TMG News

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The Importance of Crystallinity in Plastics Performance

Jeffrey A. Jansen

One of the fundamental characteristics of polymeric materials is the organization of their molecular structure. Broadly, plastics can be categorized as being semi-crystalline or amorphous. Understanding the implications of the structure, and specifically the crystallinity, is important as it affects material selection, part design, processing, and the ultimate anticipated service properties.

Most non-polymeric materials form crystals when they are cooled from elevated temperatures to the point of solidification. This is well demonstrated with water. As water is cooled, crystals begin to form at 0 °C as it transitions from liquid to solid. Crystals represent the regular, ordered arrangements of molecules, and produce a distinctive geometric pattern within the material. With small molecules, such as water, this order repeats itself and consumes a relatively large area relative to the size of the molecules, and the crystals organize over a relatively short time period. However, because of the relatively large size of polymer molecules and the corresponding elevated viscosity, crystallization is inherently limited, and in some cases, not possible. Polymers in which crystallization does occur, still contain a relatively high proportion of non-crystallized structure. For this reason, those polymers are commonly referred to as semi-crystalline. Polymers, which because of their structure, cannot crystallize substantially are designated as amorphous. As illustrated in Figure 1, amorphous polymers have an unorganized loose structure. Semi-crystalline polymers have locations of regular patterned structure bounded by unorganized amorphous regions. While some modification can be made through the use of additives, the extent to which polymers are semi-crystalline or amorphous is determined by their chemical structure, including polymer chain length and functional groups.

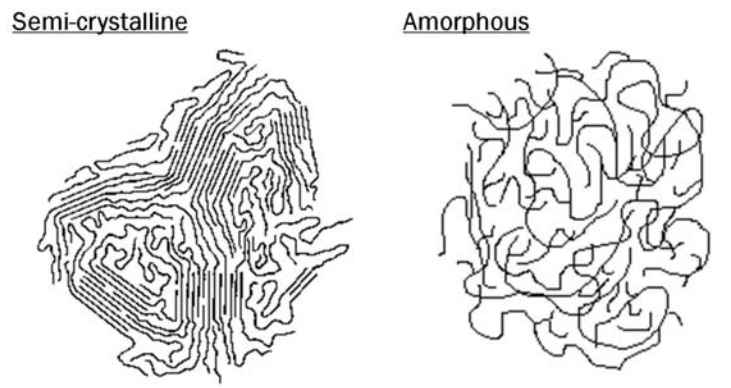

Figure 1: Semi-crystalline polymers contain sections of ordered structure, while amorphous polymers have an unorganized structure.

The ordered arrangement of the molecular structure associated with crystallinity results in melting when a sufficient temperature is reached. Because of this, semi-crystalline polymers, such as polyethylene, polyacetal, and nylon, will undergo a distinct melting transition, and have a melting point (T_m). Amorphous polymers, including polystyrene, polycarbonate, and poly(phenyl sulfone), will not truly melt, but will soften as they are heated above their glass transition temperature (T_g). This is represented by the differential scanning calorimetry thermograms included in Figure 2.

The difference between semi-crystalline and amorphous molecular arrangement also has an implication on the mechanical properties of the material, particularly as they relate to temperature dependency. In general, amorphous plastics will exhibit a relatively consistent modulus over a temperature range. However,

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as the temperature approaches the glass transition temperature of the material, a sharp decline will be observed. In contrast, semi-crystalline plastics will exhibit modulus stability below the glass transition temperature, which is often subambient, but show a steady decline between the glass transition temperature and the melting point. This is shown in Figure 3.

Due to their viscoelastic nature, time and temperature act in the same way on polymeric materials. Because of this, the changes within the material as a function of time can be inferred from the stability of the material versus temperature.

Aside from the time and temperature dependence, other key properties of polymeric materials are determined by their semi-crystalline\amorphous structure. Some generalizations of characteristic properties are listed in Table 1.

Table 1
Characteristic Properties

Semi-crystalline	Amorphous
• Distinct and sharp melting point	• Soften over a wide range of temperature
• Opaque or translucent	• Transparent
• Better organic chemical resistance	• Lower organic chemical resistance
• Higher tensile strength and tensile modulus	• Higher ductility
• Better fatigue resistance	• Better toughness
• Better creep resistance	
• Higher density	• Lower density
• Higher mold shrinkage	• Lower mold shrinkage

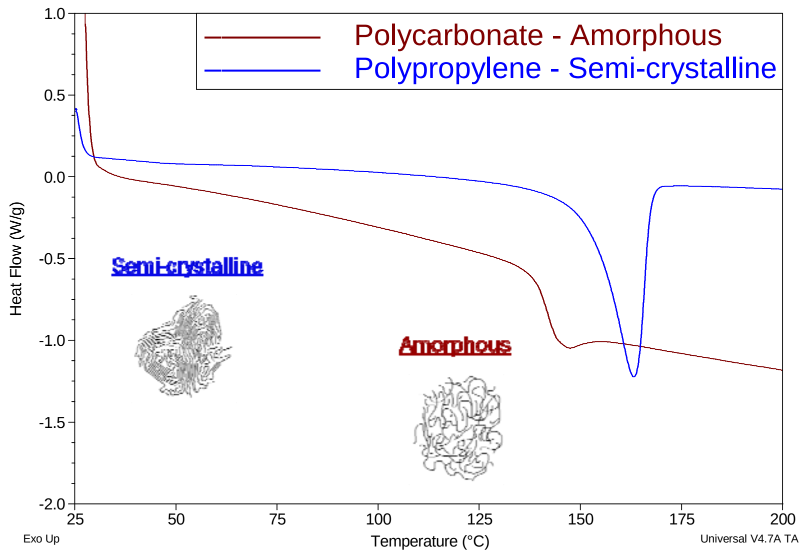

Figure 2: Differential scanning calorimetry thermogram showing a melting transition of a semi-crystalline polymer and a glass transition for an amorphous polymer.

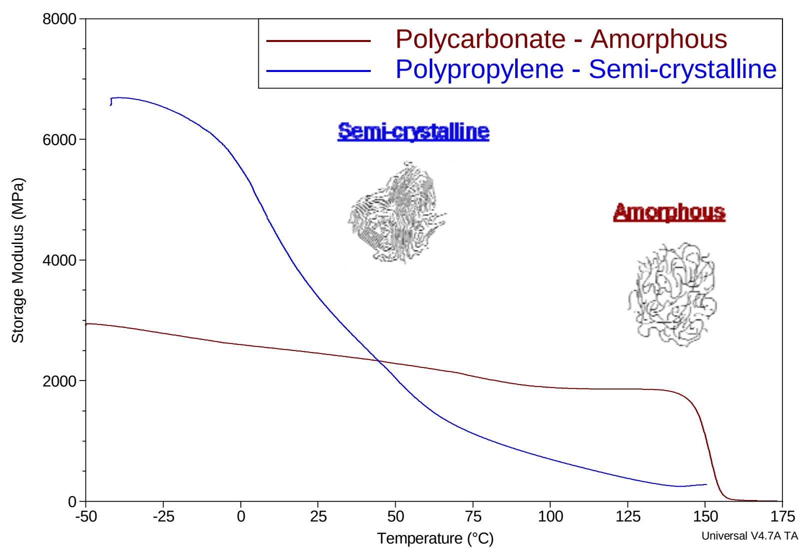

Figure 3: Dynamic mechanical analysis thermogram showing the storage modulus as a function of temperature for semi-crystalline and amorphous polymers.

If you would like more information regarding plastic material properties, plastic failure, or other plastics issues, please contact The Madison Group at 608-231-1907, or email at jeff@madisongroup.com.

Upcoming Society of Plastics Engineers Webinars

Educational Opportunities - SPE Webinars

Webinars provide a cost-effective way to expand your knowledge of plastics. The Society of Plastics Engineers (SPE) offers a wide selection of high quality webinars, many of which are taught by Jeffrey A. Jansen from The Madison Group. Below is a list of the upcoming webinars:

Understanding Plastic Failure Rate
Thursday, November 20, 2014 10:00 a.m. Central Time

Introduction to Plastics
Thursday, January 15, 2015 10:00 a.m. Central Time

Degradation Failure of Plastics
Wednesday, February 18, 2015 10:00 a.m. Central Time

Plastic Failure Prevention
Thursday, March 5, 2015 10:00 a.m. Central Time

The Effects of Impact and Other Rapid Loading Mechanisms on Plastics
Wednesday, April 15, 2015 10:00 a.m. Central Time

Ductile to Brittle Transitions in Plastic Materials
Thursday, May 21, 2015 10:00 a.m. Central Time

For more information on the webinars or to register, contact SPE's Scott Marko at 203-740-5442 or smarko@4spe.org.

Webinars that have been previously given are also available as a recorded DVD. Some that may be of interest are:

Failure Analysis of Plastic — 3 Parts

Basic Rubber Technology

Thermal Analysis in Failure and Compositional Analysis

Creep Rupture Failure of Plastics

For more information contact SPE's Scott Marko at 203-740-5442 or smarko@4spe.org.

SOCIETY OF PLASTICS ENGINEERS

Cross-Sectioning as an Analysis Tool

Jacob Nemec

A common question that is encountered during a failure analysis, design review, or a quality inspection of a plastic article is "what is occurring within the part?" The question is raised due to the inability to observe key internal regions of the part such as assembly interfaces, mechanical interactions, or internal defects. An engineer cannot evaluate what they cannot see, which is where cross-sectioning becomes a valuable tool.

A typical cross-section involves selection of a sectioning plane through the area of interest in the part. The part is then cut through this plane and the sample is mounted/potted in an epoxy compound and polished to a mirror finish. The polished cross-section can then be examined visually and microscopically at magnifications exceeding 1000X, if required.

Key areas of interest where cross-sectioning can be of use include, but are not limited to:

- **Plastic welds (*Figure 1*)**
- **Metallic inserts (*Figure 2*)**
- **Knitlines (*Figure 3*)**
- **IMD label interfaces (*Figure 4*)**
- **Overmold layer interfaces (*Figure 5*)**
- **Metallic plating on plastic substrates (*Figure 6*)**
- **Adhesive bond quality (*Figures 4 and 5*)**
- **Suspected void regions (*Figures 1, 3, and 6*)**
- **Material/pigment streaking (*Figure 3*)**
- **Internal cracking (*Figure 2*)**

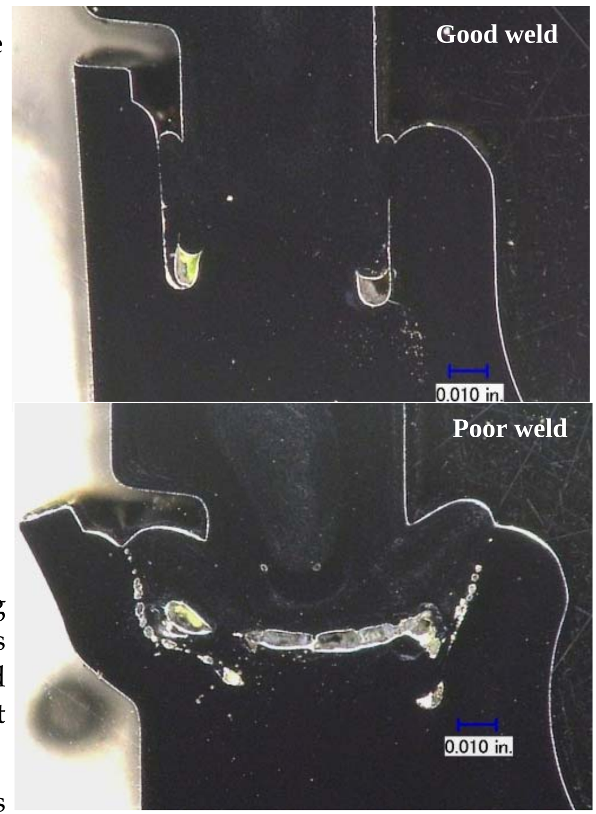

Figure 1: Ultrasonic weld cross-sections.

If you have been in the plastic manufacturing industry long enough, you have likely needed to inspect several of the areas listed above. Cross-sectioning provides a cost—effective and timely view of these areas, and can provide insights about normally hidden features of the part/assembly.

For example, the images in Figure 3 illustrate cross-sections prepared through the knitline region of two parts produced using a pre-compounded resin and a color concentrate. Failures were occurring as fractures during use in the parts produced using the color concentrate. No failures were reported in the parts manufactured using the pre-compounded resin. As visible in Figure 3, the dispersion of the colorant in the pre-compounded part was excellent, while the colorant dispersion of the color concentrate part was poor. The parts were produced on the same press under similar conditions. However, the differing properties of the resins, due to the different coloring methods, led to a well-fused knitline on the pre-compounded parts and a large internal void at the knitline of the color concentrate parts. The exterior surface of the parts showed no significant differences. In this case, an inspection of the interior of the parts was critical in determining the cause of failure and the corrective actions required to prevent future failure.

A drawback of cross-sectioning, is that it is limited to only the plane(s) selected. Other methods of analysis, such as CT scanning may provide a more broad and detailed picture of the part as a whole. However, in many cases, a simple cross-section can identify whether and where a problem exists, and a valuable starting point on how to fix the problem.

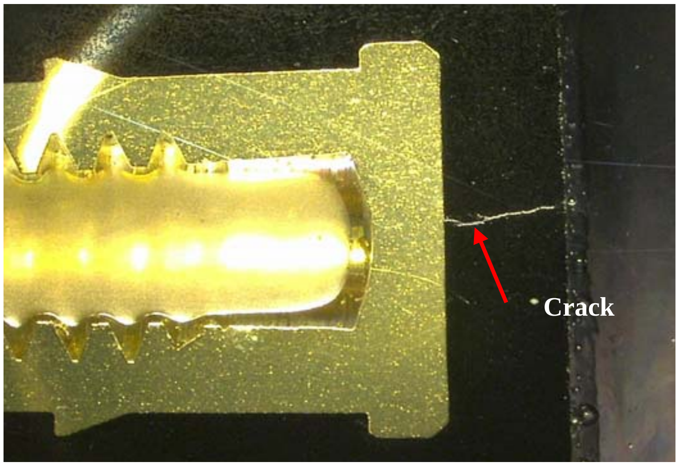

Figure 2: Cross-section of cracking near metallic insert.

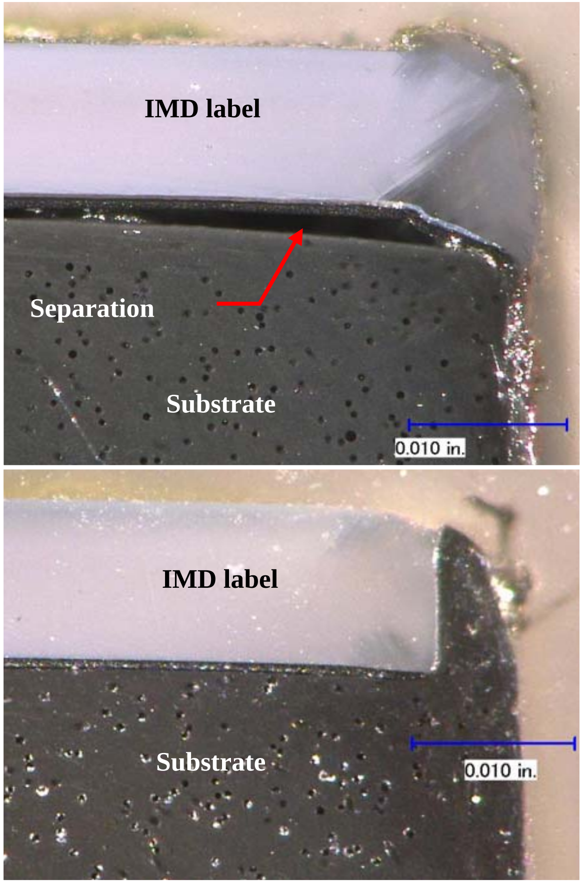

Figure 4: IMD label cross-sections.

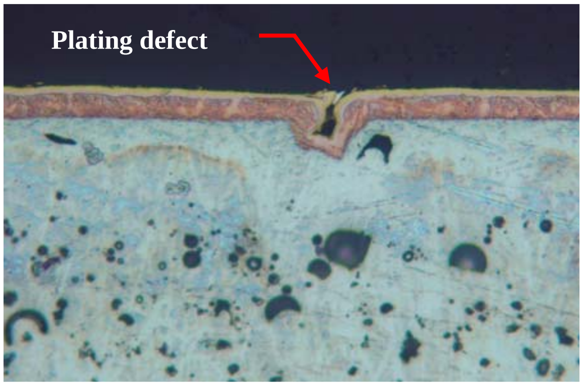

Figure 6: Cross-section of plating defect.

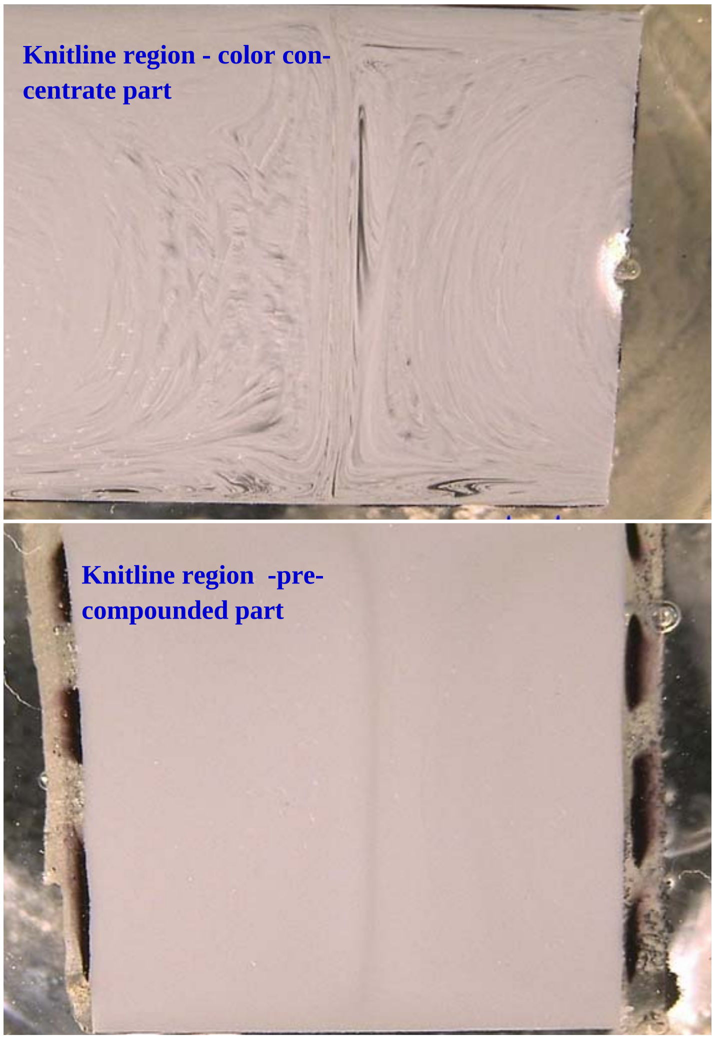

Figure 3: Knitline cross-sections.

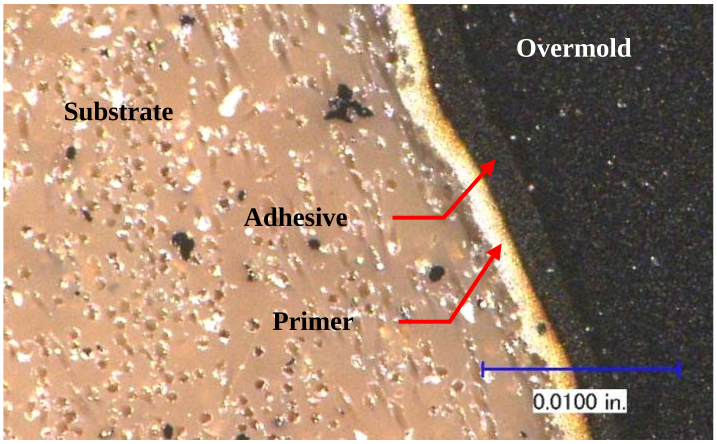

Figure 5: Overmold cross-section.

If you would like more information regarding the use of cross-sectioning as an analysis tool please contact The Madison Group at 608-231-1907, or email jake@madisongroup.com.

The Madison Group Completes Move to New Headquarters

After a year of planning and construction The Madison Group officially moved into its new headquarters on October 17th. The new building, which is approximately 13,000 square feet, was custom designed to The Madison Group 's specifications.

"The building satisfies a huge need to house our rapidly expanding company. Our new facility has a number of new labs, offices, conference and meeting rooms, a library and a recreational area for the employees," said Paul Gramann, President. "All our employees gave input into the design of building and were continually onsite with subcontractors to ensure the building met our specifications. The building was a true team effort on all accounts."

The Class A steel structure building has a unique brick exterior design with large sections of glass to maximize the use of natural light. The building is situated on two acres of land to also accommodate future expansion.

"The new building will strengthen our ability to meet the needs of our clients and employees. We are extremely excited about our expansion and the future", said Gramann.

The Madison Group Adds Engineering Staff

We are pleased to announce that Dayton Ramirez has joined our growing team of plastics engineers at The Madison Group. Dayton received his B.S. in Plastics Engineering from the University of Wisconsin– Stout in 2013 and joined the Madison Group after graduation. His responsibilities include performing failure and design analysis on thermoplastic, thermoset and rubber parts. He has previous experience in process/part evaluation, development and optimization while working with multiple manufacturing facilities on injection molding machines (15-3500 ton), thermoformers, multilayer sheet extruders, and multilayer blown film lines.

"We are pleased to have Dayton Ramirez join our growing team of engineers at The Madison Group. Dayton brings excellent hands-on experience and training in the behavior of plastics that will bolster our capabilities to help solve our customer's plastics problems," said Bruce Davis (CEO).