AC 2008-1447: UNDERGRADUATE MATERIALS RESEARCH: TENSILE IMPACT TOUGHNESS OF POLYMERS

Mir Atiqullah, Southern Polytechnic State University

Dr. Mir Atiqullah is an Associate Professor in the department of Mechanical Engineering Technology at Southern Polytechnic State University, Marietta, GA. He received his Ph.D. in mechanical engineering from Purdue University, West lafayette, Indiana in 1996. He has been teaching engineering and engineering technology since 1996 and has interest in design, materials, manufacturing, mechanics, optimmzation, biosensor, among others. He is a regular participant in ASEE conferences and active member of various divisions.

Undergraduate Materials Research: Tensile Impact Toughness of Polymers

Abstract

Materials science and engineering knowledge is vital for a solid foundation in mechanical engineering. However, often students lose interest in this subject under the pressure of other mainstream subjects such as mechanics, design, manufacturing etc. Strong foundation in materials leads to improved student interest and success in follow up courses such as design. A group of 4 senior machine design students was assigned to design and build a prototype of a bench top portable impact tester for polymers. The tester was designed to use standard ASTM D1822[1] procedure and specimens. The readout of the impact fracture energy is intentionally designed to require the user to do some fundamental calculations, thereby refreshing some physics of work, energy and velocity. Various polymeric materials are tested at various strain rates in a Universal Testing Machine and the impact tester. With the limited set of data acquired so far correlation was observed between strain rate and the fracture energy. It is expected that continued experimentation will provide clear correlations for various polymers. Two aspects of materials education is emphasized in this endeavor. First the engineering design and second the materials research. Both have been achieved to reasonable extents. Furthermore the interest developed among students has been an added benefit. This paper provides a detail account of the background, the design, application outline and the results of the research. The tester has been included in the materials laboratory syllabus for current semester. As many as 5 sections of 12 students can use the tester per semester. Usage of the tester is described in a format suitable for use in a materials laboratory. Extended set of experimentation and collection of student feedback are planned.

Key Words

Materials research
Impact test
Strain rate
Strain hardening
Ductile-to-brittle transition
Glass transition temperature

Introduction

Polymers are as common these days as steel was during the industrial revolution. More and more industrial, commercial and domestic products are manufactured from plastics. Thus it is of vital importance that students understand the structure, mechanical properties as well as failure modes of plastics in general. Most materials tensile properties vary with temperature, higher values drive the strength down and ductility up. At certain lower temperature (range) many otherwise ductile materials, including metals and polymers, behave more like brittle materials. And thus their responses to loads also change. For metals this temperature range is known as ductile-to-brittle temperature (range). Similar characteristic of polymers is known as glass transition temperature. Generally this transition happens within a bounding temperature range. While standard tensile test as well as izod test on polymers are very useful and fundamental to materials testing, polymers behave in a unique fashion when pulled suddenly with an impact load, which mimics high strain rate. Impact testing explores an object's reaction to high deformation rate or strain. An impact test is intended for determining the energy absorbed in fracturing a test piece at high velocity/strain rate. There are 2 standard bending impact tests; Charpy and Izod. Figure 1 shows standard specimens for these tests. Figure 2 shows the level of energy absorbed by specimens of a particular material tested at different temperatures.

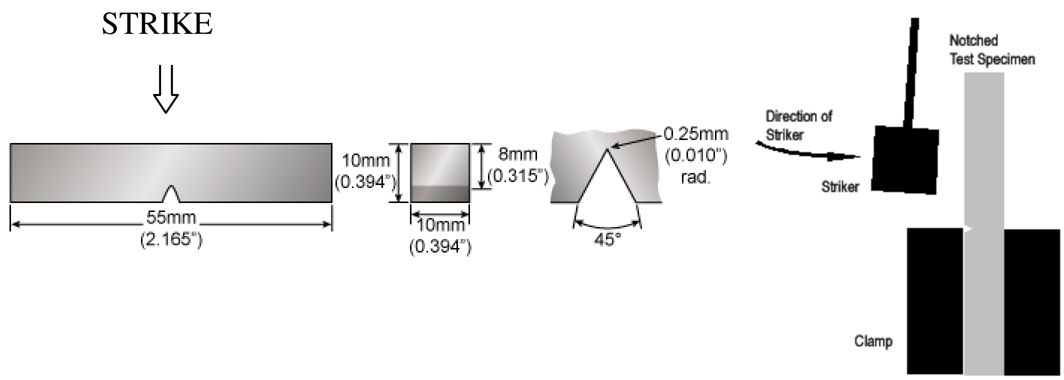


Figure 1: Standard (a) charpy and (b) izod specimen. Izod specimen has the same notch geometry, only tested vertically.

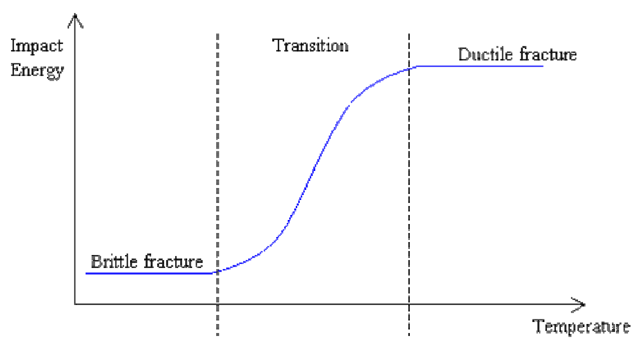
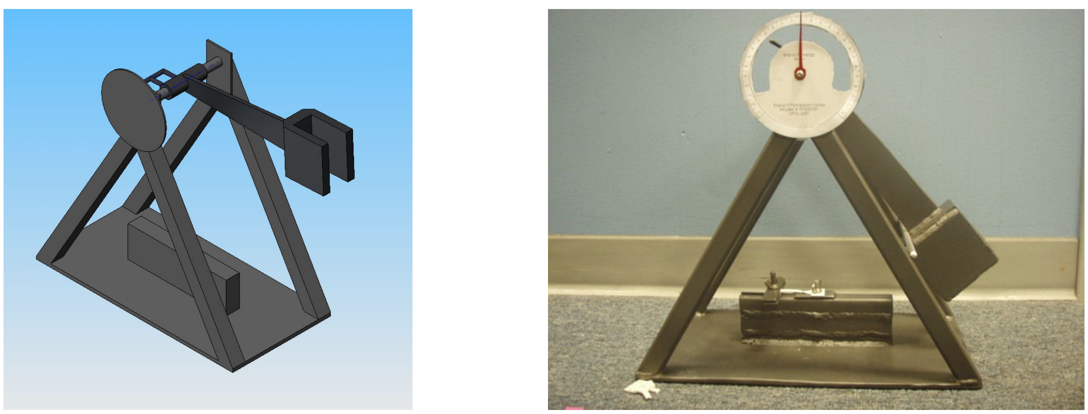


Figure 2: Idealized ductile-to-brittle transition (metals) or glass transition (polymers) as temperature decreases.

The outputs of the test are the energy that is absorbed by the specimen during the deformation and fracture. The higher the energy the higher is the impact toughness of the material. The results are not absolute but rather comparative. Thus toughness measured by one method, such as, tensile impact, can only be compared with results from same test using standard specimens. The ASTM D1822[1] sets the standard for tensile impact testing. It specifies the measurement of energy needed per unit cross section area to fracture or break a specimen under tensile impact. This test is prescribed for materials that are too flexible or too thin for standard Izod impact test (ASTM D256[2]) or standard tensile test (ASTM D638[3]). Strain rate in the former method is very high and in the latter very low. ASTM D1822[1] tests utilize strain rate in between these two but closer to that of ASTM D256[2]. The bench top tester would use the familiar halter shaped specimens and a swing pendulum mechanism to perform the tests. The dimensions of these specimens would be uniform for our tests, but no attempts were made to follow exactly the ASTM standard sizes. The success of the current design and prototype would clear the way for a redesign for a standard size tester using standard size specimens. Nevertheless, materials laboratory students could use the bench top version and uniform sized specimens without losing the essence of the impact characteristics of polymeric materials, the goal of the exercise.

The final design of the tester and the prototype are shown in figure 3. Figure 3(b) also shows a white specimen clamped to the base. Various thin polymer consumer products were the source of specimen materials. Specimens were cut from plastic milk jugs, chemical containers etc. as long as a flat specimen could be cut out from the container. This resulted in various thicknesses of the specimens which prompted the need for accurate measurement of cross sectional area. Then energy absorbed during the test was divided by the cross sectional area to achieve the uniform unit of the toughness measured. It recommended that thin sheet polymer be acquired for cutting out specimens to maintain uniformity of material and geometry. One end of the specimen was clamped to the base of the tester and the other end was attached to a strike plate which would be struck by the swinging pendulum. The pictures of the strike plate with a specimen and a fractured specimen are shown in figure 4.



(a) (b)

Figure 3: (a) The tester CAD model and (b) prototype.

Figure 4: (a) Strike plates with a specimen (b) fractured specimen

The scale on the tester, shown in figure 5, has been designed so that the user needs to note the release angle used and the angle to which the pendulum will swing after striking the specimen. Then the energy absorbed can be calculated from the charts relating the angle to the energy. Various considerations such as volume and center of gravity of pendulum, material density, mass of the strike plate etc. are included in the data energy charts.

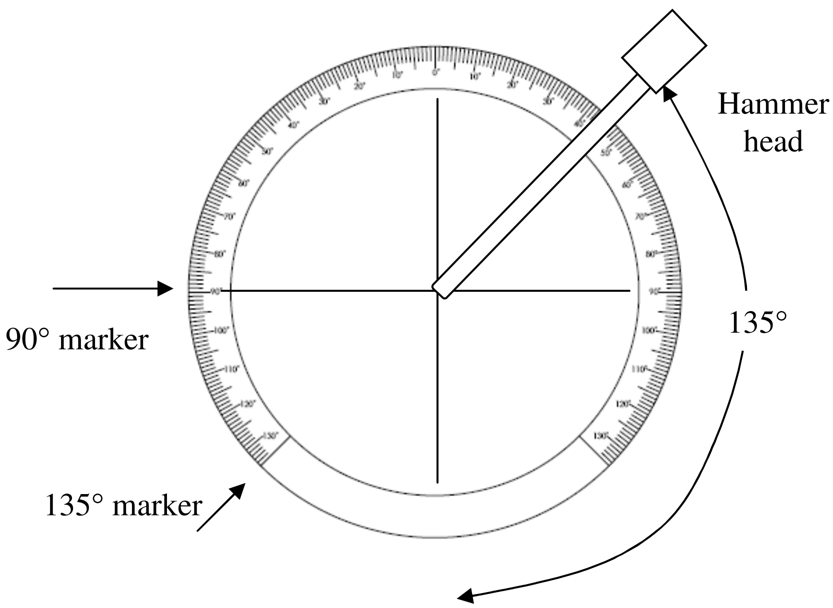


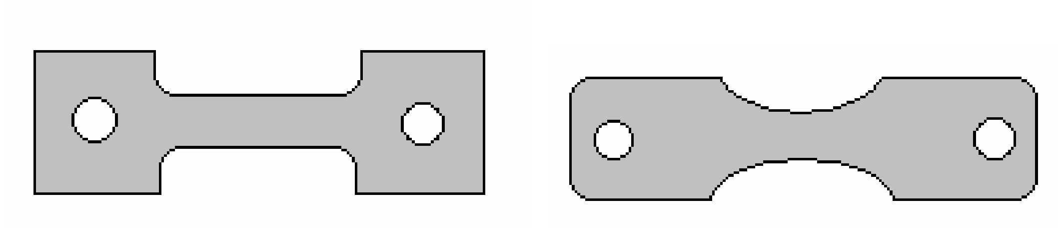
Figure 5: Pendulum swing scale 0 - ±135 degrees. Two different pendulum release positions (135° and 90°) are shown. Energy is a nonlinear function of the angle. (not to scale)

Procedure

The strike plates (a pair) is clamped to the specimen using the wing nut and screw as shown in figure 4(a). The pendulum is held securely away from the central region by a solid bar across the frame. Then the specimen/plate subassembly is attached to the base of the tester using another wing nut making sure the specimen is aligned with the swing path of the pendulum and the strike plates are perpendicular. Now the pendulum is raised to the desired angle (e.g. 135 deg.) and released. Caution must be exercised to avoid injury by the high velocity heavy pendulum. The specimen is broken and thrown forward with the swinging pendulum. The swing angle after striking is noted from the tester scale as indicated by the needle arm. The data is entered into the data table shown in table 1. The specimen pieces are put together at the fractured location and measured for elongation and reduction in area as measure of ductility. The net energy absorbed is calculated by subtracting energy left over from the starting energy of the pendulum. The test should be repeated multiple times for a given specimen type as the test data varies randomly which is due to statistical variation of material properties. Other sources of error include specimen geometry, strike plate positioning, variation of release position and the position readout inaccuracy. Excessive indentation of the hardened strike plates at the impact locations, although unlikely, should be reason for replacing them. An average of multiple test data would be a better representation of the expected toughness of the specimen material.

Notes on the experiments

- Students can perform the tests independently, once it is demonstrated by the instructor.
- The specimens should be cut from a standard sheet of polymer for uniformity of thickness.
- Two standard specimens could be used, S and L types as shown in figure 6 below.
- Round hole punches 8 mm and 25 mm and a carpenter's chisel (3/4 inch) was successfully used to cut out the specimens. Thus the uniformity can be guaranteed.



(a) (b)

Figure 6: Two standard specimen (a) type L and (b) type S.

Precautions

- The specimen should not be too tightly fastened to the strike plate or the base. Else some bending may be introduced if specimen is not perfectly aligned.
- Avoid any not smooth cut as any notch would prompt a fracture and skew the results lower.
- Take multiple measurements at various locations on the gage length as it is uncertain exactly where it will fracture.
- Stay clear of the swing of the pendulum
- Only one person to load and operate the tester (release the pendulum).

Laboratory Presentation

This experiment is performed as a laboratory experiment[4] and has been presented in a conference[5]. The tester is used on various types of polymer specimens, preferably of varying thicknesses. It may be done during one 3-hour or two 2-hour laboratory periods utilizing two types (long and short) of specimens. The instructor demonstrates the various components, settings, safety and experimental precautions, specimen geometry (gage length, cross section dimensions, fillet radius), and finally operation of the tester.

The following points are discussed as a pre-lab lecture:

- Dependence of ductility of materials on temperature is emphasized.

- Comparison to metallic materials' ductile-to-brittle transition is drawn.
- Potential energy and equivalent kinetic energy is elaborated using the data related to the impact tester in use.
- Then strain rate is estimated using the calculated velocity of the pendulum at striking point.
- Different strain rates are achievable by releasing the pendulum from different angular positions/heights.
- Average strain rate can be calculated from average of the release and final angular positions.
- Inaccuracies will be introduced by the friction of the bearings as well as air. This can be verified by running the test without any specimen. More over some energy will be absorbed by the strike plate. This can be estimated by running the test with the strike plate on the frame but without any specimen. The energy loss should be noted and used as the correction factor for the strike plate.

Prerequisite Knowledge

The students must have already had a standard materials science course or be currently enrolled in one. Additional information is available at various internet resources[7-12]. The following topical background is necessary for extracting full benefit from this lab experiment:

Bonding	Atomic structure
Crystal structure	Polymer structures
Ductility	Materials/metal failure modes under stress
Slip planes and directions	Strain hardening

Ductile-to-brittle transition for metallic materials
Glass transition temperature for polymers

Objectives

The main objective is to experience the plastic fracture behavior under impact loading and the effect of strain rate on the apparent strength of materials, especially the polymers. The following are few of these specific objectives:

- To experimentally determine the tensile impact behavior of polymer samples, specially the energy absorbed upon fracture/unit cross sectional area.
- To compare impact toughness in tension between various polymers.
- To experimentally determine the Glass Transition temperature of polymeric materials by testing a specific polymer at various temperatures, especially at very low temperatures. (This may require special cooling media within close proximity of the tester and special hooks on the tester for very fast specimen placement. These are not part of current tester design).
- Compare these results with standard and published data

Equipment and Supplies

Main equipment is the Tensile Impact Tester. Moreover the following supplies/or instruments are also needed.

- A dial/digital caliper for measuring the specimen gage area geometry and before and after the impact.
- A flat and a Philips screw driver for attaching the specimen to the strike clamp.
- A bucket/wooden enclosure to catch the flying strike clamp after it is struck by the swinging hammer.
- Specimens – preferably multiple specimens of same standard size.
- Heating and cooling media, if glass transition is the objective.
- Tongue for handling hot/cold specimens
- Safety goggles

Experimental data

Following is a suggested format for data collection and calculation.

Specimen Material (if known) ____

Polymeric Formula (if known) ____

Specimen Type L or S (other if ISO)

Gage length ___________ (inches) width (w) __________ (in.) thickness (t) ________(in.)

Cross Sectional Area, A= (w x t) = _________X___________ = in.^{2}

The data table, which can be used for noting the test results, is shown in Table 1. Sample position-Energy relationship is given in Table 2 in intervals of 10°. Energy at any other angular positions could be found by interpolation with little error.

Table 1: Data table for impact energy absorbed by the specimen

	Gage Length	Width Inch.	Thickness.	Start Angle	Start Energy	End Angle	End Energy	Delta Theta	Energy absorbed	Energy/ unit area
Sample #	In.	in.	in.	deg.	ft-lb	deg.	ft-lb	deg.	ft-lb	ft-lb/in^2
1										
2										
3										
….										

In addition to the energy data of in Table 2 the energy can also be calculated by the potential energy formulation based on arm length to center of gravity, weight of the pendulum, and angular position if the angular position is known. An easy to use formula is:

$$\text{Energy } E = W.H$$

where, $H = 2.\ R \sin^2 (\alpha/2)$; R =Arm radius, H =Height,
W =Weight of pendulum, α=Angular position;

Table 2: Sample Energy data at various angular positions of the pendulum.

Arm Radius to C.G. = 8.5 inches		Weight = 6 lbs	
Angle (deg)	**Angle (Rad)**	**Height(Inches)**	**Potential Energy**
0	0.0000	0.000	0.00
10	0.1745	0.129	0.77
20	0.3491	0.513	3.08
30	0.5236	1.139	6.83
40	0.6981	1.989	11.93
50	0.8727	3.036	18.22
60	1.0472	4.250	25.50
70	1.2217	5.593	33.56
80	1.3963	7.024	42.14
90	1.5708	8.500	51.00
100	1.7453	9.976	59.86
110	1.9199	11.407	68.44
120	2.0944	12.750	76.50
130	2.2689	13.964	83.78
135	2.3562	14.510	87.06

Conclusion

Polymer tensile impact properties are studied as part of overall materials education within an undergraduate curriculum. Materials and mechanical design are interrelated which was orchestrated by this project. A student group designed and built a bench top tensile impact tester for polymers. The prototype is successfully tested. Experimental procedure has been laid out clearly for easy experimentation. The quality of data and confidence in procedure can be improved by using standard and accurately produced specimens. The design can be scaled up for testing stronger or larger specimens as energy is limited by the arm length and weight of the pendulum. However, it is not practical to keep building new testers but a well calibrated tester and carefully designed laboratory activity would be valuable addition to undergraduate materials laboratory. Although the tester is calibrated in FPS units it can be used with metric units as easily. This could even be a part of student exercise. The interest in materials study among the students has increased since the tester was designed and built by the students. The students' learning would be assessed by a quiz/test shortly after the impact lab is concluded. The author is willing to cooperate with interested educational institutions to design and build their own testers.

Acknowledgment

The author wishes to acknowledge the facility and opportunity provided by the Southern Polytechnic State University in support of this project. The students Luke Pinion, Ross Atha, Jeremy Pence, Edgar Herrington were the designers and builders of the tester. Gandrav Bhagat and Jeanfils Saint-Cyr were the researchers who modified the tester scales and performed tests. The author wishes to extend his thanks to them as well.

Bibliography

1. Tensile Impact – ASTM D1822. IDES: The Plastics Web. http://www.ides.com/property_descriptions/ASTMD1822.asp .
2. ASTM D256 – for standard Izod impact test.
3. ASTM D638 –for standard tensile test.
4. Mir Atiqullah, 'Charpy Impact Test,' laboratory handout, spring 2007. Southern Polytechnic State University, Marietta, GA.
5. Mir Atiqullah, "Materials Education via Design Project: Tensile Impact Tester," presented at the National Educator's Workshop, NEW2007, November 4-7, 2007, Lynnwood, Washington, USA.
6. William D. Callister, Jr. "Materials Science and Engineering-An Introduction," 7th ed. John Wiley & Sons, Inc. 2007.
7. Tensile Impact – ISO 8256. IDES: The Plastics Web. http://www.ides.com/property_descriptions/ISO8256.asp .
8. Tensile Impact Test. Plastics Technology Laboratories http://www.ptli.com/testlopedia/tests/tensile_impact-D1822.asp .
9. DeGuire, Mark. "Impact Testing & the Brittle-Ductile Transition." Case Western Reserve University. http://dmseg5.case.edu/Classes/emse201/overheads/impact.pdf .
10. http://www.matweb.com/
11. http://www.ptli.com/list.asp
12. http://www.ides.com/