FAIRFIELD UNIVERSITY
School of Engineering
Department of Mechanical Engineering

MEEG 2206L
Energy Transfer
Laboratory

Laboratory Experiment No. 3

Title: Impact Toughness Testing

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Instructor: Dr. Naser Haghbin

We have proofread the report and all the data in this report is from our experiments conducted in the lab.

Group No.: 3
Section No.: 1

Group Members:
Jackson: Apparatus and equipment table, Conclusion and Future work, Application in Industry, Appendix
Mike: Discovery Questions, Apparatus and Equipment Table, Conclusion and Future Work, References, Appendix
Cody: Abstract, Background/Theory, Purpose, Governing Equations, Experimental Overview, Procedure, Discussion
Danny: Application in Industry, Results, Appendix, Abstract, Governing Equations

Abstract

The purpose of this experiment was to calculate the impact energy of three different samples of 3D printed Poly Lactic Acid (PLA). Each sample of PLA had a different number of shells, which essentially determined how thick the walls of the sample were. We believed that the impact energy would increase in proportion to the number of shells. The test was completed using a Static Systems BLI Izod Impact Tester and a Charpy Impact toughness test. Toughness is the ability of a material to absorb energy and plastically deform without fracturing. This is very important because it determines how long a material might last in a structure, how much energy it can undertake, and what kind of loads might be too large for it. The Static Systems BLI Izod Impact Tester is a machine that stabilizes a material at its base and has a pendulum that swings down and swiftly exerts a large amount of force on the material. If the material cracks, then the pendulum continues to swing through, and the height of that swing is measured. The three PLA samples were designed through SolidWorks in accordance with a provided drawing. They were each in the shape of a rectangular block with a notch at the heigh of where the pendulum would strike. The only variable across the three samples was the number of shells, which were 2, 5, and 10 for samples 1 through 3 respectively. In each trial, the sample was secured at the base, with the notch located at the point where the pendulum would strike, the pendulum was released, the sample broke, and the height of the pendulum was recorded. However, each sample was manufactured in a different way. One was printed in a way so that its fibers were perpendicular to the strike of the pendulum. One was printed so that its fibers were parallel with the strike, and one was printed missing a face. This significantly impacted the results. The perpendicular sample performed in accordance with our hypothesis, with hardness increasing linearly with wall count from 0.03 to 0.11 ft-lbs of impact energy. The parallel sample increased linearly from 0.015 to 0.025 ft-lbs, with each trial being less than the perpendicular sample and a much smaller rate of change from trial to trial. The sample missing a face behaved completely unexpectedly, increasing from 0.016 to 0.045 ft-lbs over the first two trials, but then down to 0.035 ft-lbs in the third. So, our hypothesis was correct for the perpendicular sample, and to less of a degree for the parallel sample, but incorrect for the sample missing a face.

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1. Introduction

1.1. Background/Theory

A material's toughness is determined by how much energy it can absorb before fracturing. In an engineering context this is an extremely important measurement. It should be heavily considered when choosing a material for a structure, especially in regards the amount of energy that the material will have to absorb. We performed a Charpy Test for toughness, in which the conditions were a notch on the sample, and a high strain rate from the point of impact of a pendulum swinging into the sample. This test gives toughness in the context of sudden loads or impacts, so its measurements would be most relevant to fields such as defense from projectiles, car materials, or any other situation where a material must bear a sudden and forceful load without fracturing.

1.2. Application in Industry

The importance of toughness testing in industry mainly comes down to ensuring that a selected material will plastically deform under the expected conditions rather than fail catastrophically. Fundamentally, toughness is a material's ability to absorb energy before fracture. Several fields require materials that can plastically deform below a certain threshold before fracture. Buildings designed to withstand earthquakes must be able to plastically deform, rather than stay rigid [1]. As seen in Fig. 1, a company in California is beginning to build ten-story buildings using mass timber to mitigate earthquake effects [1]. The beams are reinforced with cross-laminated timber and are used because of their ability to absorb energy. Another application in which impact toughness must be measured is in pipeline and storage systems for any industry storing potentially combustible, toxic, or dangerous fluids. For instance, in the Soybean Processing industry, hexane is used to extract oilseeds from their hulls. The Hexane Solvent Extraction unit seen in Fig. 2 undergoes toughness testing to ensure that it can withstand any potential abrupt impacts that might mistakenly result from the heavy machinery used within the facility. Hexane is highly combustible, and thus is thoroughly contained at all times. In the mining industry,

Fig. 1. TallWood is a project designed to prove that tall earthquake-protected buildings can be made of wood. Toughness of building materials, particularly under seismic activity, is extremely noteworthy in areas where earthquakes are common. Buildings in these areas are rigorously tested to prove that they can withstand these stresses. A high toughness is integral to the beams used, in the sense that these members must be able to plastically deform, and not fail under these circumstances.

Fig. 2. Toughness tests are applied to the metal components under extreme pressure and stress due to compressed hexane during oilseed extraction. When condensed hexane gas is enclosed by metal surfaces within the piping and tanks, each component must be measured and checked for toughness to withstand the pressure. Failure to design components of the correct toughness could lead to the highly combustible gas releasing abruptly, causing substantial damage and posing significant safety concerns.

1.3. Purpose

The Purpose of this experiment was to calculate the different impact energies of three samples of 3D printed PLA. The samples each had a different number of shells so that we could determine the relationship between the shells and impact energy. We hypothesized that the more shells the material had, the more impact energy it would have. From the impact energy, we could gain a better understanding of what the toughness of the material was. This is important because toughness plays a major role in how different materials are used, how durable they are, and what kinds of loads they can bear.

1.4. Governing Equations

The primary equation used in this experiment was the one used to find the impact energy of the three samples,

$$PE = mgh$$

(1)

where PE is the potential energy of the pendulum before it swings, *m* is the mass of the pendulum that hits the sample, *h* is the height of the pendulum before it swings, and *g* is the acceleration due to gravity. By measuring the initial potential energy, as well as the final potential energy at the point the pendulum swings to, one can find the difference between the two to determine the energy expended on breaking the sample.

1.5. Discovery Questions

In this lab we determined the impact toughness of the three samples of 3D printed PLA using the Charpy Test. Each sample had either 2, 5, or 10 shells, which resulted in different values of the test that allowed us to calculate the impact Energy. Our goal was to determine the impact energy for all the samples and plot it as a function of the number of shells so that the relationship between them and their respective impact could be observed and interpreted. We hypothesized that samples with more shells would have a greater impact energy than the samples with less shells.

2. Methods

2.1. Experimental Overview

In this experiment, a Static Systems BLI Izod Impact Tester was used to complete a Charpy Test on three different samples of 3D printed PLA. Each of the samples had a different number of shells. To calculate the impact energy of each of the samples, they were secured on the base of the impact tester, and a pendulum swung down, striking the sample and eventually reaching a height that was measured by the machine and recorded in our data. From this data, we could calculate the impact energy of each of the samples.

2.2. Apparatus and Equipment Table

The Satec Systems BLI Izod Impact Tester is a hammer that is released from a fixed position using a button, and after it hits the sample block the hammer then swings up and stops at the highest point. As seen in Fig. 4. each sample block has a different number of shells and the Satec Systems BLI Izod Impact Tester aids in determining the impact toughness of each sample. Also, stated in Table 1, we refer to the different equipment and software that we used to conduct this experiment. This includes the Satec Systems BLI Izod Impact Tester, the Ender 3D Printer which was used to print the test samples, SolidWorks which was used to create the model for the test blocks, and Microsoft Excel which was used to record and plot our data.

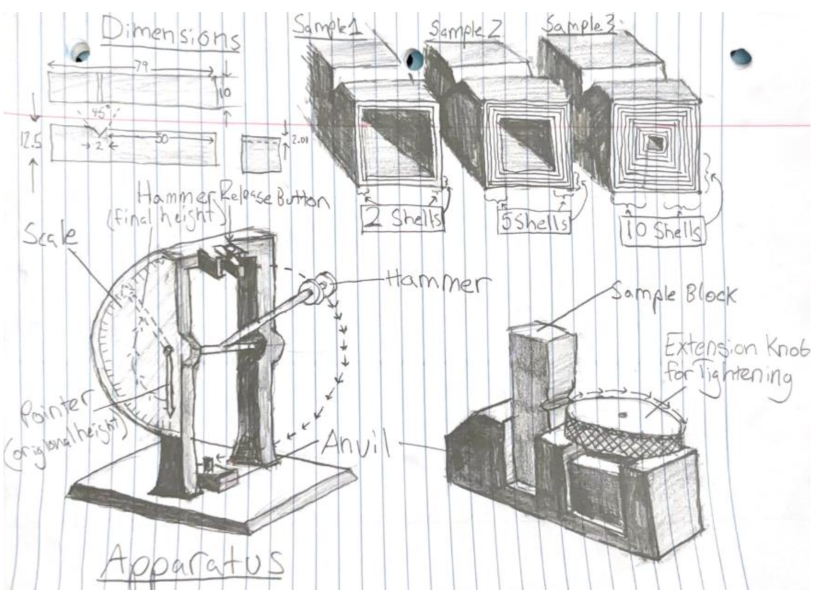

Fig. 4. Diagram of the samples of 3D printed PLA, and the Satec Systems BLI Izod Impact Tester with a magnified view of the sample block being tightened by the extension knob. The drawing includes the three samples of PLA with view of the inside to show the different number of shells in each. The drawing also explains the different parts of the apparatus.

Table 1. Equipment and software used to test the impact toughness of the 3D printed samples of PLA. The Satec Systems BLI Izod Impact Tester tested for impact energy. SolidWorks was used to design the samples of PLA, and the Ender 3D Printer was used to print the samples. Microsoft Excel was used for the recording and plotting of our data.

Equipment and Software	**Accepted Value**
Satec Systems BLI Izod Impact Tester	**N/A**
Ender 3D Printer	N/A
3D Printed Samples PLA	3 Samples (2, 5, 10 shells)
SolidWorks	N/A
Microsoft Excel	N/A

2.3. Procedure

1. Balance the Static Systems BLI Izod Impact Tester by turning the knobs beneath it until the bubble is centered.
2. Lift the pendulum and lock it at the top using the pin.
3. Move the longer needle to its starting position in which it is pointing vertically downward and is located at point 0 on the scale.
4. While standing clear of the pendulum, carefully press the black release button at the top of the machine that allows the pendulum to swing down.
5. Record the location of the longer needle once the pendulum has fully swung through. Repeat steps 2 through 5 for two more trials.
6. Repeat steps 2 and 3.
7. Place Sample 1 (2 Shells) into the slot at the base of the machine. The notch on the sample should be facing the direction from which the pendulum will be coming from. Be sure that the sample is both tightened and centered.
8. Repeat steps 4 and 5 for three trials with Sample 1.

9. Repeat steps 2-5 for three trials with Samples 2 (5 Shells) and then again for Sample 3 (10 Shells).

3. Results

Using the Static Systems BLI Izod Impact Tester on the Vertically Printed sample, we recorded an impact energy of 0.15, 0.2, and 0.25 ft-lbs for 2, 5, and 10 walls respectively. For the Bottom Missing Print sample, we recorded an impact energy of 0.016, 0.045, and 0.035 ft-lbs. For the Horizontally Printed sample we recorded an impact energy of 0.03, 0.06, 0.11 ft-lbs. The impact energies for each trial can be found in Tables A.1-A.3 in the Appendix. The apparatus automatically measured the potential energy of the pendulum before the swing and the potential energy at the end of the swing using Eq. (1). By subtracting the final potential energy from the initial, we calculated the impact energy.

As can be seen in Fig.5, the results for each sample were significantly different. The Vertically Printed Sample barely increased in its ability to withstand impact energy as the number of walls increased. The Bottom Missing Sample actually decreased in its ability to withstand impact energy as the number of walls increased. The Horizontally Printed Sample was the only sample that behaved in the manner that we hypothesized it would. As wall count increased, its impact toughness increased linearly. A standard deviation could not really be taken for this experiment, as each trial and each sample differed in either wall count or design.

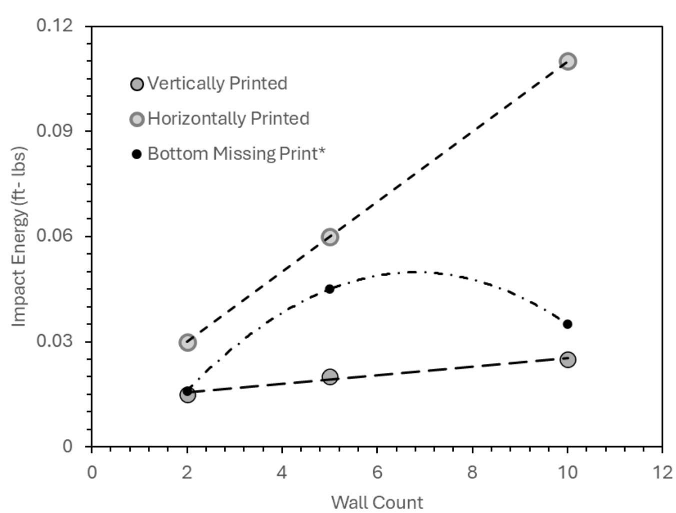

Fig. 5. Graph of the three group's samples. Each group printed their sample differently, leading to significantly different results. The Horizontally Printed sample was printed with its fibers perpendicular to the pendulum's blade. The Vertically Printed sample was printed so that its fibers were in line with the pendulums blade. The Bottom Missing Print sample was printed with one of the faces missing.

4. Discussion

As we expected, the impact energy of the samples was higher when the number of shells was higher. This was in accordance with our original hypothesis. Material toughness is the amount of energy absorbed by the material before fracturing. A material can undergo a brittle fracture or a ductile fracture. A brittle fracture indicates that the material did not have a very high level of toughness and absorbed little energy. This occurs when there is little to no plastic deformation of the material before fracturing. Conversely, ductile fractures indicate a higher level of toughness because the material will experience a certain amount of plastic deformation before fracturing. Because the impact on our material was swift and highly concentrated, it fractured quickly and without a great amount of plastic deformation. However, because the impact energy increased with the number of shells in the samples, it can be noticed that the fractures became less brittle, and underwent more plastic deformation before fracturing, when the number of shells was higher.

In our group, we recorded scale readings of 0.565, 0.570, and 0.575 for samples 1, 2, and 3 respectively. These values yielded impact energies of 0.015, 0.020, and 0.025. As Fig. 5 indicates, these values are linear and indicate consistent increase in impact energy with respect to number of shells. However, there could be some error in our data because the number of shells increased from 2 to 5 across the first two samples and 5 to 10 across the second and third samples, but our increase in impact energy across these samples increased by the same amount each time. This would suggest that it is not a directly proportional relationship between number of shells and impact energy. This error could be due to the construction of our samples. They were supposed to be 3D printed horizontally, but ours was printed vertically. This can slightly alter the structural composition of the material, potentially causing this slight error in our measurements.

In the group that printed the sample correctly, they measured scale readings of 0.58, 0.61, and 0.68 for samples 1, 2, and 3 respectively. These values yielded impact energies of 0.03, 0.06, and 0.11. This group's impact energies were more consistent with the change in the number of shells. As the data shows, the increase in impacts energy from across samples 2 to 3 was slightly greater than the increase across samples 1 and 2 which aligns with the increase in shells. The last group printed their samples incorrectly, and without a bottom. Therefore, the trends in their impact energies were not consistent with those of the first two groups. They yielded impact energies of 0.016, 0.045, and 0.035 for trials1, 2, and 3 respectively. As shown in Fig. 5. This did not yield a linear relationship between shells and impact energy, and the errors in their printing prevent that data from reliably representing the relationship.

5. Conclusion and Future Work

The impact tester was used to observe the amount of impact energy that was absorbed by the different test blocks of PLA. The equation used was equation (1) or the potential energy equation in which we multiplied mass, height, and gravity to find the potential energy of the system. Then, when observed the data we recorded we found that the range of our Sample 1 test blocks were .015 - 0.03 ft lbs, the range for Sample 2 test blocks were 0.02 - 0.06 ft lbs, and the range for Sample 3 test blocks were 0.025 - 0.11 ft lbs. A source of these ranges getting larger and larger could be because of the differences in the construction of our test blocks, which led to larger discrepancies in the values. One way to counteract that would be by having uniform test blocks that all had a consistent design and construction.

Further experimentation could be done to observe how each test block was fractured and how they differed from each other depending on how many shells they had. Interesting fracture lines were formed from each block to the next during this experiment, with different angles of cuts at different points of each block. Each of these angles and shapes could be measured and discussed in the future, providing deeper insight into how exactly these fractures happened in the milliseconds of impact, and why different numbers of shells created these similar but varying reactions. A few other approaches that could be taken to achieve a greater knowledge of the subject and its application would be manipulating different properties of the subject blocks, such as the infill density, the infill percentage, and even the material used in the 3-D printing process. This could give us further insights beyond how many shells lead to certain impact energy and allow us to see how particular printing techniques and materials contributed to this as well, discussing topics of materials science and material selection in the design process. We could also have one group do the printing of the samples to reduce the differences between the samples and to get more consistent results. Finally, in the future there could be a section in this experiment where you discuss the differences between each group's samples and how they might affect your results.

References

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Appendix

Table A.1. Measurements discovered for group one. This table represents the values for the sample that was printed so that its fibers were in line with hammer's strike. The impact energy increased linearly but only by small degrees with an increase in wall count.

Sample	# of Shells	Scale Reading w/ out sample (ft lbs)	Scale reading with sample (ft lbs)	Impact Energy (ft lbs)
1	2	0.55	0.565	0.015
2	5	0.55	0.57	0.02
3	10	0.55	0.575	0.025

Table A.2. Measurements for group two. This table represents the values for the sample that was printed so that the fibers were perpendicular to the hammer's strike. The impact energy increases linearly and by large degrees in accordance with gain in wall count.

Sample	# of Shells	Scale Reading w/ out sample (ft lbs)	Scale reading with sample (ft lbs)	Impact Energy (ft lbs)
1	2	0.55	0.58	0.03
2	5	0.55	0.61	0.06
3	10	0.55	0.66	0.11

Table A.3. Measurements for group three. This table represents the values for the sample that did not have a face. As can be seen, the impact energy increased from 2 walls to 5 walls but decreased from 5 walls to 10 walls, which is not normal considering the other examples.

Sample	# of Shells	Scale Reading w/ out sample (ft lbs)	Scale reading with sample (ft lbs)	Impact Energy (ft lbs)
1	2	0.556	0.572	0.016
2	5	0.565	0.61	0.045
3	10	0.565	0.6	0.035