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Impact Properties of Polyester Resins

by

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Abstract

Manufacturers of composite materials are often concerned with how tough or durable a composite part will be in service. Generally designers will look at the tensile elongation value of a given resin as an indicator of a resins ability to absorb or transfer energy when subject to a particular dynamic load. This paper investigates impact properties of several different resin chemistries and whether and to what extent the "static" tensile elongation value of a resin relates to a composites ability to absorb energy when subject to an impact load. Tensile elongation values (ASTM D638) are compared with Izod (ASTM D256) and puncture-type (ASTM D3763) results for both clear cast and reinforced laminates.

Introduction

Composite structures may be subject to a variety of loading conditions depending upon their application. These applied "forces" may be internal or external and be chemical, thermal, electromagnetic or mechanical in nature.

Designers will often look at a number of different physical and mechanical properties of a material to determine its suitability for service. Within the composites industry, one of the properties that is looked at with much scrutiny is the percent-elongation of a resin (as determined by a standard tensile test like ASTM D638). Percent-elongation is considered to be a good indicator of a resins durability or toughness when subject to a mechanical load.

This paper looks at the impact properties of six different resin chemistries and investigates whether and to what extent the tensile elongation value of a resin relates to its mechanical toughness.

Experimental Design

This study considers six resin chemistries including PG-Maleate (PG-M), dicyclopentadiene (DCPD), orthophthalic (Ortho), terephthalic (Tere), isophthalic (Iso) and vinyl ester (VE). All resins in this study are at 60% non-volatiles (40% styrene), promoted identically using 12% cobalt and dimethylaniline (DMA) and inhibited with hydroquinone (HQ) for a gel time of 30 minutes. All resins were initiated with 1.25% by weight methyl ethyl ketone peroxide (MEKP).

Eighth-inch thick clear-castings were made between glass plates. The castings were cured at 77°F for 16 hours and then post-cured for 2 hours at 150°F and then 2 hours at 250°F. Clear cast tensile, Izod impact and puncture specimens were fabricated and tested in accordance with ASTM D638, ASTM D256 and ASTM D3763, respectively.

Laminates were fabricated at 40 weight-percent glass using four plies of 1.5 ounce chopped strand mat. The laminates were made via hand lay-up between polyethylene terephthalate polyester sheets and allowed to cure at 77°F for 16 hours. The laminates were post-cured for 2 hours at 150°F and then 2 hours at 250°F. Laminate tensile, Izod impact and puncture specimens were fabricated and tested in accordance with ASTM D638, ASTM D256 and ASTM D3763, respectively.

Theory

Materials may be classified as either "brittle", "tough" or "ductile". Brittle materials are identified by low strain-to-failure, but may be quite strong. Tough materials are generally characterized by both high-strength and high strain-to-failure. A ductile material usually has low-strength, but a very high strain-to-failure. The stress-strain behavior of these three material classifications is illustrated by the load-displacement curves of Figure 1.

By definition the energy absorbed by a material during loading to the point if failure is the area under the load-displacement curve as illustrated in Figure 1 and is represented by

$$Energy = \int_{x=0}^{x=x_{failure}} P(x)dx$$

where P is the applied load and x is the displacement.

The toughness of a material is defined as the energy absorbed per unit volume during loading to the point of failure. This is equivalent to the area under the stress-strain curve as defined by

$$Toughness = \int_{\varepsilon=0}^{\varepsilon=\varepsilon_{failure}} \sigma(\varepsilon)d\varepsilon$$

where σ is the stress (σ=P/A), ε is the strain ($\varepsilon = \Delta L/L$), A is the cross sectional area and ΔL is the change in length L.

Results

The results of the tensile, Izod and puncture-type impact testing are given in graphical form in Figures 2 – 10. Figures 2-5 are clear-cast tensile-elongation, tensile-toughness, Izod impact energy and puncture-type impact energy vs. resin chemistry, respectively. Figures 6-10 are laminate tensile-elongation, tensile-toughness, Izod impact energy, puncture-type impact energy, and first-crack puncture-type impact energy vs. resin chemistry, respectively. Note that each plot shows the spread of the data along with the average value for each data set.

Figure 11 shows one set of clear-cast puncture-type impact specimens after testing. Figure 12 shows one set of puncture-type laminate impact specimens after testing. The drop height and weight used for each specimen type is listed in Figure 13 and 14 (Tables 1 and 2). Note that the clear-cast specimens where impacted using different drop heights (related to how easily each specimen type failed). Laminate specimens were all tested from the same drop height.

Discussion

The test data was arranged to depict specific resin properties as a function of resin tensile elongation. The clear-cast tensile-toughness, Izod impact energy and puncture-type impact energy vs. clear-cast tensile-elongation data is displayed in figures 15-17, respectively. For each plot, the box represents the area of data scatter and the dot represents the average of the data for each chemistry.

Figure 15 depicts a linear relationship between tensile-elongation and resin toughness. A relationship would be expected since the toughness is the area under the stress-strain curve (i.e. resin toughness is a function of strain). Figure 16 shows the Izod impact energy vs. tensile-elongation. A linear relationship appears to exist; although this terephthalic resin shows the most departure from this trend. Figure 17 shows the puncture-type impact energy vs. tensile-elongation. A linear relationship appears to exist for all but this terephthalic resin chemistry.

The laminate tensile-toughness, Izod impact energy, puncture-type impact energy and puncture-type first-crack energy vs. clear-cast tensile elongation are given in figures 18-21. From this data, clear cast tensile elongation does not appear to be related to laminate tensile-toughness, laminate Izod impact energy or laminate puncture-type impact energy. Does the glass reinforcement play a dominant role in these three instances? Are the fiber-matrix interface properties (bonding) more critical than the resin elongation? On the other hand, there does appear to be a linear relationship between clear-cast tensile elongation and laminate impact-type energy to first-crack (Figure 21). In other words, resins with higher tensile elongation appear to inhibit the initiation of damage (crack initiation).

So why would there be a difference between first-crack energy and laminate failure energy as it relates to clear-cast tensile-elongation? Well, there may be a relationship between clear-cast tensile-elongation and the laminate properties previously mentioned. The caveat is that data presented here does not account for the amount of damage that occurs during laminate failure. Looking at Figure 12, while the impact height and weight were identical for the laminates tested, and while the results show that the laminates absorbed similar amounts of energy to failure, you can see that the amount of damage (crack propagation) done to each specimen type differs noticeably. In other words, the amount of crack-surface-area created in each specimen is different. The damage appears to be more localized in the laminates fabricated from the higher tensile elongation resins.

Unfortunately, there is not a good method for measuring the amount of damage done to a laminate. If you were able to quantify the amount of new surface area created by fracturing the resin and glass, it might be possible to get a better "picture" of the relationship between clear-cast tensile-elongation and the laminate impact properties. Fortunately, the energy absorbed to first-crack gives a measure of the relationship between clear-cast tensile-elongation and laminate impact properties.

Conclusion

Different resin chemistries impart different levels of toughness to a composite part just as they would affect any other mechanical property. There does appear to be a relationship between a resins tensile-elongation value and a laminate's impact toughness. The relationship is observable in a puncture-type impact-test by determining the energy to first-crack. However, as with any material used for a given application, while certain simplifying assumptions may be used for initial material screening, there is no substitute for testing the actual materials and construction as not all materials or material combinations may exhibit an expected behavior.

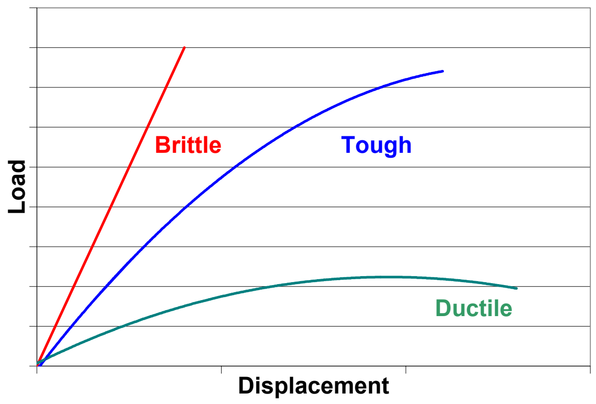

Figure – 1. Load vs. Displacement showing brittle, tough and ductile materials. Energy = area under load displacement curve.

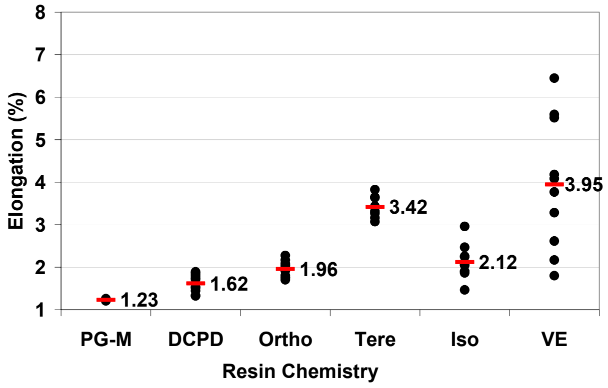

Figure – 2. Clear-cast tensile-elongation vs. resin chemistry.

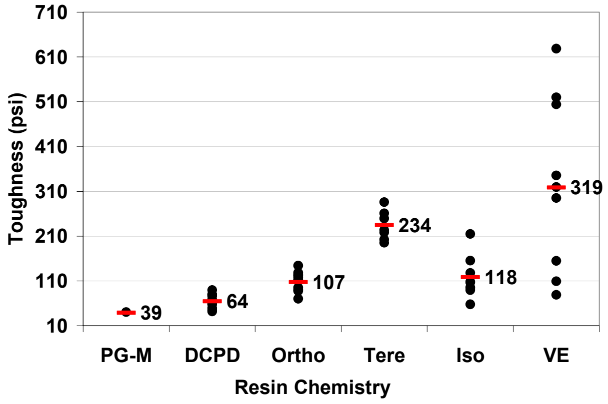

Figure – 3. Clear-cast tensile toughness vs. resin chemistry.

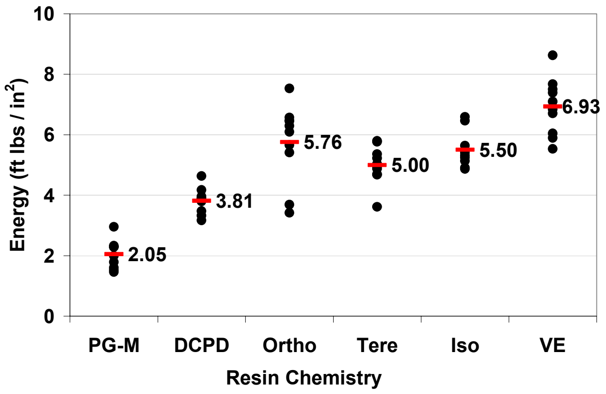

Figure – 4. Clear-cast Izod impact energy vs. resin chemistry.

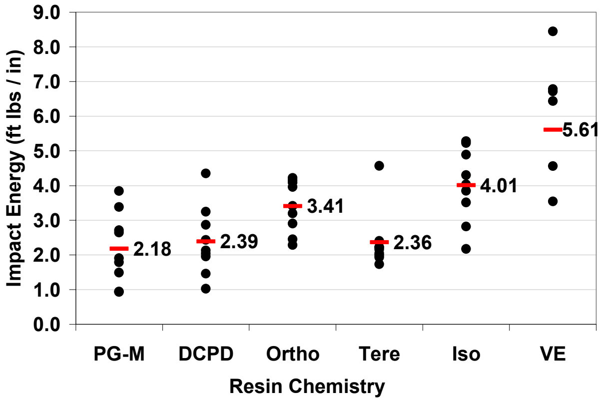

Figure – 5. Clear-cast puncture-type impact energy vs. resin chemistry.

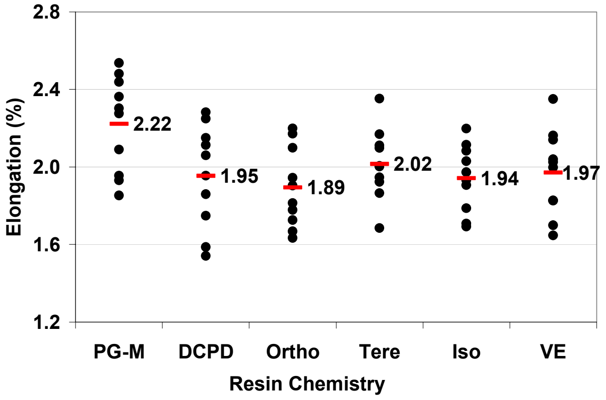

Figure – 6. Laminate tensile-elongation vs. resin chemistry.

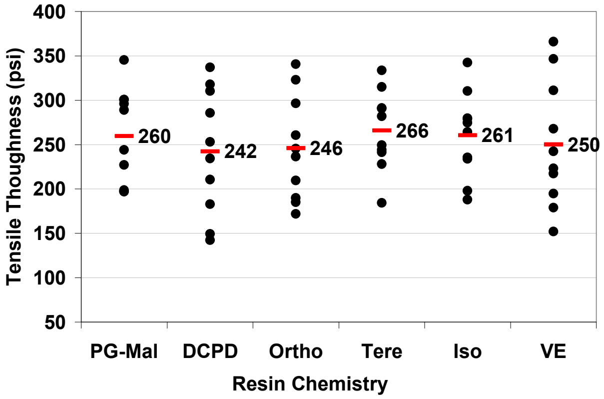

Figure – 7. Laminate tensile-toughness vs. resin chemistry.

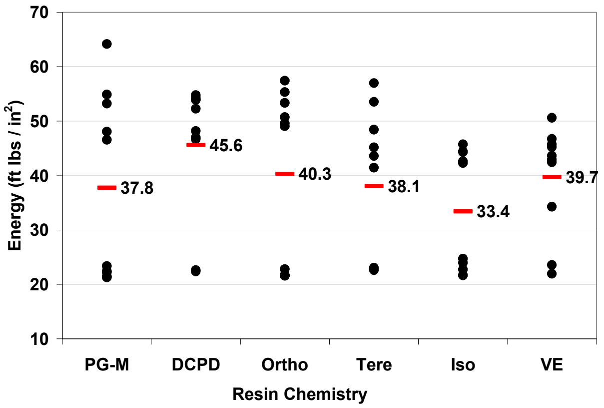

Figure – 8. Laminate Izod impact energy vs. resin chemistry.

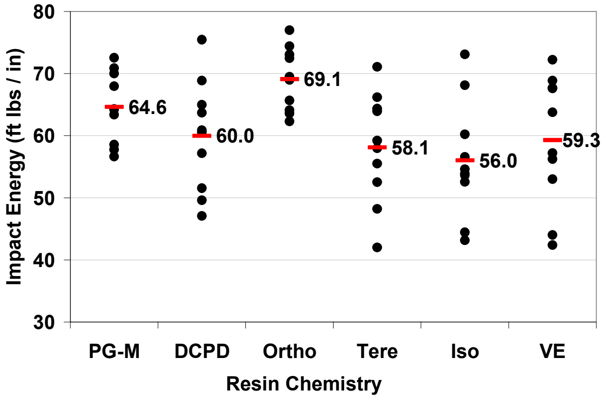

Figure – 9. Laminate puncture-type impact energy vs. resin chemistry.

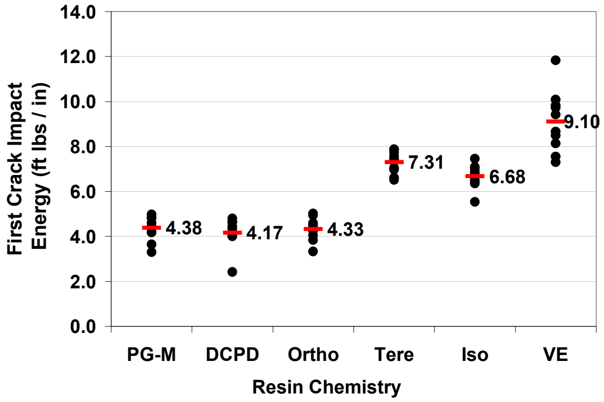

Figure – 10. Laminate puncture-type first-crack impact energy vs. resin chemistry.

Figure – 11. Clear-cast puncture-type impact specimens.

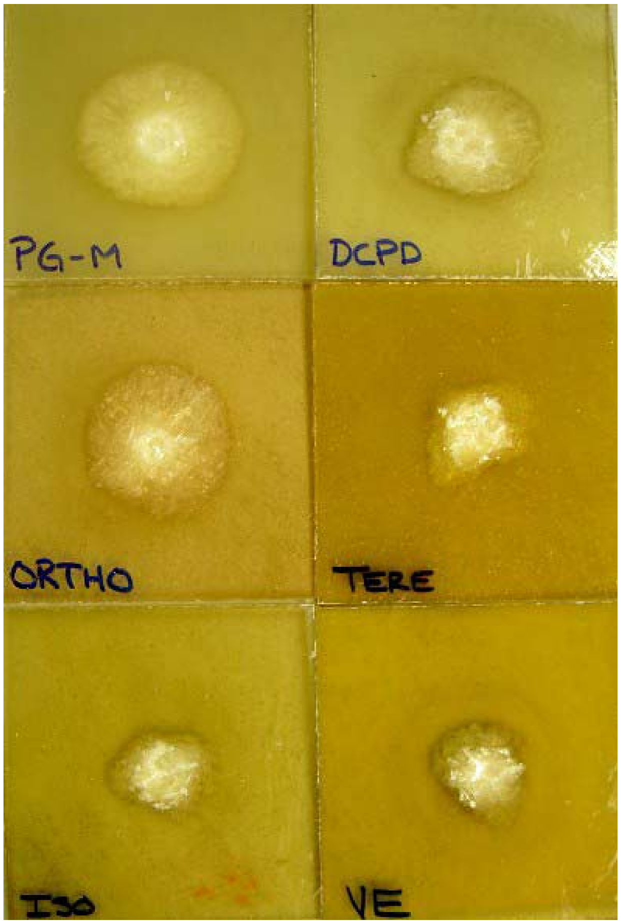

Figure – 12. Laminate puncture-type impact specimens.

Clear Cast	Impact Height (in)	Impact Weight (lbs)
PG-M	0.60	11.3
DCPD	0.60	11.3
Ortho	0.60	11.3
Tere	0.72	11.3
Iso	0.72	11.3
VE	1.20	11.3

Figure – 13. Table – 1 Clear-cast puncture-type impact load configurations.

Laminate	Impact Height (in)	Impact Weight (lbs)
PG-M	12.0	11.3
DCPD	12.0	11.3
Ortho	12.0	11.3
Tere	12.0	11.3
Iso	12.0	11.3
VE	12.0	11.3

Figure – 14. Table – 2 Laminate puncture-type impact load configurations.

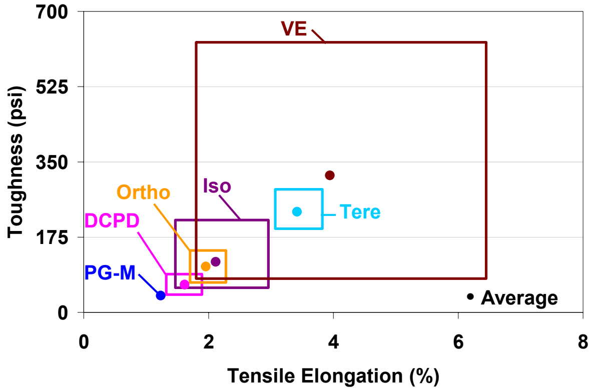

Figure – 15. Clear-cast tensile-toughness vs. clear-cast tensile-elongation.

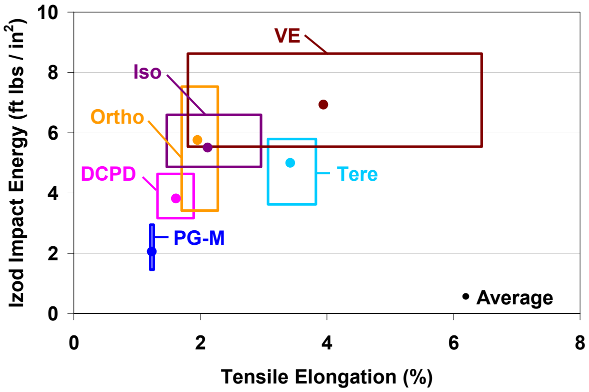

Figure – 16. Clear-cast Izod impact energy vs. clear-cast elongation.

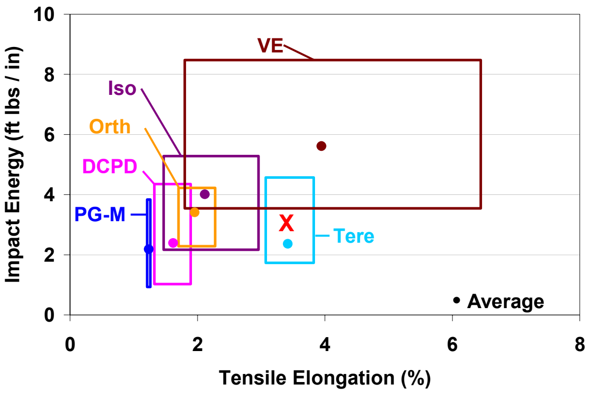

Figure – 17. Clear-cast puncture-type impact energy vs. Clear-cast tensile-elongation.

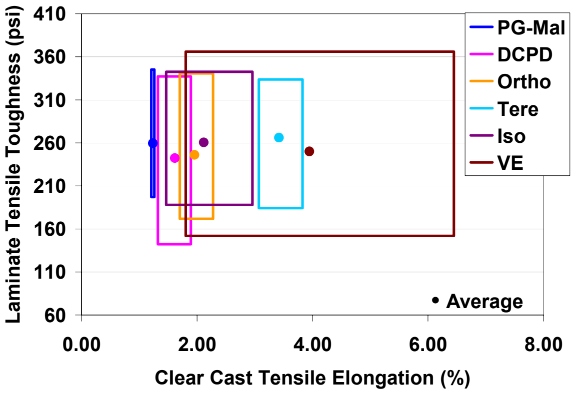

Figure – 18. Laminate tensile-toughness vs. clear-cast tensile-elongation.

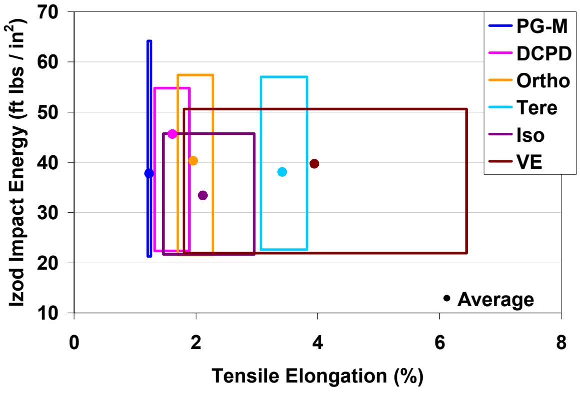

Figure – 19. Laminate Izod impact energy vs. Clear-cast tensile-elongation.

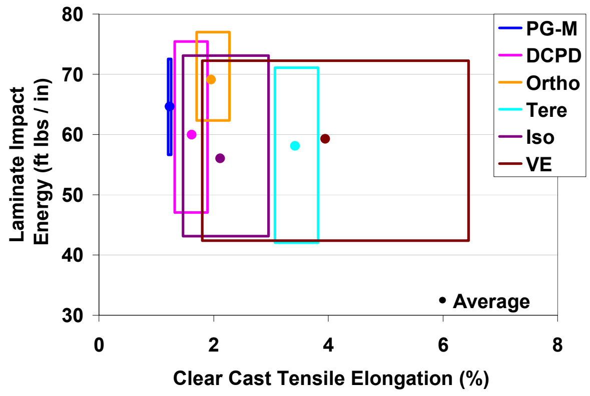

Figure – 20. Laminate puncture-type impact energy vs. clear-cast tensile-elongation.

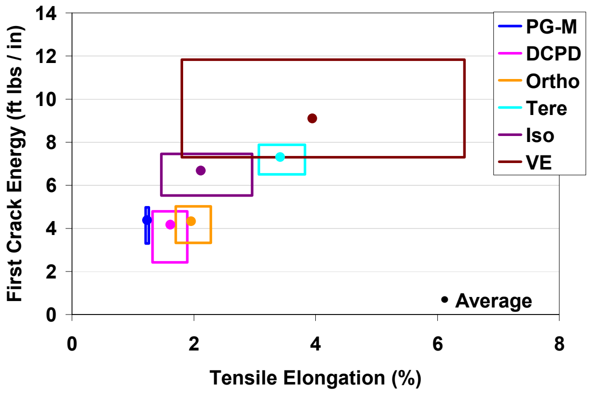

Figure – 21. Laminate puncture-type first-crack impact energy vs. clear-cast tensile-elongation.

Author:

Dr. Stephen Brooks is a Senior Engineer for Reichhold Industries, Inc. With 13 years experience in the composites industry, his composites background includes hand lay-up, spray-up, pultrusion, compression molding (SMC/BMC), resin transfer and resin infusion molding and filament winding.