Charpy and Izod Experiment

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Abstract

Charpy and Izod experiments are one of the most basic structural experiments that is usually constituted to find the energy absorbtion of a material that contains a flaw, e.g., a notch. In spite of the fact that it is one of the key concepts of structural engineering, hardly any scientific experimentation has been done probably due to the test forming the basis of the science branch. This paper serves as a starting point for undergraduate students who wants to see the experimentational outcome of the theoretical findings that they have seen over the course of their curriculum accompanied by computational analyzes, if necessary. Among others, the algorithm used in this projects portrays a rather fascinating structure which composes a harmony alongside with this prerequisite of material sciences.

Charpy and Izod Experiment

Charpy and Izod are two experiments that are especially commonly used in the United States of America. Earlier conventions of this experiment are produced by S. B. Russel in the late 1980s. The idea behind the experiments was to find the residual fracture energy by means of pendulum motion, however the earlier foundations proves that the initial purpose of the tests are merely consists of experimentation of un-notched specimens. This was considered to be the main purpose and process of the experiments until 1897. In 1897, Frémont provided an alternative to the test by means of a spring-loaded machinery which failed to be adapted to. In spite of the previous inventions Georges Charpy truly, in a sense, revolutionized the experiments by introducing his own theory on the subject matter. In the early 1990s, George has done experiments that undergone a standardized method which not only redesigned the first pendulum design that is done by S. B. Russell but provided precise analysis of notched samples.

Charpy and Izod tests responds to a wide selection of materials. This materials consists of various material classes such as metals, polymers and composites. As these experiments are one of the backbones of structural experiments it would be meaningless to provide any alternative titles to this experiments, however different usage areas of the experiments would picturize a common theme that is considered among the experiments. One such field is aerospace industry. Another experimentation that would go similar to Charpy and Izod tests would improve the learning curve. One such experiment is strain hardening experimentation that provides certain design parameters such as yield strength, tensile strength, ductility, resilience, and toughness. Many students who study under a curriculum which most likely includes Charpy or Izod experiments, preferably both, would benefit from the multiple experimentation that would be used in their assignments throughout their career as it is widely used in many industries, e.g., aerospace industry, maritime industry and et cetera. One should get a grip of different experimentation and measurement techniques that are usually accompanied by Charpy and Izod tests such as image processing and scanning electron microscope because these methods are a common theme in the aerospace industry (Demirci, Tarakçıoğlu, Avcı, & Erkendirci, 2014).

Charpy and Izod tests are done for material specimens that includes a notch in their designs as in any kind of fracture tests. The material specimen should preferably consist of a rectangular cross section area The apparatus for making Charpy and Izod tests are presented in Figure 1. Pendulum motion releases a load that is gained from the pendulum motion of a material that is at the end the of pendulum stick. Firstly, the pendulum is released from a stationary position that is above the specimen that one wants to experiment on. The height is measured and the stationary hammer is released. The hammer is expected to complete a successful pendulum motion followed by the fracture of the test specimen. The orientation of the specimen is important to find the minimum required energy of a material to break. This concludes the maximum load capacity of the material specimen due to the fact that the minimum energy that causes the material to break refers to the real-life working principals of itself as it is only capable of holding or withstanding load that is determined from Charpy and Izod experiments. The fracture is followed by a continuos motion of the pendulum. Pendulum will start to rise again but only to a certain degree because the fracture absorbed the energy that is gathered from the gravitational acceleration of the pendulum motion. The new height, i.e., the maximum -and therefore the first- height the hammer reaches after fracture, is measured to be worked on later. Newly acquired height will be lower than the initial height as it is impossible for the hammer to reach to its initial position because of the energy lost from both friction and the fracture. For low frictions, e.g., that are caused by air, machine, can be easily ignored if the design tolerances allows to. Nevertheless one should not be so eager to ignore friction altogether. Small differences in the design can pummel up to a major flaw in the technical considerations. Hence frictions and other technical difficulties should be maintained at a certain tolerance level. Further information of the machine should be sought if it is not designed by the workplace that an engineer is working on or simply the design elements are unreachable at the moment in any way. To put it simply, the potential energy difference, excluding friction and other external forces, portrays the absorption energy. This statement concludes the Charpy and Izod test. It is important to mentioned essential concepts that one would come across during the experiments test-material's physical size and shape along with notch specifications are an important section of the experiments that would affect the result heavily.

One of the prime objectives of Charpy and Izod tests are to determine the ductile-to-brittle transition temperature. This transition is an essential concept in design since the temperature affects the working principle of a product. One might assume that the material that an aircraft's body is made of would react differently to forces when it is on cruise-flight. At elevated altitudes temperature is significantly decreased. The decrease in temperature weakens the aircraft's body's quality. The aircraft is expected to react as brittle to various forces impacted by wind and other animalia. Different atomic structures will result in a different fracture characteristic. The attributes of a materials resides in its chemical state. Other than the absorbed energy, various electron microscopes -even macroscopic view- would bring about the fracture characteristics, i.e., ductile or brittle, for the broken material. This serves as a relatable statement for the ductile-to-brittle transition temperature. Fracture characteristics of an object serves as an estimated temperature point for the transition temperature. Nevertheless, there is no definitive way to establish a certain value for the ductile-to-brittle transition temperature. Even experiments such as Charpy and Izod impact tests refers to a boundary value for the transition temperature. Nonetheless, one might accept the transition temperature where the material's surface shows completely fibrous characteristics. Figure 2 represents typical metallic material behavior for ductile-to-brittle transition. As can be seen, low strength FCC and HCP metals accompanied by high-strength materials show little to no change compared to low strength BCC metals. Therefore, it is safe to say that Charpy and Izod impact tests are a crucial experiment for the design of low strength BCC metals. Another important concept called slip plane and slip direction should be introduced at this section. Slip planes are the most densely packed plane in the cubic structure and slip directions are the closed-packed directions that deformation tend to happen. These two concepts form a slip system when they are combined together. BCC metal's traits are expected to be brittle. This is due to the quantity of the slip systems. HCP contains 3 unique slip systems while the necessary amount of slip systems that are independent from each other for plastic deformation to take place in a polycrystalline material is at least 5. This slip system limit for the plastic deformation to take place is a concept that is taken from Von Mises' deformation criteria. This makes HCP materials brittle as can be seen from Figure 2. Aside from hexagonal closed packed structures, face centered cubic metals contain 12 slip systems and their edge and screw dislocations are relatively athermal. This results in a ductile characteristic. Although body centered cubic metals have 48 slip systems within itself, its edge and screw dislocations are not athermal. In a simpler manner, it is safe to assume that these dislocations tend to interfere with each other and obstruct the dislocation motion. Therefore BCC and HCP metals are expected to be brittle while FCC metals tend to be ductile. In addition to this, Charpy and Izod tests determines an essential concept in Figure 2. The ductile-to-brittle transition temperature changes a significant amount of properties in BCC materials. Without taking this design parameter into consideration, one might expect a failure of a product that is greatly influenced by temperature changes. Moreover, both semicrystalline and amorphous polymers' fractures are brittle at low temperatures, and both have relatively low impact strengths. However, they experience a ductile-to-brittle transition over a relatively narrow temperature range.

Theoretical Background

The calculations will be made in this section represents the notations that are used in Figure 1.

$$E_{h'} = E_h - E_i - E_f$$

where E_f represents the energy that has been lost from friction and E_i denotes the impact energy. This equation can be simplified as follows:

$$E_{\text{absorbed}} = E_h - E_{h'} = mgl(1 - \cos\alpha) - mgl(1 - \cos\beta) = mgl(\cos\beta - \cos\alpha) \tag{1}$$

where l is the length of the extension of the pendulum, i.e., from the hammer to the center of rotation and α and β are respectively the angles that initial and final state of the oscillation makes. When the hammer reaches at the bottom energy conservation brings about

$$\frac{1}{2}mV^2 = mgh \tag{2}$$

$$V = \sqrt{2gh} \tag{3}$$

Method

Equipment

Charpy-Izod experiment structure consists of a pendulum, impact area accompanied by emergency brakes and other safety considerations. Since Charpy and Izod experiment devices are large, complicated devices to design; they will not be discussed as they are beyond the scope of this paper. Anyhow, testing specimen properties are displayed in Table 1.

Design

First of all, the alignment of the specimen has been constituted as in Figure 1 while taking into consideration of different tests. For each test the specimen should be aligned according to the instructions in Figure 1. This is followed by the installation of the hammer. Hammer would vary in shape and mass and should be handled carefully since they are heavy. If not handled carefully, the hammer can arise dangerous situations that would end up in lethal cases. This procedure is followed by the calibration and other tasks that might be necessary for one's own test device. Charpy Test's hammer's initial angle is set to 124.4° and Izod Test's hammer is set to 160°

Procedure

When the equipment is decided and the design is created, the experiment can begin. Before starting the experiments, two different swings is necessary to determine the frictional energy that is going to be absorbed during the experiment. After conducting the first step, the experiment can begin. The pendulum is released and the pendulum starts swinging. The maximum height the first swing will reach after the impact should be measured either by a machine or by inspection directly. Although, macroscopic visuals should not be relied on for safety measures and the accuracy of the technical calculations.

Results

The experiment is resulted in a friction energy of 0.016 J and 0.026 J and a impact energy of 0.285 J and 0.29 J respectively for Charpy Test and Izod Test. Net breaking energy is the subtraction of friction forces from the total energy. Therefore net breaking energies are 0.269 J and 0.264 J for Charpy and Izod respectively. Impact resistances are found by dividing the impact energy by the width of the specimen and evaluated as follows: 694.4444 $\mathrm{J\,m^{-1}}$ for Charpy test and 753.4247 $\mathrm{J\,m^{-1}}$ for Izod test. The speed that hammer reaches at the bottom section for the two cases are determined from Equation 2 as 3.2808 $\mathrm{m\,s^{-1}}$ and 3.6155 $\mathrm{m\,s^{-1}}$ for Charpy and Izod respectively. Rise angle can be achieved via Equation 1. The rise angles are 146.82° and 119.7° for Charpy and Izod respectively. For the ease of inspection, the values are tabulated at Table 2. Final height is

$$h' = l(1 - \cos\beta)$$

Using this formula, one can easily achieve the final heights. The final heights for this tests are 404.1337 mm and 583.2568 mm for Charpy and Izod respectively.

References

Callister, W. D., & Rethwisch, D. G. (2013). *Fundamentals of materials science and engineering* (9th ed.). John Wiley & Sons.

Demirci, M. T., Tarakçıoğlu, N., Avcı, A., & Erkendirci, Ö. F. (2014). Fracture toughness of filament wound bfr and gfr arc shaped specimens with charpy impact test method. *Composites Part B: Engineering*, *66*, 7–14. doi:https://doi.org/10.1016/j.compositesb.2014.04.015

Table 1

Charpy and Izod testing equipment

	Properties of Charpy Test	Properties of Izod Test
Mass	1.286	1.092
w	7.2	7.3
l	220	390
E	5	5.5
α	160	124.4

Note. w denotes the width of the specimen; l represents the length of the pendulum, i.e., the distance between the center of rotation and the hammer; α represents the hammer's initial angle and E denotes the impact energy. The specimen properties are presented in the table. All mass units are in kilograms, energy units are in joules and length units are in millimeters.

Table 2

Charpy and Izod Test results

	Results of Charpy Test	Results of Izod Test
Friction energy	0.016	0.026
Net breaking energy	0.269	0.264
Impact resistance	694.4444	753.4247
Impact speed	3.2808	3.6155
Rise angle	146.82	119.7
h’	404.1337	583.2568

Note. This table shows the results of the experiment. Details and units can be found at the Results section.

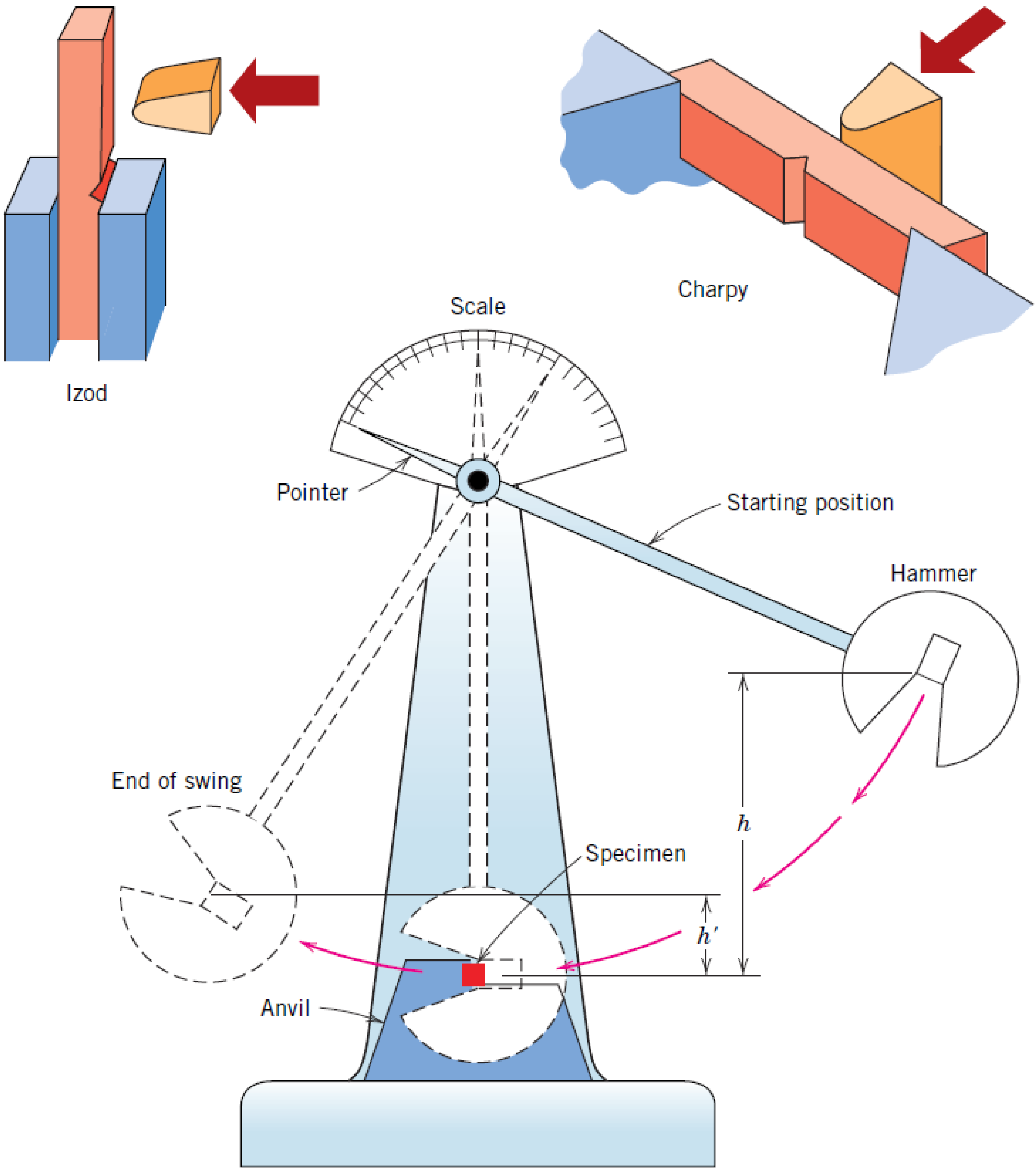

Figure 1. Figures above represents a typical Charpy and Izod experiment. The arrows indicate the impact path for Charpy and Izod tests. Adapted from Callister and Rethwisch, 2013, p. 267.

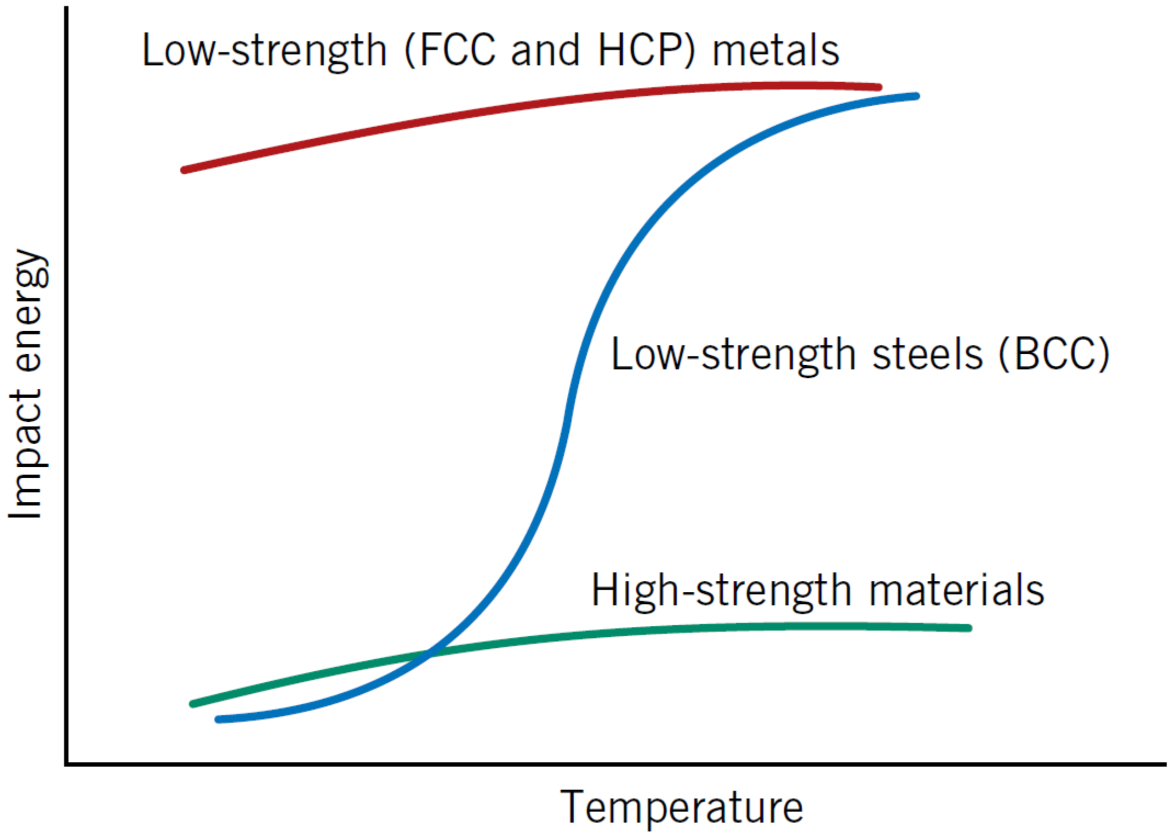

Figure 2. Ductile-to-brittle transition temperatures for various types of metals.

Adapted from Callister and Rethwisch, 2013, p. 269.