

Materials Education via Design Project: Tensile Impact Tester

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Abstract

Materials education is a key foundation for engineering education, especially mechanical engineering. A mandatory materials course with a laboratory component is included in almost all engineering or engineering technology programs. This may include demonstration, testing, and/or simulation of materials properties and behavior under various loading and environmental conditions. Limited time and credit hours may limit the number and variety of laboratory exercises. Often lack of testing apparatus adds to the problem. Understanding and testing for polymer characteristics under various loading condition is critical materials education. While tensile testing of polymers is easily included alongside metallic tensile testing using a Universal Testing Machine, testing for polymer behavior under impact loading is a different issue. Given the simplicity of an impact tester a senior design group was assigned the project to build a bench-top Tensile Impact Tester for polymeric samples. The goal was to design and build the Tensile Impact Tester which would be integrated into materials laboratory. A swing arm pendulum type impact tester was designed, built and tested using familiar halter shaped polymer specimens. The specimens were cut out from commercially available polymer sheets. The pendulum can be released from different angular positions or heights. However, for ease of data calculations, it was released from two standard angular positions. The nonlinear nature of pendulum energy with respect to the release angle was handled using a conversion chart. Thus two different Hammer release heights could be used without having to change the scales on the machine. Polymeric materials could be tested for glass transition characteristics by using specimens at a wide range of temperatures, especially cold ones. The portable and precision nature of the tester along with ease of use made it a valuable and fun addition to our materials testing laboratory.

Key Words

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

Target grade level(s)

This laboratory experiment is targeted towards the junior level engineering and engineering technology students. Students should already have had or must be in a concurrent engineering materials or materials science or similar course. It is advisable to do this experiment after lectures on polymeric materials structures and properties but not necessary.

Mode of presentation

This experiment is performed as a laboratory experiment. 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.

Prerequisite Knowledge

The students must have already had a standard materials science course or be currently enrolled in one. 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

Objective(s)

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).
- Compare these results with standard and published data

Equipment and Supplies

To perform this experiment the Tensile Impact Tester is needed. 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

Introduction

As more and more industrial, commercial and domestic products are manufactured from plastics, it is increasingly important 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 response to loads also changes. For metals this temperature range is known as ductile-to-brittle temperature (range). Similar characteristic of polymers is known as glass transition temperature. Often 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 tests. Figure 1 shows standard specimens for Charpy and Izod tests. Figure 2 shows the level of energy absorbed by specimens of a particular material tested at different temperatures.

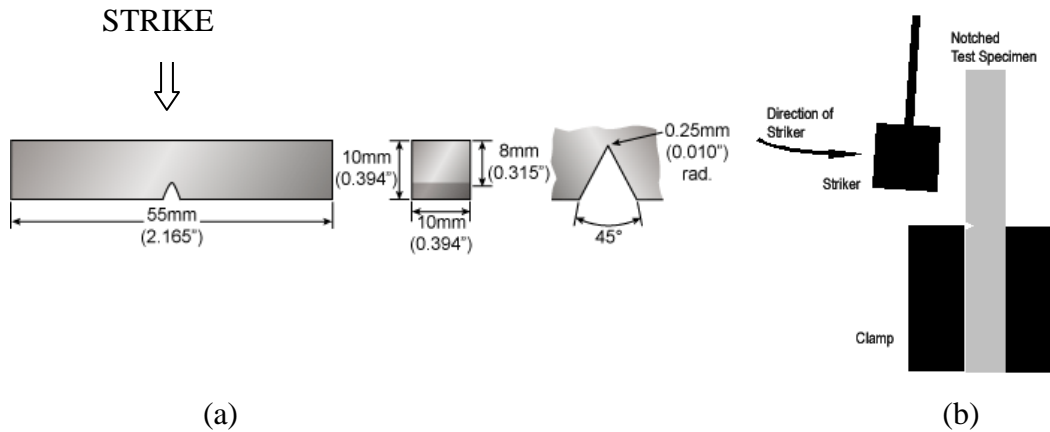


Figure 1: Standard (a) Charpy and (b) Izod specimen. Izod specimen has the same notch geometry, only tested vertically.

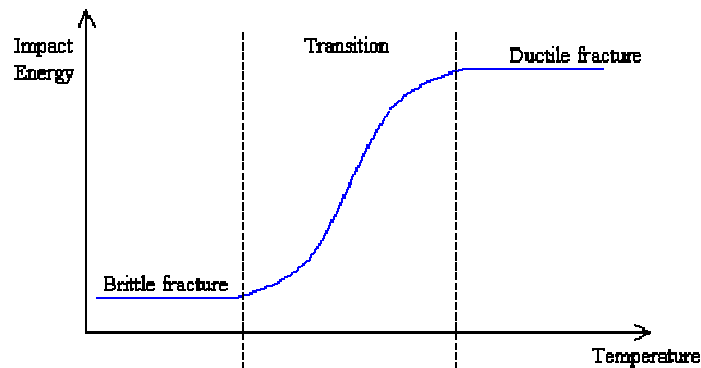
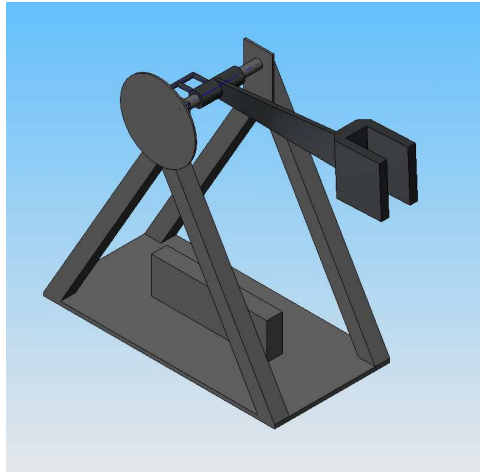


Figure 2: Idealized ductile-to-brittle transition (metals) or glass transition (polymers) as temperature decreases.

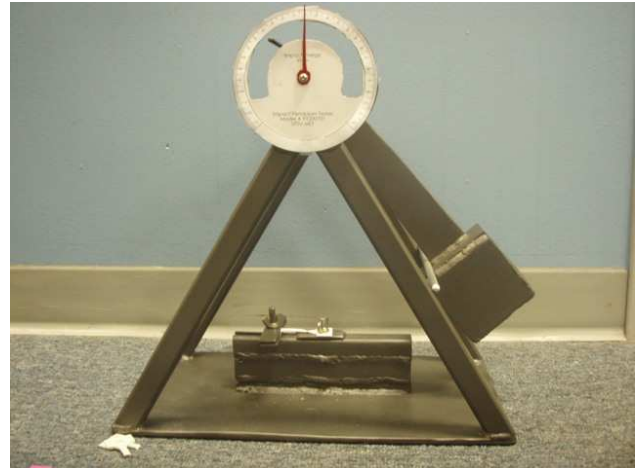
The results of the test are the energy that is absorbed by the specimen during the deformation and fracture. The higher the energy the higher is the impact toughness of the material. The results are not absolute but rather comparative. Thus toughness measured by one method, such as, tensile impact, can only be compared with results from same test using standard specimens. The ASTM D1822 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) or standard tensile test (ASTM D638). Strain rate in the former method is very high and in the latter very low. ASTM D1822 tests utilize strain rate in between these two but closer to that of ASTM D256. 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. This deviation was justified as a small budget project. It was understood that success of the 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 the following figures 3. Figure 3(b) also shows a white specimen clamped to the base.



(a)



(b)

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

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 standard 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 strike plate with a specimen and a fractured specimen is shown in figure 4.



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 provided relating the angle to the energy.

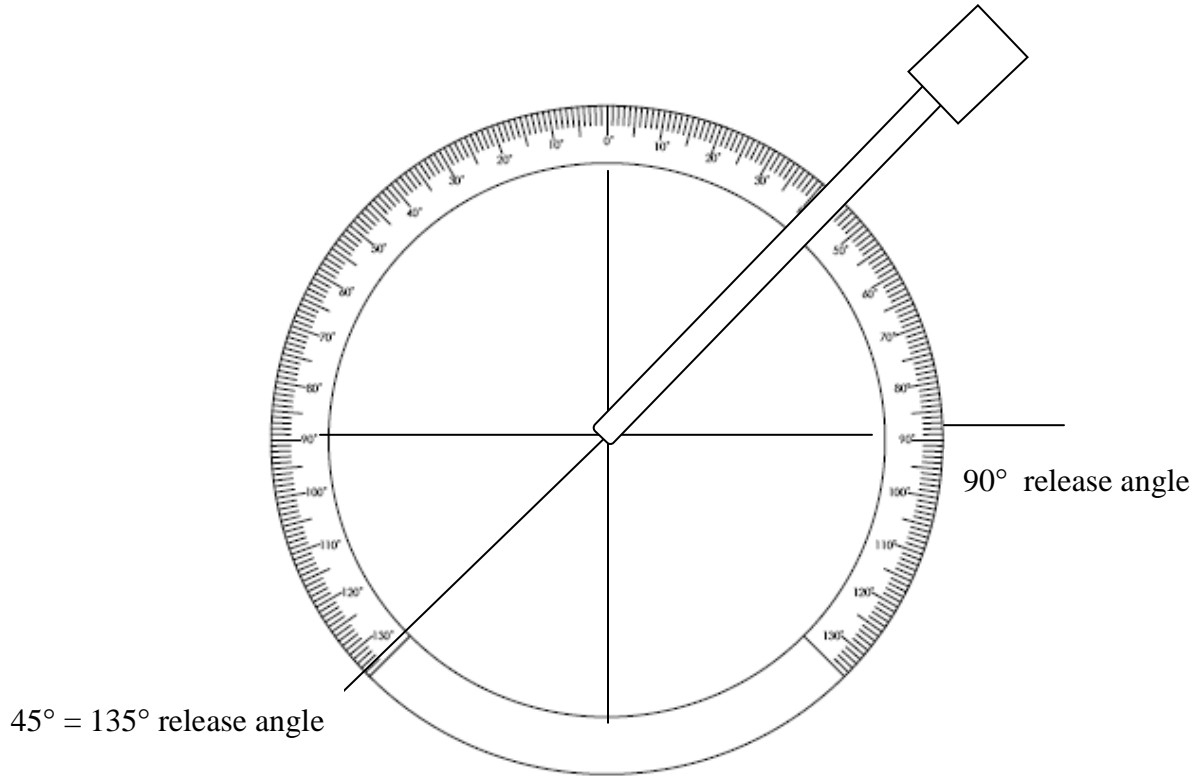


Figure 5: Pendulum swing scale 0 - ± 135 degrees. Two different pendulum release angular positions are shown. Energy is a nonlinear function of the angle. (components not to scale)

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. An average is a better representation of the expected toughness of the specimen material.

Comments

- The test can be performed by students very easily and often with no error.
- The specimen 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.
- It would be advisable to use punches made specifically for these specimens so that uniformity of the specimens is maintained.

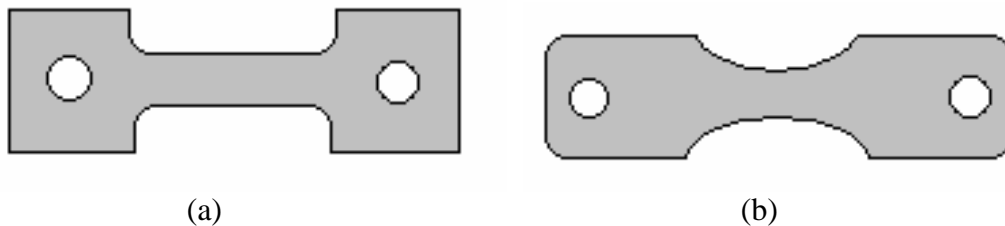


Figure 6: Two standard specimen types (a) L and (b) S.

Few 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).

Evaluation of the activity

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, $A = (w \times t) = \underline{\hspace{2cm}} X \underline{\hspace{2cm}} = \hspace{2cm} \text{in.}^2$

The data table, which can be used for noting the test results, is shown in Table 2, containing few sample data. The position-Energy relationship is given in Table 1.

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 #				Deg.	Ft-lb	Deg.	Ft-lb	Deg.	Ft-lb	Ft-lb /in ²
1				90	51	75	37.8	15	13.2	
2				90	51	72	35.24	18	15.76	
3				90	51	76	38.66	14	12.34	
4				90	51	71	34.40	19	16.60	

The data for energy of the pendulum corresponding to various angular positions is given in table 2 for convenience. 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. An easy to use formula is:

Arm radius = R, Height =H, Weight of pendulum = W, Angular position = α ;

Then $H = 2 \cdot A \cdot \sin^2(\alpha/2)$; and Energy $E = W \cdot H$

Energy at any other angular position could be found by linear interpolation with little error.

Table 2: Angle of pendulum and corresponding energy

Arm Radius to C.G. = 8.5 inches		Weight = 6 lbs	
Angle	Angle (Rad)	Height(Inches)	Potential Energy
0	0.0000	0.000	0.00
5	0.0873	0.032	0.19
10	0.1745	0.129	0.77
15	0.2618	0.290	1.74
20	0.3491	0.513	3.08
25	0.4363	0.796	4.78
30	0.5236	1.139	6.83
35	0.6109	1.537	9.22
40	0.6981	1.989	11.93
45	0.7854	2.490	14.94
50	0.8727	3.036	18.22
55	0.9599	3.625	21.75
60	1.0472	4.250	25.50
65	1.1345	4.908	29.45
70	1.2217	5.593	33.56
75	1.3090	6.300	37.80
80	1.3963	7.024	42.14
85	1.4835	7.759	46.56
90	1.5708	8.500	51.00
95	1.6581	9.241	55.44
100	1.7453	9.976	59.86
105	1.8326	10.700	64.20
110	1.9199	11.407	68.44
115	2.0071	12.092	72.55
120	2.0944	12.750	76.50
125	2.1817	13.375	80.25
130	2.2689	13.964	83.78
135	2.3562	14.510	87.06

Conclusion

Utilizing senior design class and driven by the need for impact testing in the materials laboratory, a bench top tensile impact tester for polymers is developed. A prototype is successfully built and tested. Experimental procedure has been laid out clearly for easy experimentation. The quality and confidence can be increased by using standard and accurately produces specimens. Specially made punch is recommended for repeatability of the dimension of specimens. The design can be scaled up for testing stronger specimens as energy is limited by the arm length and weight of the pendulum. Any institution wishing to replicate this development process may contact the author for more information.

Bibliography

1. ASTM D638 –for standard tensile test.
2. ASTM D1822 – for tensile impact test.
3. ASTM D256 – for standard Izod impact test.
4. Tensile Impact - ISO 8256
5. William D. Callister, Jr. “materials Science and Engineering-An Introduction,” 7th ed. John Wiley & Sons, Inc. 2007.
6. Mir Atiqullah, ‘Charpy Impact Test’ laboratory handout, spring 2007. Southern Polytechnic State University.
7. www.matweb.com
8. <http://www.ptli.com/list.asp>
9. <http://www.ides.com/>