

Engineering Design For Toughness Using Rigid Geon® Vinyl Custom Injection Molding Compounds

Introduction

Toughness of rigid vinyl products is an important property affecting ease of machining and assembling as well as effecting the amount of abuse the product will take in use without breaking. Quality products are designed so they do not break in service. If toughness of plastic products is to be engineered into the product, Izod impact must be understood beyond a one point measurement, especially for the more ductile plastics. With a good understanding of toughness, products can be engineered using vinyl compounds formulated to prevent breakage in service.

Some plastic materials are capable of ductility in an Izod test; some are not. Examples of various plastic material classifications are listed below.

Common Polymers: Ductile

- Some polyvinyl chlorides (Geon rigid vinyl)
- Some polycarbonates (Lexan)
- Some polystyrene / polyphenylene oxide blends (Noryl)

Common Polymers: Brittle

- Some polyvinyl chlorides (rigid vinyl)
- Some polycarbonates
- Some polystyrene / polyphenylene oxide blends
- Polystyrene
- Poly Methylmethacrylate (PMMA)
- ABS
- Polystyrene / acrylonitrile copolymer (SAN)

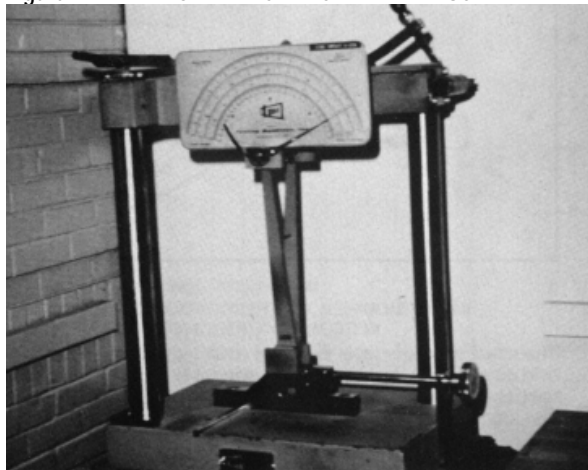
Those materials capable of ductility may also be brittle if they are not processed properly, parts are not designed properly, or the products are impacted under more severe conditions than expected.

Since rigid vinyl can be either ductile or brittle, it is important to understand its toughness.

Izod Impact Test:

Historically, the Izod impact test has been used to measure toughness of both metal and plastic materials. The most common procedure for running this test on plastic products is to use a 10 pound pendulum (Figure 1) to strike a sharply notched (0.01 inch notch radius) specimen, 1/8 inch thick at a velocity of 11 feet per second, at a test temperature of 23°C. The energy to break the specimen is recorded. If these test conditions match exactly the toughness requirements of an end-user application, it is a rare coincidence. It is also extremely important to understand the toughness of rigid vinyl at other conditions so that real product performance requirements can be correlated with practical product end use requirements.

Figure 1 IZOD IMPACT TEST APPARATUS



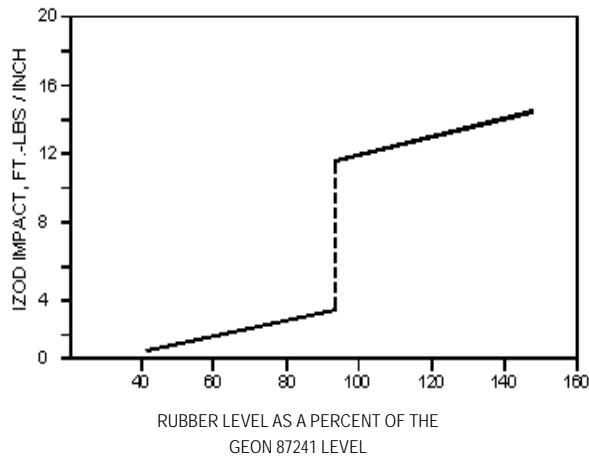
Impact Performance Due to Formulation Variables in Rigid Vinyl:

Even with materials capable of ductility, such as rigid vinyl and polycarbonate, several formulation variables can be adjusted in the compound to effect the Izod toughness. Figure 2 shows how the amount of rubber added to the rigid vinyl affects Izod toughness. However, excess rubber creates a more expensive compound and a compound with reduced stiffness. Figure 3 demonstrates that high resin molecular weight affects Izod impact. However, a molecular weight causes reduced melt flow and, therefore, an inability to fill some molds.

Any compound has normal variations in resin molecular weight (within specifications) and normal variations in impact modifier efficiency (within specifications). Figure 4 examines those variations for several compounds. The box represents the limits in the specifications. From this figure, you see that Geon® 87322 is always ductile (>5 ft./inch Izod) when tested by the standard Izod conditions, Geon® 87241 will occasionally show brittle failures in the standard Izod test.

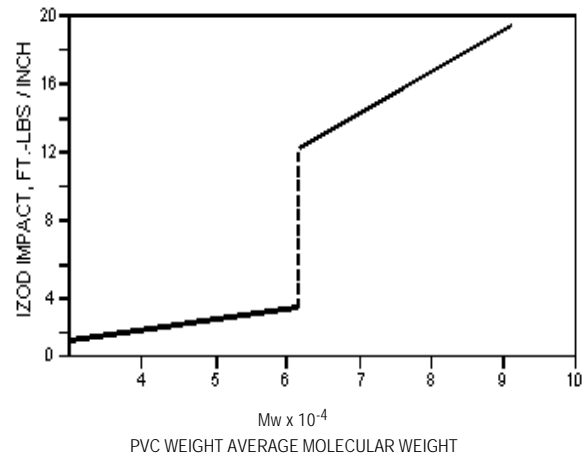
Of course, a brittle Izod value does not mean poor actual part performance. Any specimen within the box is quite similar to any other specimen within that box in composition and in actual toughness properties. It by rare chance, differences in impact in actual use correlate to differences within the box, then, of course, the wrong material has been chosen and a tougher material should be used with an appropriate safety margin to insure it is always tough in the application. Figure 4 also illustrates that if the materials are near the ductile / brittle transition, there is no significant difference between a brittle Izod result at about 2.5 ft. / inch and a ductile Izod result at about 12 ft. lbs. / inch. The key to this statement is that both materials are near the ductile/brittle transition. **Therefore, materials must be meaningfully characterized by how far they are from the ductile / brittle transition, not just by single value Izod result.** (See section on Testing / Abuse Variables.)

Figure 2



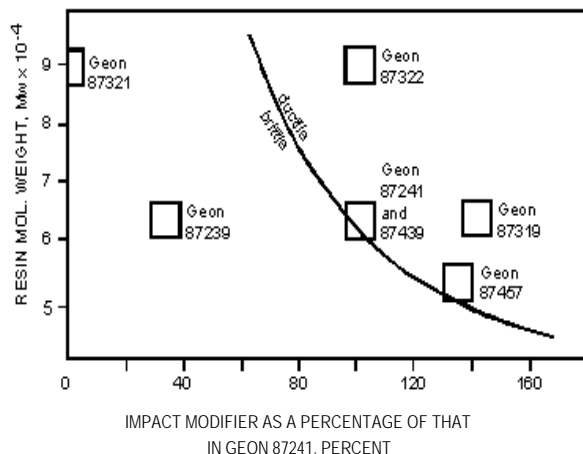
The effect of rubber level on Izod impact at 23°C at 11 feet / second impact velocity, for a .01 inch notch radius, for a rigid resin of 63,000 molecular weight, and for a 1/8 inch specimen thickness.

Figure 3



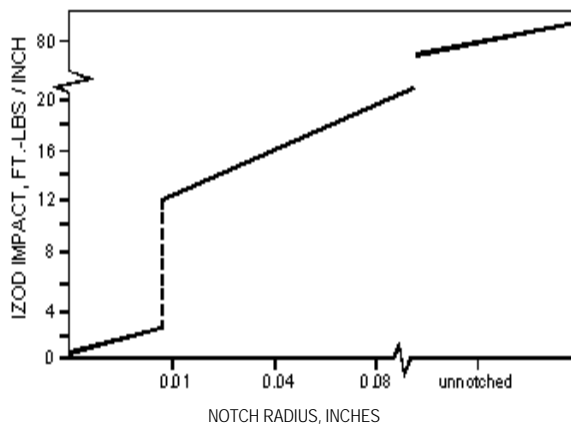
The effect of vinyl resin molecular weight on Izod impact as 23°C., at 11 feet / second impact arm velocity, for a 0.01 inch notch radius, for a 1/8 inch thick specimen, and with the rubber level held constant.

Figure 4



The effect of rubber level and vinyl resin molecular weight on the Izod ductile/brittle transition under standard conditions of 23°C test temperature, 11 feet / second impact velocity, 0.01 inch notch radius, and 1/8 inch specimen thickness.

Figure 5



Izod impact of Geon 87241 as a function the notch sharpness. Other variables are held constant at 23°C., 11 feet / second impact velocity, and 1/8 inch thickness.

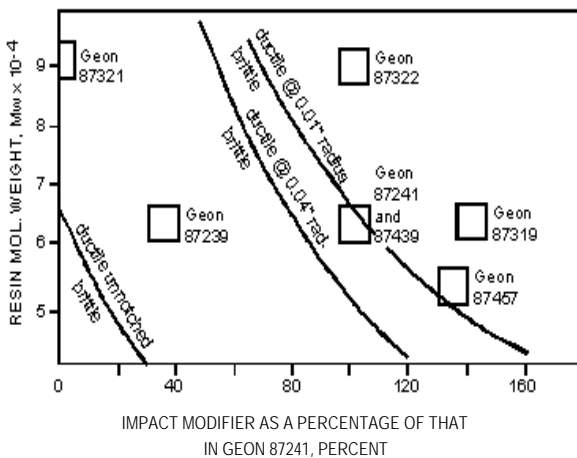
Product Design Variables Affecting Impact Performance:

Notches are stress concentrators and, therefore, can contribute to a plastic part's impact failure. The effects of sharp notches are illustrated in Figure 5. From this, one understands the importance of designing parts with generous radii in order to maximize the product toughness. Another way of saying this is that rigid vinyl compounds having more than 80 ft.lbs. / inch of Izod impact resistance can be reduced to 2 ft.lbs. / inch simply by improperly designing a sharp notch into the finished product. The effect of notch radius on the ductile / brittle transition is illustrated in Figure 6.

In a manner similar to notches, bubbles and voids are stress concentrators and must be avoided to maximize toughness. To avoid bubbles, the vinyl must be kept dry, and other good molding practices observed, to avoid trapping air as well as to avoid degrading the PVC.

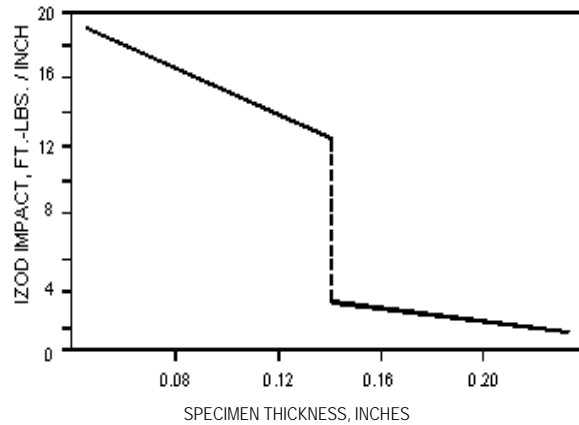
Part thickness also can play a significant role in toughness as illustrated in Figure 7. Thinner parts are more ductile. The force of impact on the Izod bar causes triaxial stresses in the notch region. These triaxial stresses are more easily relieved by local drawing in thin specimens while thicker specimens cavitate and rupture due to the lower level of local drawing. The effect of specimen thickness on the ductile / brittle transition is illustrated in Figure 8.

Figure 6



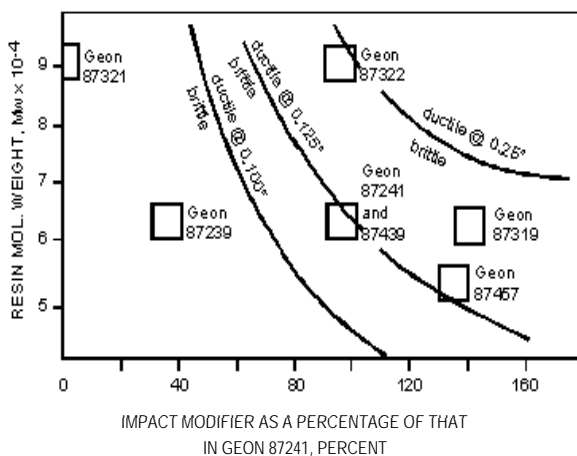
The effect of notch radius on the ductile / brittle transition. Other variables are held constant at 23°C., 11 feet / second impact velocity, and 1/8 inch thickness.

Figure 7



Izod impact of Geon 87241 as a function of the specimen thickness. Other variables are held constant at 23°C., 11 feet / second impact velocity, and 0.01 inch notch radius.

Figure 8



The effect of specimen thickness on the brittle / ductile transition. Other variables are held constant at 23°C., 11 feet / second impact velocity, and 0.01 inch notch radius.

Knit Line Impact Strength:

Often parts have unavoidable knit lines that affect impact strength. Our studies on many compounds have led us to a general rule of thumb on knit lines: the Izod impact strength of an unnotched knit line is about the same as a 0.01 inch radius notched specimen without knit line. Thus, the knit line must be considered as a weak point in the part that can easily initiate a crack. However, tough compounds and optimum processing conditions can minimize the inherent weakness at the knit line.

Testing / Abuse Variables:

The conditions under which a part is abused or impacted also plays a big role in the toughness of the part. For example, increasing the impact velocity will cause a ductile product to become brittle. The effect of Izod impact arm velocity is illustrated in Figure 9.

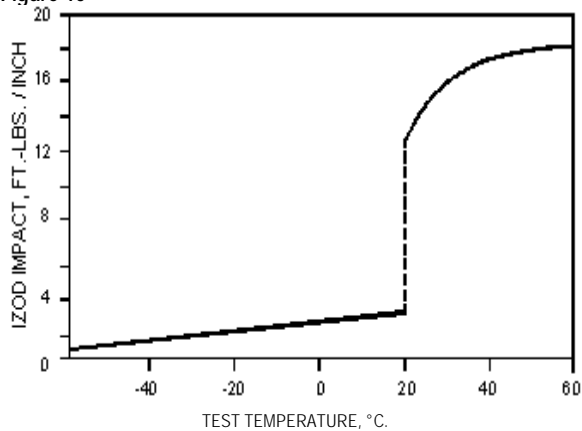
Lower temperatures cause a product to become brittle as illustrated in Figure 10. Because changing temperature causes a ductile / brittle transition, **changing the Izod test temperature is a convenient and useful method to determine how far from the ductile / brittle transition a specimen is.** As mentioned earlier, this additional information is much more useful than just an Izod value at one set of test conditions. The effect of the test temperature on the ductile / brittle transition is shown in Figure 11.

When one considers all the variables which offset the Izod test values: formulation variables, part configuration, and variations in test conditions, it's easy to recognize that it is a rare coincidence that an impact failure in actual use will correlate with an Izod test value performed at a very specific

set of standardized test conditions. Therefore, formulation variables, part design and end use performance conditions must be understood beyond an Izod test value.

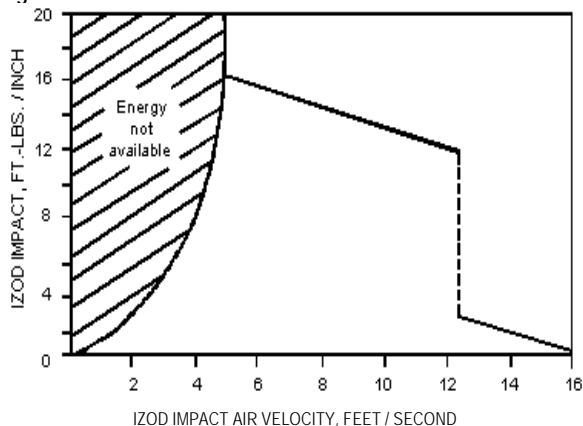
If part geometry is complex and abuse conditions poorly defined, then perhaps more than one compound should be evaluated in actual abuse conditions before specifying a compound to do the job. Since increased toughness is more costly, this step can allow specifying the most cost effective compound that will do the job.

Figure 10



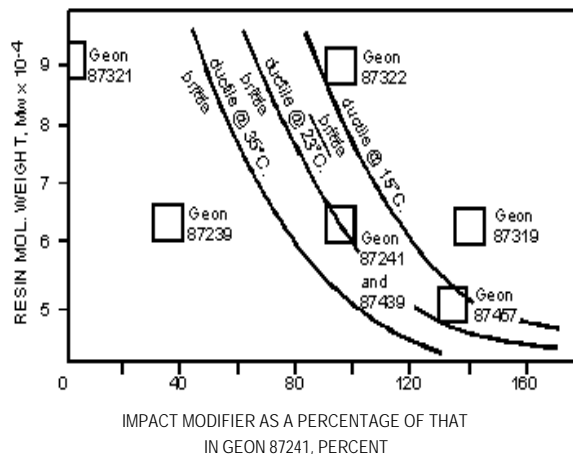
Izod impact of Geon 87241 as a function of test temperature. Other variables are held constant at 11 feet / second impact velocity, 0.01 inch notch radius, and 1/8 inch thickness.

Figure 9



Izod impact of Geon 87241 as a function of impact arm velocity. Other variables are held constant at 23°C., 0.01 inch notch radius, and 1/8 inch thickness.

Figure 11



The effect of test temperature on the ductile/brittle transition. Other variables are held constant at 11 feet / second impact velocity, 1/8 inch specimen thickness, and 0.01 inch notch radius.

Dropped Dart Impact Test:

Apparatus:

In the dropped dart test, as described in ASTM D4226, a weight is dropped from various heights on an unnotched specimen (the apparatus shown in Figure 12) to determine the energy for one-half the specimens to fail. For molded specimens, the C125 dart (conical with 0.125 inch radius tip) (Figure 13) would be preferred because it causes failure in typical specimen thicknesses more readily than the hemispherical dart.

Variables Affecting Dropped Dart Impact:

Since the dropped dart test requires a flat specimen, product design variables such as notches are not readily evaluated. Unlike the Izod test, there is no discontinuity in

Figure 12

DROPPED DART TEST APPARATUS.

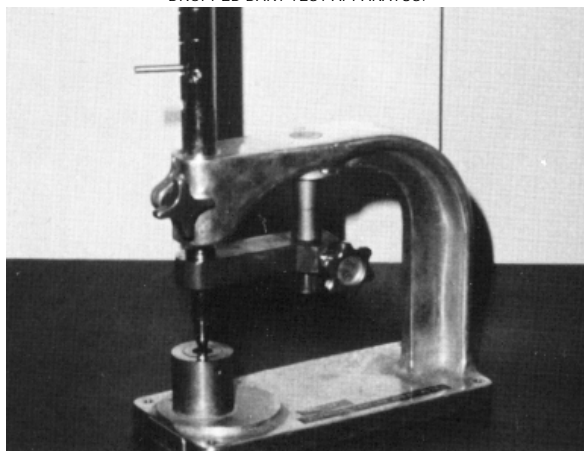


Figure 13

THE CONICAL DART IS PREFERRED FOR MOST INJECTION MOLDED PARTS.



the impact curve. Simply dividing the energy by specimen thickness eliminates thickness as a variable.

Dropped dart impact is a measure of the energy to both initiate a crack plus the energy to propagate the crack, while the sharply notched Izod test mainly measures the energy to propagate a crack. As can be seen in the following table, the energy involved in initiating a crack (in dropped dart testing) is substantial compared to the energy required to propagate a crack (in Izod testing).

TEST	IMPACT ENERGY (ft.-lbs./Inch of thickness)
Brittle Break in Izod	2.5
Ductile Break in Izod	15
(Brittle or Ductile Break in Dropped Dart)	200*

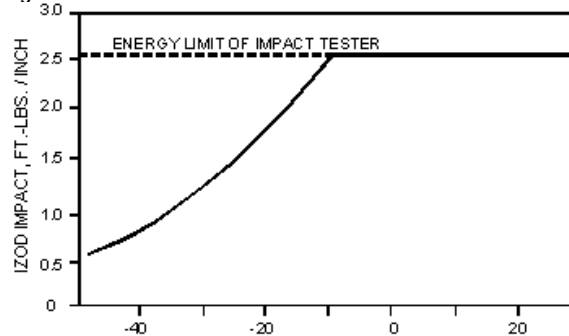
*The normally used units for dropped dart impact are converted for comparison.

This is another confirmation of the need to avoid sharp notches in the design of finished plastic parts.

Dropped dart impact test temperature affects the impact toughness of rigid vinyl as shown in Figure 14. However, at higher temperatures such as room temperature, the test is non-discriminatory because most materials reach the limit of test energy available in the test apparatus. Therefore, rigid vinyl compounds should be tested at -20°F (-29°C) or lower, so that parts and materials can be discriminated according to toughness.

ASTM D4226 Method B (the energy for brittle failure) is the method that best correlates to actual toughness.

Figure 14



Dropped dart impact toughness of Geon 87241 as a function of test temperature. ASTM D4226, method B, C.125 dart.

When rigid vinyl compounds are dropped and tested at -20°F (-29°C), the resin molecular weight, the impact modifier level and efficiency, each affect the impact toughness as shown in Figure 15. The pattern illustrated by the dropped dart test is very similar to the pattern shown by the ductile/brittle transition in the Izod test. Both higher molecular weight and higher impact modifier levels increase the dropped dart toughness of resulting compounds and parts. However, in some compounds there is a shift in impact modifier efficiency because the impact modifier behaves differently in efficiency for crack propagation than for crack initiation. For example, Geon® 87439 behaves in a manner similar to ABS materials, both having lower dropped dart impact than typical impact modified rigid vinyl compounds. This is indicated by lower impact modifier efficiency in dropped dart testing than Izod testing.

Because the dropped dart impact results do not have a discontinuity in the curve, as Izod results do, it is easier to understand and interpret the dropped dart results. The compound or the finished part is dropped dart impacted from

various heights at -20°F (-29°C) to find the energy for one-half the specimens to fail. Therefore, the dropped dart test can be useful as a material specification and/or for part quality control.

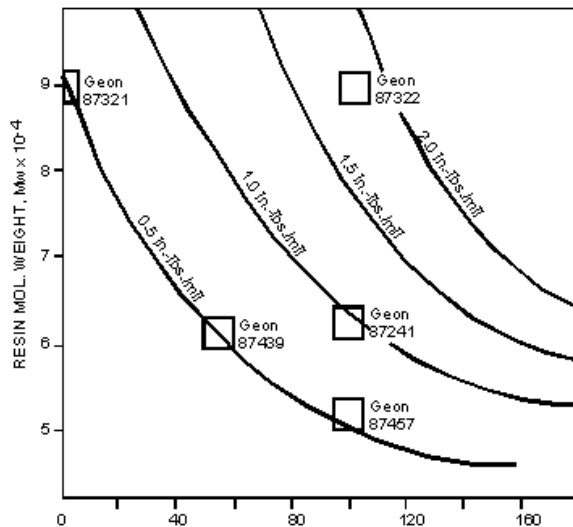
Specifications

The dropped dart impact test is useful for compound and product duct specifications. The following table lists some suggested classifications for specifications and quality control.

Impact Requirements	Specifications
Minimal Impact	1.0 inch-lbs. / mil @ 73°F
Good balance between impact and cost	1.0 inch-lbs. / mil @ -20°F
Excellent toughness	2.0 inch-lbs. / mil @ -20°F
Virtually unbreakable	2.0 inch-lbs. / mil @ -30°F

*ASTM D4226, Method B, C.125 Dart

Figure 15



IMPACT MODIFIER AS A PERCENTAGE EFFICIENCY OF THAT IN GEON 87241, PERCENT

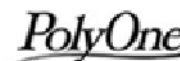
The affect of PVC molecular weight and impact modifier level on the dropped dart impact toughness at -20°F (-29°C) using 1/8 inch specimens, ASTM D4226, method B, and C.125 dart.



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