the long-term properties of the composite material will be effected. Therefore, an assessment of the creep properties was conducted via dynamic mechanical analysis (DMA). The DMA was utilized using the time temperature superposition principle to generate a master curve. For this article, a life expectancy determination will be completed for a 30 MPa service load placed on the material. Based on measured tensile data shown in **Figure 3**, this would result in a 291% to 311% safety factor compared to the yield strength of the material. The long-term life expectancy of the part exposed to 30 MPa is shown in **Figure 4**. The data showed that an average fiber length change from 1.386 mm to 0.879 mm resulted in the 96% drop in the life expectancy. This is a dramatic shift in properties. Therefore, an important aspect when utilizing glass filled materials, is to determine how glass fiber lengths will influence the long-term properties and measure the glass fiber length within the part.

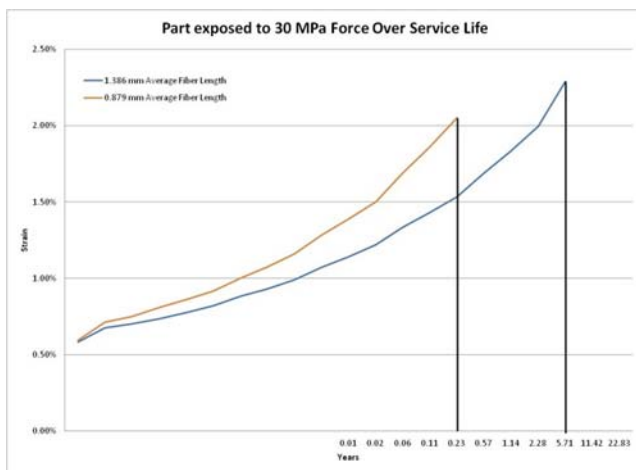


Figure 4: Long-term data.

ing part performance. There are multiple ways to characterize the fiber length of the material. These techniques can range from manual measurement to using automated image-processing algorithms. To gain an understanding into the measurement techniques, a background into the measuring processes will be reviewed. For most techniques, the initial task is separating the glass fibers from the polymer. The method typically utilized for the separation is heating the material in an oven. During heating of the material, the polymer will undergo thermal decomposition, leaving behind the higher temperature resistant glass fibers. However, if too high of a temperature is utilized, the fibers can undergo a softening process that will hinder

How Glass Fibers Affect the Long-Term Properties of a Composite Material and the Importance of the Glass Fiber Measurement (cont.)

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fiber measurement. This could mean that some high temperature resistant polymers, may require alternative separation techniques. Furthermore, dependent on the material, other inorganic or high temperature resistant fillers/additives could be present within the incombustible material and restrict measurement.

Upon separation of the glass fibers, the fiber will require a dispersion technique to allow for a measurement process to be utilized. There are multiple ways this can be performed such as manual, solution and/or funnel dispersion of the fibers. With the completion of the dispersion phase, the fibers are ready to be measured using the desired technique.

Manual measurement of the fibers through a digital image is the most simplistic of the techniques. However, this technique will often result in capturing the longer fibers, with minimal measurements of the short fibers.

This will result in a higher than expected average fiber measurement. Furthermore, this measurement technique is dependent on the individual completing the technique, which can result in variability between samples and labs.

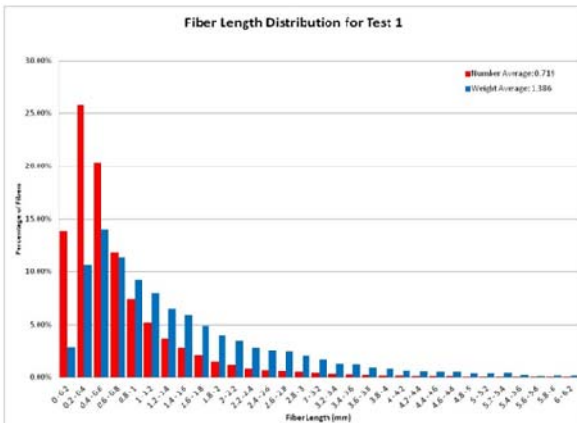


Figure 5: View of a fiber length distribution chart.

Another method that can be utilized is using automated image-processing algorithms to characterize the glass fiber length distribution. The algorithms will result in the measurement of each glass fiber down to the threshold distance set by the user. Furthermore, the algorithms will distinguish between multiple fibers that cross over each other and the curvature of the glass fiber. Unlike the variation from a manual measurement method, this is a more advanced method that results in minimal difference, and is not dependent on the user. Furthermore, the results offer a complete representation of the fiber lengths through a fiber length distribution chart, **Figure 5**.

Whatever measurement technique is utilized, it is important to know what the fiber length distribution is and how changes in length will affect the properties of the composite material.

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Upcoming Educational Conference

CAMX 2017 Conference: Monday – Thursday – December 11-14th, 2017
Orange County Convention Center, Orlando, FL

Wednesday, December 13, 2017 – *Antoine Rios, Ph.D.*

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.

Click on the link for more information:

https://camx17.mapyourshow.com/7_0/sessions/session-grid.cfm?grid-eventsby=Day&grid-eventdate=2017-12-13&grid-pageload=sessions%252Fsession-details.cfm%253FScheduleID%253D49

Upcoming Educational Webinars

Thursday, December 14, 2017 – Jeffrey A. Jansen - SpecialChem
Combining DMA, DSC, FTIR... for Optimal Material Analysis
 9:00 am CST



This course will help you optimize key properties (Tg, HDT, crystallinity, oxidation rate, component migration, etc.) of your materials. Will discuss in details factors affecting results using relevant cases (**Polymer identification, contamination, failure analysis**).

You often have to **mix multiple tools (DSC, DMA, FTIR, TMA...)** to either **characterize** your materials or solve complex formulation or processing issues.

However, if you are not clear which tool to use, when and how to complement data from these multiple techniques for better analysis, it can cost time and money.

Join this course to:

1. **Design a better material analysis plan** by clarifying the type of information you will receive from each characterization method (DMA, DSC, TGA, FTIR...).
2. Extract more value (Extent of oxidation, HDT, Tg, contamination...) by learning **how to efficiently cross data** from multiple characterization techniques.
3. **Wisely optimize performance of your plastic materials** by seeing in practice how to proceed on real-cases (Material identification, contamination, failure analysis)

Please click on the link below to register.

https://omnexus.specialchem.com/online-course/10047-best-combine-dma-dsc-ftir-for-optimal-material-analysis?lr=eTC100471&li=200180802&tgt=&utm_source=MKG&utm_medium=EML&utm_campaign=eTC100471&m_i=5VZhW%2BaMQWvN5JWXa5Vxruofs_QuZjtTmSUHbv73rC2VOQ1I2Z6kMD7tMC8papDxZ8N6jWnx_jr%2BzbgrNqvtejjKOH95s

Thursday, January 18, 2018 – Jeffrey A. Jansen - Audio Solutionz
Thermal Analysis of Elastomers
 10:00 am CST



Thursday, February 15, 2018 – Jeffrey A. Jansen – Audio Solutionz
Introduction to Silicone Elastomers
 10:00 am CST



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