Charpy Impact Test Experiment

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***Abstract*—The main purpose of this experiment is to analyze the ability of different materials to absorb impact energy through a Charpy impact test. Two different materials were chosen for the experiment, brass and marble. These materials were chosen due to their variance in mechanical properties, marble being a major brittle material and brass being a ductile material. It was found that the marble absorbed less energy than the brass specimen. That was due to the fact that, being a brittle material, the marble did not undergo much deformation before fracturing, in turn absorbing less energy. The brass, being a more ductile material, experienced significant elastic and plastic deformation before reaching its fracturing point, therefore absorbing a lot more energy.**

***Index Terms*— Charpy, Energy, Impact, Work**

I. Introduction

THE resistance to impact loads is an important consideration while selecting materials for systems that are expected to encounter suddenly applied loads. The kinetic energy brought upon by a sudden impact needs to be dissipated through the material in order to keep it from failing. The purpose of this lab is to analyze the ability of different materials to absorb and dissipate impact energy using the Charpy impact tester.

The Charpy impact tester consists of an impactor mounted at one end of a metal rod whose other end is anchored to a rigid frame at a pivot point [2]. The impactor and the rod serve as a simple pendulum to impose impact forces on a test sample when the pendulum is held (Figs. 1-2).

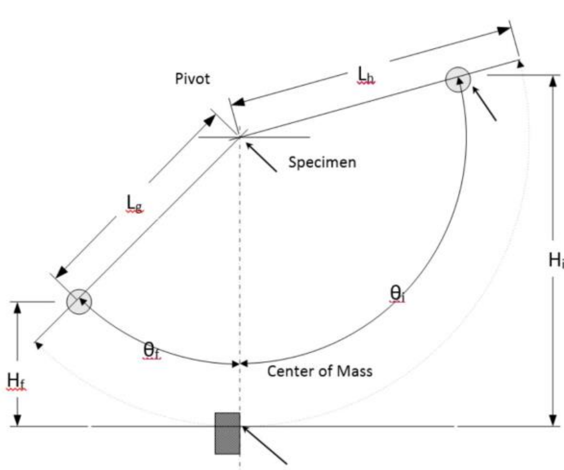

Fig. 1. Impact tester pendulum schematic

Fig. 2. Charpy impact tester schematic

II. Procedure

Required Materials for Lab

This lab will require: a Charpy impact tester with an angular position sensor and a strain gaged pendulum, a computer with LabVIEW installed and the required VI, a DAQ, a strain gage amplifier in ½-bridge, one brass notched specimen, one marble notched specimen, rulers, micrometers, and calipers. All tools and equipment listed above were provided in the lab.

Specimen Measurements

The two notched specimens needed to be measured before the start of the experiment. The height of both specimens was measured using calipers. Width measurements were made with the use of a micrometer for more accurate results

Experiment Set Up

The Charpy impact tester as set up by the instructors. A schematic of the impact tester is shown in Fig. 1. The first step was calibrating the machine readings. To do that, the instructor let the pendulum swing freely. From the data gathered, a tare value for the voltage of the position sensor can be calculated in order to establish the zero position of the pendulum with respect to the vertical. Another calibration procedure done was a hang test to find the bias errors that come with all the voltage readings from the Charpy tester. From that, voltage data was collected to find the tare value needed to zero the Vamp values (Fig. 3).

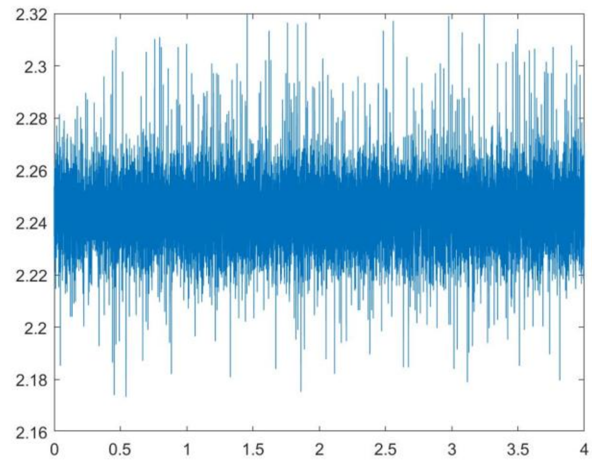

Fig. 3. Random error associated with Vamp readings from hang calibration test.

After that, the marble specimen was installed into the machine. The pendulum was brought up to a starting position of about 90° from the vertical. From there, the pendulum was released so it would hit the specimen at the bottom. After impact and fracture of the specimen, the pendulum was stopped and the VI terminated.

The brass specimen was then installed into the machine. Once again, the pendulum was brought to a starting position of about 90° from the vertical. From there, it was released, hitting and fracturing the specimen at the bottom. After impact, the pendulum was stopped and the VI terminated.

III. Results

Raw voltage signals were recorded from the position sensor, strain gage, and excitation sensor for each test. The marble specimen impact caused an initial 0.5V spike on the strain gage (Fig. 4). The brass specimen impact in turn caused an initial spike of almost 1.5V on the strain gage (Fig, 3).

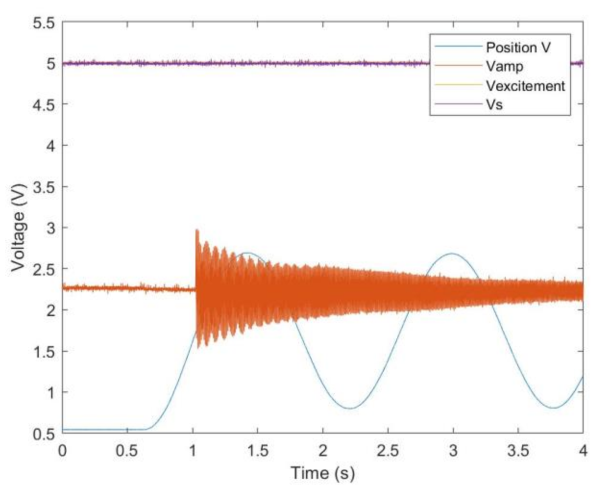

Fig. 4. Plot of voltage readings from position, strain, and excitement sensors gathered during the marble impact test.

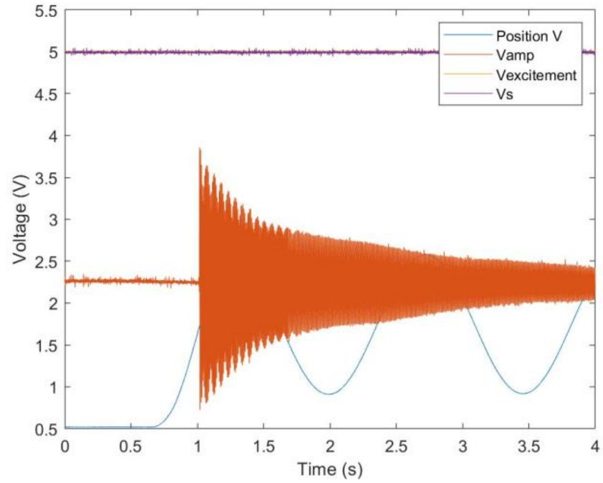

Fig. 5. Plot of voltage readings from position, strain, and excitement sensors gathered during the brass impact test.

Using the data gathered during the calibration phase of the experiment, tare values were found for the position and amplification voltages. The position voltage was tared by a value of 1.746 V while the amplified voltage was tared by a value of 2.445 V. A calibration constant *C* was also calculated to scale the positional voltage readings to corresponding angle values. The scaling constant was formulated to be

$$C = \frac{\Delta\theta}{\Delta V} = \frac{180^{o}}{V_{+} - V_{-}} = 68.67\ {}^{o}/V \quad (1)$$

Through these calibration values, the original data was calibrated to yield more accurate results. This treated data was then used to calculate reference angle, height, strain, stress, force, and distance values. Using these new results as references, the wind resistance and friction losses were calculated (Table I). Taking these losses into account, the energy absorbed by the specimen during each test was calculated. The energy absorbed by the brass specimen was 6.27 J and by the marble specimen was 4.0 J.

TABLE I
Energy Values for Two Specimens

Energy Value	Brass	Marble
Energy Absorbed	6.27	4.01
U_{el}	1.55	0.20
U_{pl}	10.47	1.33
U_{total}	12.02	1.53

Work done on the specimen was another way to account for the energy losses experienced by the pendulum. The work was found through numerical integration of the force of impact as a function of the displacement of the pendulum (Figs. 6-7). The work done on the brass specimen was found to be 2.59 J and on the marble specimen it was 1.27 J.

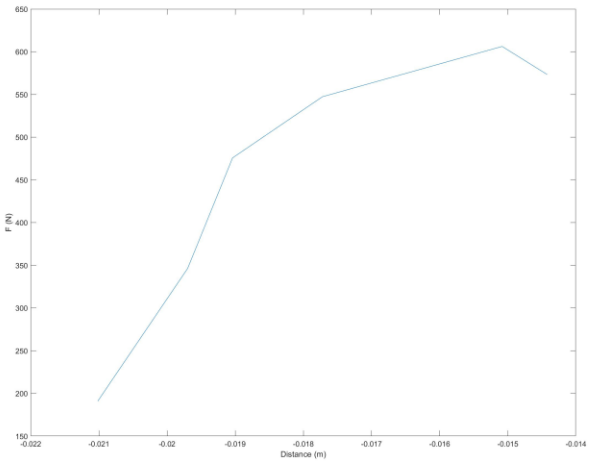

Fig. 6. Plot of impact force as a function of the displacement of the pendulum for the brass sample.

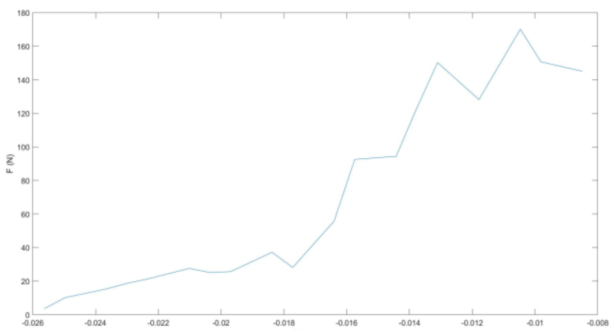

Fig. 7. Plot of impact force as a function of the displacement of the pendulum for the marble sample.

IV. Discussion

The purpose of this lab was to understand design considerations while selecting materials for suddenly applied loads, such as the impact force of the pendulum in lab. Initially, the energy absorbed by each specimen was deemed to be the total loss in potential energy experienced by the pendulum from its initial position to its other extreme position at the other side of its period. However, that value was an overestimate of the energy absorbed by the sample because it also included energy losses coming from wind drag and friction. Data from a free swing test was then used to calculate the average energy loss experienced by the system only due to drag and friction. The resultant energy loss was then subtracted from the prior total energy loss found to yield an accurate value for the energy absorbed by each specimen.

Another method of finding the energy loss experienced by the pendulum is through finding the work done on the specimen during impact. To accomplish that, the force of impact needed to be calculated. The force of impact can be calculated using the equation

$$F_{im} = \frac{F_{CM} b}{l} = \frac{E\varepsilon I b}{avc} = P \tag{2}$$

All of these values were either collected during testing or calculated using the gathered data. A more detailed calculation of each term and their values are included in the Appendix. To find the work involved with each impact, the displacement of the pendulum during the impact was also needed. The displacement was found using the equation of an arc length

$$r = \theta l \tag{3}$$

These two important quantities needed to be found for a very specific section of the collected data. In the roughly four seconds of data collection, only a very small fraction of time (0.004s for marble and .001s for brass) actually corresponds to the time of contact between the pendulum and the material in test. In the plot of Vamp v. time, the contact time span starts at the bottom of the first voltage peak (impact) and ends at the peak (fracture). Therefore, these time ranges were found so further analysis could be done pertaining to that phase of the experiment (Figs. 8-9).

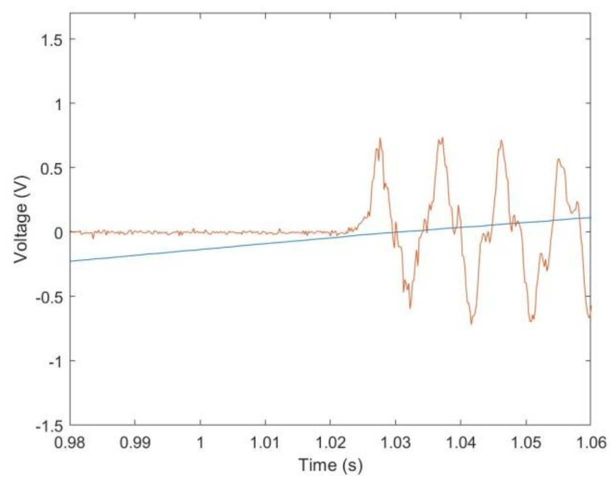

Fig. 8. Plot of Vamp v. time zoomed into impact time span for the marble specimen.

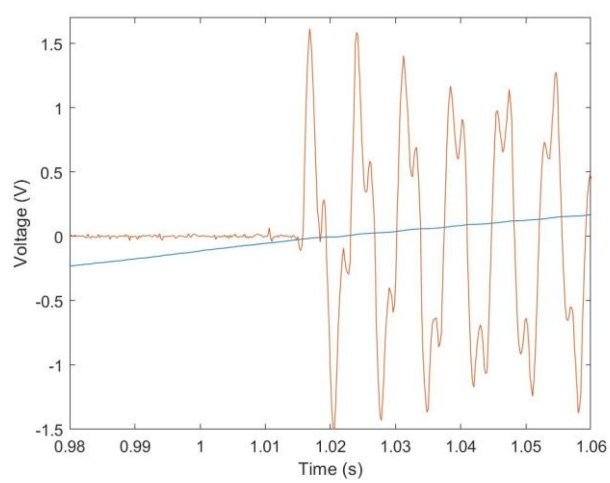

Fig. 9. Plot of Vamp v. time zoomed into impact time span for the brass specimen.

Having the displacement of the pendulum and the impact force corresponding to this displacement, the work could then be found by integrating the function of force v. displacement. The function was integrated using the trapezoidal method on MATLAB. The simple version of the method does bring a significant amount of error (4), but it was deemed accurate enough to represent the data set gathered.

$$Error = -\frac{(b-a)^3}{12} f^2(\xi) \tag{4}$$

However, a more accurate result could be achieved by splitting up the data set into multiple trapezoidal methods, which was what was used to calculate the total work at the end (Figs. 10-11).

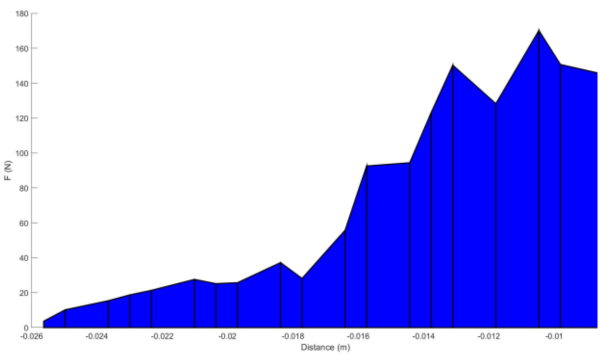

Fig. 10. Area being integrated from the plot of impact force as a function of the displacement of the pendulum for the marble sample.

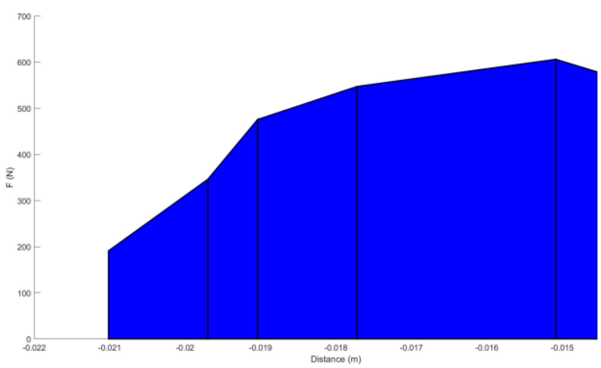

Fig. 11. Area being integrated from the plot of impact force as a function of the displacement of the pendulum for the marble sample.

There were a significant amount of calculations involved with these methods, thus a lot of uncertainties needed to be kept in track. The pendulum height uncertainty can be found by

$$U_H = \sqrt{\left(\frac{\partial H}{\partial B}\right)^2 U_B^2 + \left(\frac{\partial H}{\partial \theta}\right)^2 U_\theta^2} \tag{5}$$

Then, the uncertainty on the area moment of inertia can be found by

$$U_{I_m} = \sqrt{\left(\frac{\partial I_m}{\partial b}\right)^2 U_b^2 + \left(\frac{\partial I_m}{\partial h}\right)^2 U_h^2 + \left(\frac{\partial I_m}{\partial t}\right)^2 U_t^2} \tag{6}$$

$$U_I = \sqrt{\left(\frac{\partial I}{\partial w}\right)^2 U_w^2 + \left(\frac{\partial I}{\partial H}\right)^2 U_H^2} \tag{7}$$

The uncertainty in the arc length can be found by

$$U_{l_{arc}} = \sqrt{\left(\frac{\partial l_{arc}}{l}\right)^2 U_l^2 + \left(\frac{\partial l_{arc}}{\partial \theta}\right)^2 U_\theta^2} \tag{8}$$

The uncertainty in the energy lost and the energy absorbed is calculated below

$$U_{E_{lost}} = \sqrt{\left(\frac{\partial E_{lost}}{\partial m}\right)^2 U_m^2 + \left(\frac{\partial E_{lost}}{\partial g}\right)^2 U_g^2 + \left(\frac{\partial E_{lost}}{\partial \Delta H}\right)^2 U_H^2} \tag{9}$$

V. Conclusion

A. *Level II Subheading*

The main purpose of this experiment was to analyze the ability of different materials to absorb impact energy through a Charpy impact test. Two different materials were chosen for the experiment, brass and marble. These materials were chosen due to their variance in mechanical properties, marble being a major brittle material and brass being a ductile material. It was found that the marble absorbed less energy than the brass specimen. That was due to the fact that, being a brittle material, the marble did not undergo much deformation before fracturing, in turn absorbing less energy. The brass, being a more ductile material, experienced significant elastic and plastic deformation before reaching its fracturing point, therefore absorbing a lot more energy. These characteristics should be considered when making design choices pertaining to systems that might experience the type of sudden loading scenarios proposed by this experiment.

Appendix

TABLE II
Uncertainty Values

Term	Uncertainty Value
θ	0.5mm/m
l	5x10^-5 in
w	5x10^-5 in
h	5x10^-5 in
Gravity	0.001 m/s^2
M	0.05 kg
E- brass	20 MPa

TABLE III
SUMMARY OF VALUES

Measurement	Value	Units
L	0.88	m
b	0.71	m
v	0.255	m
a	0.17	m
M	1.88	kg
E_{brass}	97 [1]	GPa
$\sigma_{y_{brass}}$	135 [2]	MPa
$\sigma_{u_{brass}}$	345 [2]	MPa
E_{marble}	60 [3]	GPa
$\sigma_{y_{marble}}$	-	-
$\sigma_{u_{marble}}$	9 [4]	MPa
c	0.0128	m
I	2E-08	m^4
Gain	1100	
G_f	2.1	
W_{marble}	1.2739	J
W_{brass}	2.592	J
$F_{imp_{marble}}$	170.12	N
$F_{imp_{brass}}$	606.2	N

Extra calculations dealing with previous results:

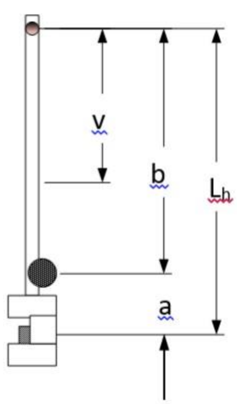

Fig. 12. Reference dimensions used in calculations.

$$\Delta(PE) = Mg\left(H_i - H_f\right) = losses \quad (10)$$

$$M_{SG} = F_o \, x \, v \quad (11)$$

$$\sigma_{SG} = \frac{M_{SG}c}{I} = \frac{F_o vc}{I} \quad (12)$$

$$F_o l = F_{CM} a \quad (13)$$

REFERENCES

[1] N. Arakere,"Lab 4 Lecture Notes", WEIM 1064, 2019.
[2] G. Subhash and S. Ridgeway, Mechanics of Materials Laboratory Course. Morgan & Claypool Publishers, 2018, pp. 151-162.
[3] Ezlok.com. (2019). Brass Mechanical Properties | E-Z LOK. [online] Available at: https://www.ezlok.com/brass-properties [Accessed 30 Oct. 2019].
[4] Elginfasteners.com. (2019). Brass | Elgin Fasteners. [online] Available at: https://elginfasteners.com/resources/materials/material-specifications/brass-material/ [Accessed 30 Oct. 2019].
[5] Makeitfrom.com. (2019). Marble :: MakeItFrom.com. [online] Available at: https://www.makeitfrom.com/material-properties/Marble [Accessed 30 Oct. 2019].
[6] Matweb.com. (2019). Marble. [online] Available at: http://www.matweb.com/search/datasheet.aspx?matguid=a1c4c37b55e24765bcb63b4665b44f05 [Accessed 30 Oct. 2019].