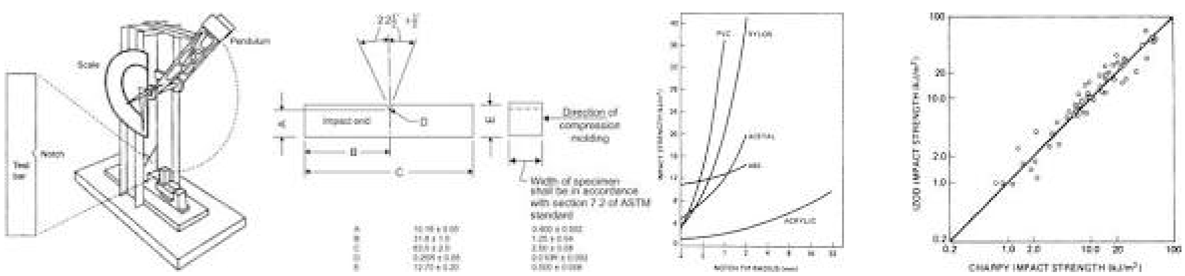
I am writing this wee blurb on impact testing of thermoplastic materials. Impact testing and ductile/brittle transition.

Polymeric materials are sometimes subjected to rapid stress loading or impact loads. The most prevalent test for evaluation impact is “notched Izod”. I was schooled and learned specifically about the Izod test. The Izod test is typically a benchtop test. The test is named for its inventor **Edwin Gilbert Izod.** In this test a small test specimen is clamped in a vise. This specimen has a V-shaped notch in it, facing forward.

ASTM (American Society for Testing and Materials) has a documented method, see ASTM D256. Another method of testing impact was the Charpy.

The following pictorial was cut and pasted from the Internet.



Edwin Gilbert Izod

This Izod test was developed for testing toughness of metals, a metal test.

The Izod pendulum impact toughness test is described in the standard ASTM D256. This method requires a minimum of five and preferably ten or more individual readings to get a good average for the impact resistance of a material. The total impact energy depends on both the size of the test specimen

General Electric (GE), which invented polycarbonate, knew they had a very tough material in polycarbonate. GE used this Izod test to compare their polycarbonate to metal. Notched Izod was a test used in the metal industry. Polycarbonate is a very tough plastic. Tough means it can take a blow or a hit or is impact-resistant. What better way to show case your polycarbonate than to have it compared to metals?

In 1955, GE's Dr. D. Fox applied for a U.S. patent on polycarbonate. The same year Bayer in Germany had also applied for a U.S. patent on a molecule invented by Dr. Hermann Schnell that was virtually identical to Fox's. The two companies entered into an agreement regarding selling polycarbonate.

Certain materials such as polystyrene have poor impact resistance. When plastic use became a reality, they were deemed substandard relative to other materials such as wood, glass and metal due, I believe, to their poor impact performance. Compact disc cases (Do we remember those?) are brittle. They are manufactured from polystyrene. Polycarbonate is used for things like canopies for fighter aircraft. Very high end. The Popemobile has polycarbonate windows, as well, made from high molecular weight polycarbonate or long molecules of polycarbonate. Both these applications are specialty applications.

Since GE (now Sabic) was the industry leader in engineered thermoplastic, every other thermoplastic supplier followed. The notched Izod test became the test that people could relate to or compare their products with. It is my opinion that notched Izod is a poor test for plastic because this test uses a notched specimen.

When we design a plastic part, we design without notches/sharp corners. This is taught in Plastics Design 101. On any given part there may be a change in plane – the addition of a wall on a flat surface, for example. This corner needs to have a generous radii or a fillet. Below are examples of radius and fillet.

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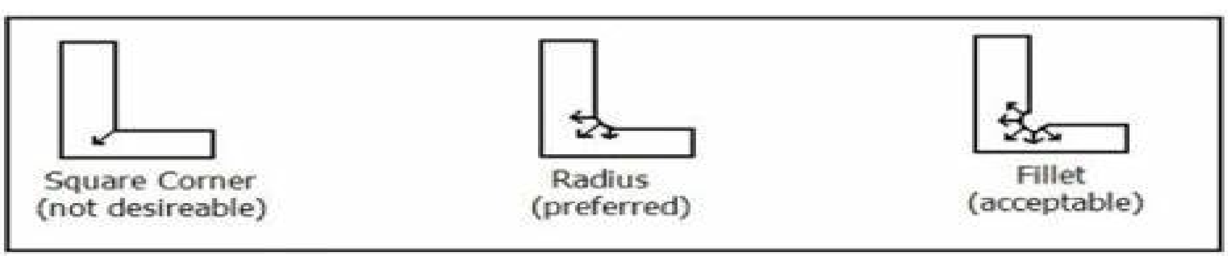

The other aspect of this notched Izod procedure is the notch is put into the test bar, in my opinion rather precariously. There is a procedure to make the notch, however the procedure is subject to interpretation (without explicit details). The process is conducted by human hands. Human hands can vary the cutting. It is my opinion that the cutting of the notch can be inconsistent. The inconsistent notch will create inaccurate results. Lab-to-lab there will be inconsistencies. Is the data sufficient for us to make a comparison or a decision on a particular lot of material or on a material selection? I reiterate that notches and sharp corners are not part of a plastic part design. Semi-crystalline thermoplastics acetal (AKA polyoxymethylene acetal) is an example of a semi-crystalline thermoplastic. Semi-crystalline thermoplastics are more susceptible to poor impact performance relative to amorphous thermoplastics such as ABS (AKA acrylonitrile butadiene styrene).

The Charpy impact test was developed by S.B. Russell and Georges Charpy at the turn of the 20th century. It remains to this day one of the most popular impact testing methods due to the relative ease of creating samples and obtaining results. The test apparatus consists of a weighted pendulum, which is dropped from a specified height to contact the specimen. The energy transferred to the material can be inferred by comparing the difference in the height of the pendulum before and after the fracture.

Both Charpy and Izod impact testing are popular methods of determining impact strength, or toughness, of a material. In other words, these tests measure the total amount of energy that a material can absorb. This energy absorption is directly related to the brittleness of the material. Brittle materials, such as ceramics or glass, tend to have lower impact energy absorption rates than ductile materials like copper or aluminum.

Understanding a material's energy absorption properties is critical, as it predicts how much plastic deformation the material will be able to withstand before catastrophic failure. It is also important to understand the similarities and differences between these two common impact test methods.

Charpy Impact testing

A Charpy test specimen, which is placed horizontally into the machine, is typically a 55 x 10 x 10 mm (2.165" x 0.394" x 0.394") bar with a notch machined into one of the faces. This notch, which can be either V-shaped or U-shaped, is placed facing away from the pendulum and helps to concentrate the stress and encourage fracture. Testing can be performed at both ambient and reduced temperatures, sometimes as low as -425^{o} F.

Charpy impact testing is mostly performed to ASTM E23, ASTM A370, ISO 148, or EN 10045-1. While the test is mostly performed on metals, there are also several standards that exist for plastics and polymers, including ASTM D6110 and ISO 179.

Izod Impact testing

The Izod impact test method was first described by Edwin Izod in 1903. The test apparatus and specimen design are very similar to Charpy impact, with some notable differences, including the orientation of the specimen, which is clamped into the apparatus vertically with the notch facing toward the pendulum. The pendulum then impacts the sample at a specified area above the notch.

Izod impact testing can be performed on either plastic or metallic specimens. Plastic samples are typically a 64 x 12.7 x 3.2 mm bar with a machined V-shaped notch. Metallic samples are typically round 127 x 11.43 mm bar with 1 or 3 machined V-shaped notch(es).

Common Izod impact test methods include ASTM D256, ASTM E23, and ISO 180.

Notched Izod impact is a single point test that measures a materials resistance to impact from a swinging pendulum. Izod impact is defined as the kinetic energy needed to initiate fracture and continue the crack or propagate the crack.

While both the Izod and Charpy methods measure similar properties, the specimen design and testing configuration are different enough that care should be taken when choosing with method to perform.

The pendulum impact test involves the measurement of the energy required to break a test specimen that is clamped at the ends and then struck in the centre by a pendulum weight. The energy required to break the specimen is obtained from the loss in energy of the pendulum. This energy is simply the difference in potential energy of the hammer before and after the impact, such as:

$$E_{frac} = m\,g\,(h_S - h_E)$$

where m is the mass of the hammer, h is its height, and g is the gravitational acceleration ($9.81 m/s^2$). The values are reported in terms of absorbed energy per unit of thickness at the notch (such as J/m or ft·lb/in). Alternatively, the results may be reported as absorbed energy per unit cross-sectional area at the notch (J/m^2 or $ft{\cdot}lb/in^2$).

Should you decide to perform Izod impact, you will need to decide which specimen configuration to use. There are varying configurations of round specimens versus square specimens and single-notched specimens versus those with up to three notches. Since it is often required to average three results for impact testing, the three-notch specimen could be more economical, as it will take less material to get three impact results. Another possible advantage of the three-notch sample is that the result can be an average of directions depending on the specimen configuration. This could help eliminate bias caused by directional properties if this is a concern for your material. You cannot mathematically compare notched Izod results with Charpy results.

In summary the three main differences between Charpy and Izod are charted below.

Material	Metal	Plastic & Metal
Type of notch	U and V	V
Position of Specimen	Horizontal, notch facing away from pendulum	Vertically, notch facing toward pendulum
Striking point	Middle of sample	Upper tip of sample
Specimen dimension	55 X 10 X 10 mm	64 X 12.7 X 3.2 MM (plastic), 127 X 11.43 mm round bar (metal)
Specification	ASTM E23, ISO 148, EN 10045-1	ASTM D25 ASTN E23 Iso 180

How does one compare J/m and J/m^2 or ftlbs./in. to ftlbs./in ^{2} or ftlbs./in to J/m^2 ? The answer is you cannot compare J/m to ftlb/in.^{2}. You cannot mathematically compare ftlbs./in to J/m^2 . The mathematics do not work to try and convert.

What is a foot pound anyway? A pound-foot (lbf·ft) is a unit of torque representing one pound of force acting at a perpendicular distance of one foot from a pivot point. My research on foot pounds and pound feet was nonconclusive. Some report foot pounds as equal to pound feet, but they are not the same. A foot pound is a unit of energy, not to be confused with the pound foot, which is a measure of **torque**. The foot pound is **a measure of a pound of force applied over one foot**. WHAT???? I suggest if you are interested in this you conduct your own research.

Pounds per square foot, or psf, and pounds per square inch, or psi, are measurements of pressure still used in the U.S. but largely abandoned elsewhere in the world. **One pound per square inch is equal to one pound-force exerted over 1 square inch of area.**

We went sometime in the 1970s from the English method of measuring things to the SI method of measuring. The International System of **Units** (**SI**), commonly known as the metric system, is the international standard for measurement. I believe PoP Inc. published an article on the international system of measurements quite some time ago. The plastics industry reports impact results in joules/meter and joules /m^2. What is a joule? Once upon the beginning of the 17th century, there lived a fellow named Isaac Newton. Dr. Newton had, I believe, the position of Lucasian Professor of Mathematics at Cambridge University in England, the most prestigious academic post in the world.

A joule, a derived **unit of work or energy** in SI, is equal to the work done by a force of one newton acting through one metre. Force is equal to Mass X acceleration. Gravity exhibits an acceleration on a falling object 9.8 meter/sec^2 . It is defined as that force necessary to provide a mass of one kilogram an acceleration of one meter per second per second. One newton is equal to a force of. 1 kg·m/s^2. A joule is named in honour of the English physicist James Prescott Joule.

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The dimensions of an ASTM D256 Standard specimen are 63.5 × 12.7 × 3.2 mm (2.5 × 0.5 × 0.125 in).

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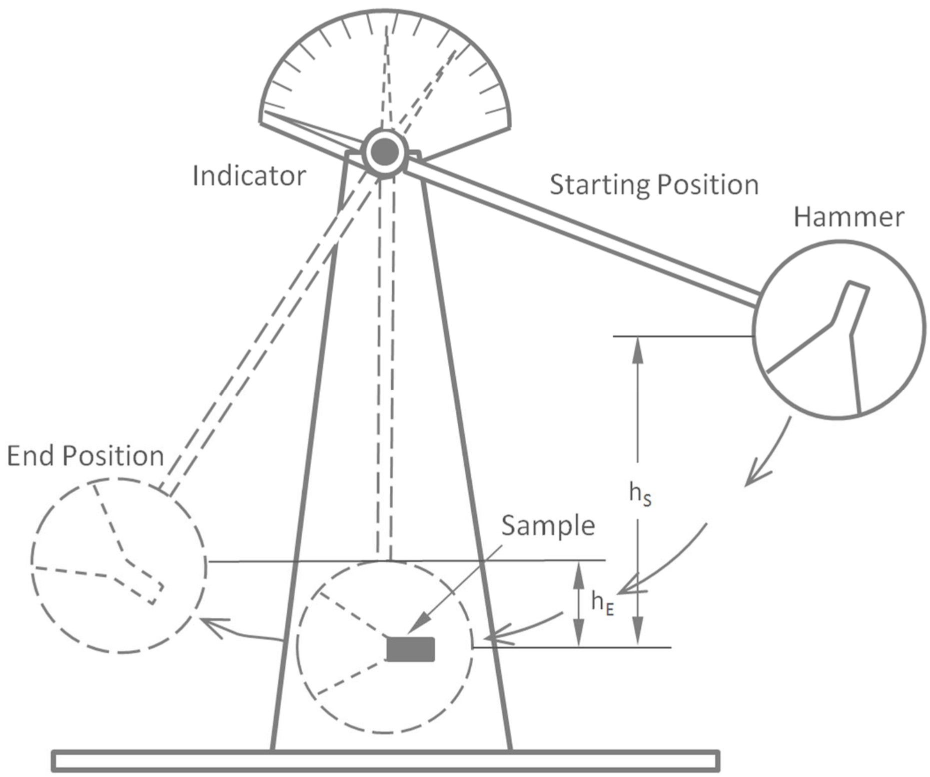
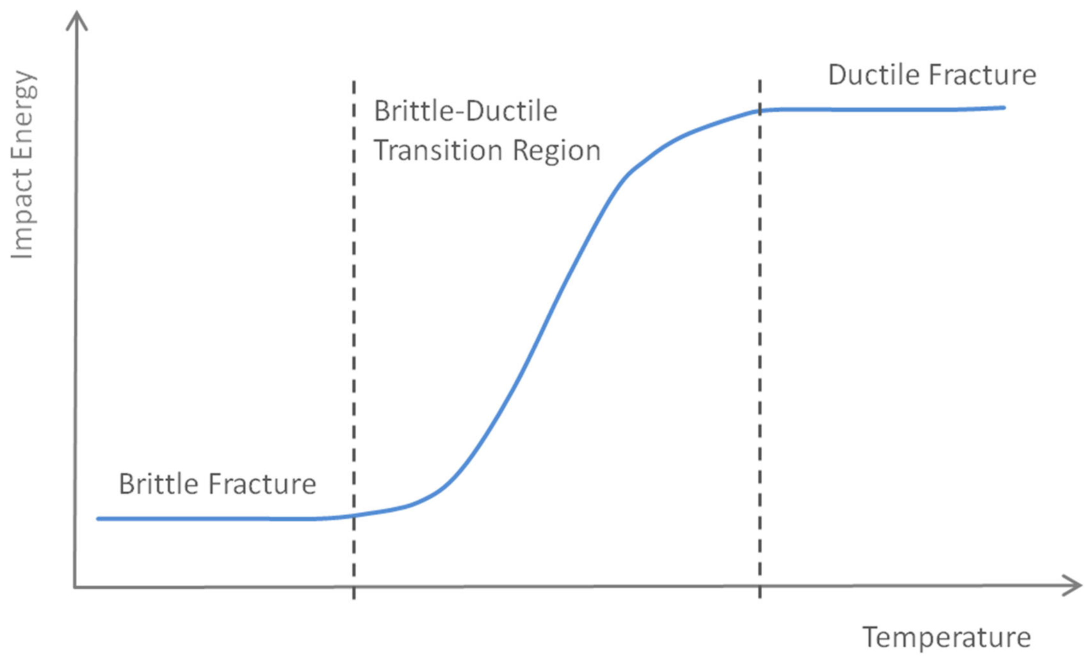


The energy absorbed in fracture has two components. These are the work of plastic deformation due to the formation of a plastic zone around the notch tip and the work required to create the fracture surfaces, which is equal to the cohesive energy that must be overcome to separate the atoms and molecules on both sides of the crack path. The energy of a ductile fracture is much larger than the energy of a brittle fracture because ductile materials undergo strong plastic deformation before and during fracture, which absorbs much more impact energy than the breaking of physical and chemical bonds (fracture surface energy).

All materials undergo a transition from ductile behavior at higher temperatures to brittle behavior at lower temperatures. At higher temperatures, the impact energy is comparatively large since the fracture is ductile. But as the temperature is lowered, the impact energy sharply decreases over a narrow temperature interval as the fracture becomes more brittle. The brittle-ductile transition can also be observed from the fracture surfaces; a ductile fracture sample has fibrous or dull surfaces whereas a brittle sample has granular and shiny fracture surfaces.



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The impact resistance (toughness) of a polymer depends on both intrinsic (belonging naturally) and extrinsic (external) factors. Important intrinsic factors are molecular structure, molecular weight (distribution), cohesive energy, and morphology (crystallinity and crystal structure), to name only a few factors. Important extrinsic factors are temperature, impact speed, shape and weight of the striker, specimen geometry, and notch size and shape.

A high molecular weight (long molecules) and narrow molecular weight distribution (the molecules are statistically close in length to one another) improves impact resistance, whereas increased crystallinity and voids lowers impact resistance.

Moons ago I was called to a customer, running glass reinforced nylon. Sawing the parts open we observed tiny voids. Further investigation yielded that the material was being processed wet. The voids or bubbles were caused by steam. The thermoplastic did not seem to be affected by the steam, however the bubbles produced notches. The parts were tested, and they had consistent breakage at the bubbles. The bubbles acted as starting points for a crack. The bubbles allowed a crack to happen.

Other more sophisticated tests include measurement of the area under the stress–strain curve in a high-speed (rapid) tensile or impact stress test.

Although polyamides (AKA nylons) exhibit good impact strength in most respects, they are quite susceptible to crack propagation, because of which their notched impact strength can be rather poor. Because of such susceptibility, products constituted of nylon are subject to brittle failure under service conditions, whereas a product containing incipient cracks is subjected to moderate or heavy impacts. It is my opinion that nylon should not be subjected to notched Izod testing. Another more specific test should be developed for nylon. I am the nylon guy 😊.

Extensive research has been conducted for the purpose of developing polyamide resin melt blends of improved impact strength, and especially of improved resistance under notched impact test conditions such as those utilized in the notched Izod impact test, ASTM D-256. Thus, for example, Epstein U.S. Pat. No. **4,174,358** discloses multiphase thermoplastic compositions in which various branched and straight chain polymers having a particle size in a range of 0.01 to 1.0 microns are dispersed in a polyamide matrix resin, and wherein the ratio of the tensile modulus of the polyamide matrix resin to the tensile modulus of the dispersed polymer is greater than 10 to 1. Although Epstein discloses a great variety of resin blends, the performance of those blends under notched Izod impact test conditions varies widely and, in some instances, the elongation is relatively low. Great variation in tensile modulus is also exhibited by the numerous individual blends disclosed by Epstein.

I will add some information on ISO testing as well. We need to compare test results tween ASTM and ISO.