ENGINEERING DESIGN
A GLOBAL VIEW OF DUPONT POLYMERS

Impact Fatigue–A New Way of Looking at the Durability of Engineering Plastics

By Peter A. Tuschak

The failure of materials by rupture is a continuing concern of design engineers. Rupture, or fracture, can occur as the result of a load larger than the load-bearing capacity of a part, or can be caused by repeated applications of a smaller load. Failure can be caused by excessive static forces or a large impact. A commonly used evaluation of the impact strength of an engineering plastic is the Izod test, which measures the energy required to break a notched test specimen struck transversely by a pendulum.

In many engineering applications, parts are stressed repeatedly at levels lower than the ultimate strength of the material. If a sufficiently high number of stress cycles are applied to a given part at any stress level, the part will fracture as a result of fatigue.

When the applied loads are impacts, a similar situation exists. If the minimum energy required to fracture a part with a single impact can be established, then an impact at a somewhat lower energy level will not cause failure However, a sufficient number of impacts at the lower level will. This phenomenon is defined as impact fatigue and the ability of a material to resist it is an important characteristic that should be considered when materials are selected for engineering applications.

Instrumented Weight Drop

To obtain measurements of impact fatigue on engineering plastics, DuPont scientists developed a repeated impact fatigue test in which an instrumented weight or tip was dropped on a Charpy beam specimen. Results of such tests (photo on left), performed on several specimens of different plastic resins, will be discussed in this article.

Table 1a ranks several plastic materials by their Izod numbers. Not surprisingly, Zytel® ST801 super tough nylon, toughened Delrin® acetal, and polycarbonate resins are at the top of the list. In Table 1b the same materials are listed according to maximum allowable energy per impact to reach 100 repeated impacts without failure. Zytel® 801 ST and toughened Delrin® still lead the pack but, in this ranking, untoughened 66 nylon—Zytel® 101—moves ahead of three of the materials listed.

The results displayed in this table suggest that the traditional ways of looking at impact strength may not always be valid when parts are subjected to large numbers of relatively low energy impacts instead of a single large impact. Figures 1 and 2—comparisons between DuPont Zytel® ST super tough nylon and Delrin® acetal (toughened), plus polycarbonate, ABS, and high impact polystyrene (HIPS) in the

Figure 1. Impact Energy/Volume

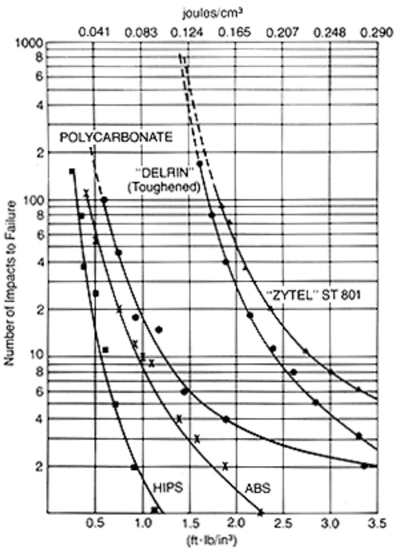
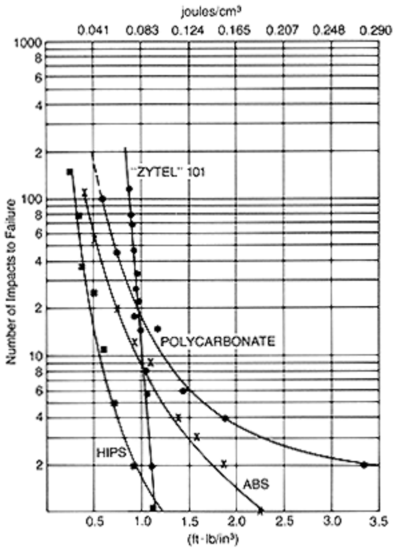
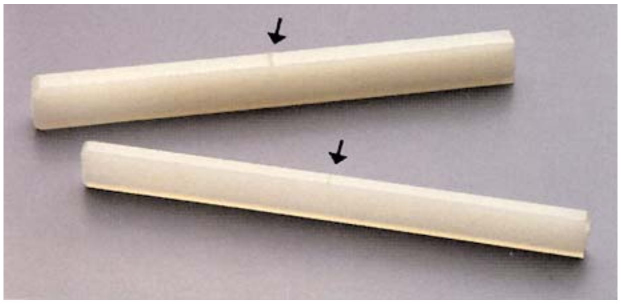


Figure 2. Impact Energy/Volume





The Charpy beam specimens used in the newly-developed impact fatigue test are notched (arrows).

first, and between Zytel® 101 and the same three competitive resins in the second—reinforce that conclusion.

Figure 1 shows the result of repeated impact tests on high impact resistant plastics at impact energy levels below the single impact failure level. In these curves, impact energy per unit volume of the sample is plotted versus the number of impacts to failure. Representing impact results on the basis of volume or as an energy density allows one to predict the approximate behavior of an actual part.

Consider a power tool which weighs 3.63 kg (8 lb) and has an injection molded plastic housing. Assume that the housing contains 377 cm^3 (23 in^3) of plastic. What happens if this tool is dropped, say from a height of 1.524 m (5 ft)?

The total impact energy is

U = 35.59 N* x 1.524 m = 54.24 joules
(U = 8 lbs x 5 ft = 40 ft•lbs)
*[3.63 kg (mass) x 9.806 (acceleration rate) = 35.59 newtons (force)]

The energy per unit volume is calculated to be

U = 54.24/377 = 0.144 J/cm^3
(U = 40/23 = 1.74ft•lbs/in^3)

Reading the appropriate number of impacts from Figure 1, the following conclusions are reached:

Tool Housing Material	Impacts Tolerated
ABS	2
Polycarbonate	4.4
Toughened Delrin® acetal	80.0
Zytel® ST 801 nylon	130.0

Of course, this is an oversimplified example—the effects of the part's shape relative to the standard test specimen were neglected. Nevertheless, the trend is clear: Toughened Zytel® and toughened Delrin® would easily be superior performers in this type of application.

A noteworthy fact is that the margin of advantage for Zytel® ST801 and toughened Delrin® in repeated impact is considerably greater than one would deduce from Izod numbers alone.

Zytel® Fatigue Life Superior

Let's turn our attention to Figure 2. On this graph the same curves for HIPS, ABS and polycarbonate shown in Figure 1 were reproduced. A curve for Zytel® 101 nylon resin, obtained by the now familiar repeated impact fatigue test, also was added. The energy density at which a single impact would cause failure is 0.091 J/cm^3 (1.1 ft•lbs/in^3). At this level, HIPS and Zytel® 101 are comparable.

But look at cases where 20 or more impacts might be required. At this fatigue life, both Zytel® 101 and polycarbonate can take 0.079 J/cm^3 (0.96 ft•lbs/in^3) of energy per impact. Clearly, for any fatigue life requiring greater than 20 impacts, Zytel® 101 is superior. Where would this characteristic become important? There are many applications such as gears, cams and other machine components where the parts are exposed to very large numbers of low energy impacts and fatigue life is a very important design criterion.

In this article we take a brief look at impact fatigue of some commonly used engineering plastics. The data presented makes it clear that the Izod test alone does not tell the whole story as far as the toughness and durability of engineering plastics is concerned.

The Izod test reflects the behavior of a material when it is subjected to a large, potentially catastrophic impact. In a large number of applications such an impact rarely occurs; however, a series of lower energy impacts occur regularly. In these applications, toughness and durability are synonymous with fatigue life, or impact fatigue, as described in this article. The repeated impact fatigue test is an appropriate measure of this type of toughness.

As always, there is no substitute for molder/end user testing of actual parts from prototype or production molds. Where low but repeated impact values are involved, tests at or closer to these values may provide a truer prediction of part durability. Preliminary studies indicate that amorphous nylons such as Zytel® 901 ST; toughened copolymers of 66 and 6 nylons, such as Zytel® 72G 33; and toughened compositions of 66 nylon, like Zytel® 408L and Zytel® 3189, could behave similarly under repeated impacts at lower energy values not previously measured.

The net result may be a much wider range of materials to be considered where long term toughness is of major importance.

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Table 1a. Ranking By Izod Value

Resin	J/m	(ft • lb/in)
Zytel® ST 801 (Dry as Molded)	907	(17)
Delrin® (Toughened)	907	(17)
Polycarbonate	854	(16)
ABS	534	(10)
HIPS	373	(7)
Zytel® 101 (Dry as Molded)	53	(1.0)

Table 1b. Maximum Allowable Energy (Per Impact) For 100 Impacts

Resin	joules	(ft • lb)
Zytel® ST 801	1.68	(1.24)
Delrin® (Toughened)	1.41	(1.04)
Zytel® 101	0.8	(0.59)
Polycarbonate	0.5	(0.37)
ABS	0.4	(0.30)
HIPS	0.38	(0.28)