# Charpy Impact Testing

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***Abstract*— This lab report used a Charpy pendulum impact test rig to analyze the differences in energy absorption of a ductile and a brittle specimen. The lab used two different methods to calculate energy absorbed: change in potential energy, and strain estimation. Both methods used a data acquisition device (DAQ) to process information from a potentiometer and a ½ Wheatstone bridge/strain gauge system attached to both sides of the pendulum. The potentiometer was used to calculate the angular position of the pendulum as it swung down. Since the potentiometer measured position as a voltage between 0V and 5V, a three-point Monte Carlo simulation was used to establish a calibration constant of 68.65 °/V. This converted the voltage values into degrees. The potential energy method used this angular position value to calculate the difference in height between the downward swing (before impact) and the upward swing (after impact). Removing losses due to various energy sinks in the system, the net result was a breaking energy of 6.47 J ± 1.28 J for the brass specimen and a breaking energy of 5.74 J ± 1.05 J for the marble specimen. The strain estimation method used the force at impact times the distance traveled into the specimen to calculate the work done. The net result was a breaking energy of 3.70 J ± 0.142 J for brass specimen and a breaking energy of 2.47 J ± 0.07 J for the marble specimen.**

***Index Terms* – Brittle Fracture, Ductile Fracture, Pendulum Impact Test, Vibrations**

## I. Introduction

THIS lab report analyzed the difference in impact fracture profiles of brittle and ductile materials. The impact device is known as a Charpy pendulum (Fig 1). This pendulum swings along a fixed path with a potentiometer-based position sensor attached to it. The potentiometer changes resistance as it is rotated which changes the voltage drop. This effectively assigns a voltage to an angular position value. However, the voltage needs to be converted into degrees/radians. This was done using a three-point Monte Carlo simulation which used the voltages at -90°, 0°, and +90°. Like previous labs, the Monte Carlo simulation created 4000 data sets that were within the uncertainty of the ° and voltage. This was then used to find a calibration constant in degrees per V and calculate the angle values of the potentiometer.

Using these angle values, it is possible to assign a datum, in this case the y axis, and calculate the angle from that datum. After this, it is possible to use simple trigonometry to find the change in height (1). With the change in height and the mass of the impactor arm, the change in potential energy (PE) can be calculated (2) [1]. This change in energy is the energy required to break the specimen plus the losses due to non-conservative forces in the swing down (3).

$$H = l - l\cos(\theta) \tag{1}$$

$$\Delta PE = Mg(H_I - H_f) \tag{2}$$

$$\Delta PE = U_{Break\ the\ Specmien} - U_{Losses} \tag{3}$$

The pendulum is configured in a ½ Wheatstone Bridge system with the two strain gauges connected to a data acquisition module (DAQ). Due to the fact that the strain in the 4130 steel pendulum is very small, an amplifier with an amp factor ($V_{Amp\ Factor}$) of 1100V is used to augment the strain values (4). The strain gauges were used in previous labs and are known to have a $G_f$ of 2.1.

$$\epsilon = \frac{2(V_{amp} - V_{tare})}{V_{Amp\ Factor} G_f V_s} \tag{4}$$

As shown in previous labs, it is possible to calculate the stress values from the strain values using Hooke's law. After doing a few simple moment balances and rearranging and substituting terms, a direct relationship between strain and impact force can be found [1]. This impact force ($F_{im}$) times the distance the impactor head travels into the part ($ld\theta$) is the net work done ($W$) during the impact of the specimen (5).

$$W = I \int_{\theta_1}^{\theta_2} \frac{E\epsilon Ib}{avc} d\theta \tag{5}$$

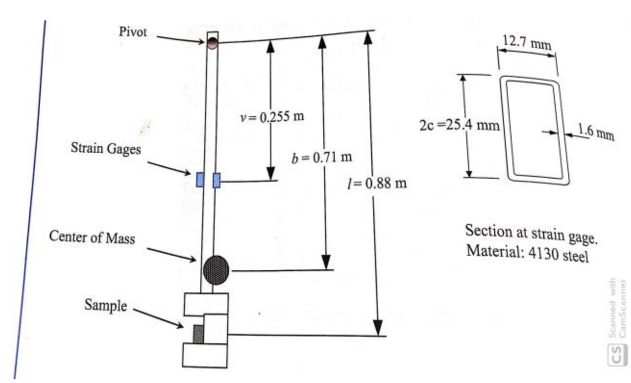


Fig 1: Dimensions of the pendulum impactor. [1]

## II. Procedure

*Basic Setup*

The lab used the Charpy testing rig. However, before the specimen tests can be started, a hang down test and a swing down test were performed.

### *A. Hang Down Control Test*

The hang down test was done first in order to establish the 0° position. The impactor head was allowed to hang at the 0° point and the voltage value at that point was recorded. The DAQ, which is connected to the potentiometer, supplies 5V for the potentiometer to span over 360°. Thus, the hang down data, positive 90° data, and the negative 90° data were used to create a trend line of degrees per volt. This was done using a Monte Carlo simulation and established the degrees per volt value of the potentiometer.

### *B. Swing Down Control Test*

The impactor head was held to a near 90° angle and dropped without adding any energy to the system. This basic swing down established a baseline energy loss value for losses due to non-conservative forces. This value allowed for the removal of all steady state energy sinks in following fracture impact tests.

### *C. Fracture Impact Test*

For both specimens the procedure is the same and should be repeated for each impact test. The specimen was mounted onto the impact cross section of the pendulum test rig. The impactor head was held up to a 90° angle and dropped without adding any energy to the system. The data was recorded and stored.

## III. Results

### *A. Monte Carlo Simulation Calibration*

Using the data acquired from the hang down test at 0°, and the data supplied by the lab instructor for the voltages at -90° and +90°, the ° per volt was calculated. This was done using a 3-point Monte Carlo simulation.

TABLE I
MONTE CARLO SIMULATION CALIBRATION

| Voltage (V) | Uncertainty (V) | Angle (°) | Uncertainty (°) |
|---|---|---|---|
| 0.388 | 5.84e-5 | -90 | 0.0267 |
| 1.74426 | 5.84e-5 | 0 | 0.0267 |
| 3.0093 | 5.84e-5 | 90 | 0.0267 |
| Slope (°/V) | | Uncertainty in m (°/V) | |
| 68.65 | | 0.0159 | |

The Monte Carlo simulation resulted in a degrees per volt of the potentiometer of 68.65 (°/V) with an uncertainty of 0.0159 (°/V)

### *B. Hang Down Test*

The VI recorded a reading of 1.744261 V at the 0° datum of the Impactor Head. This voltage value was subtracted from the position voltage for all other tests in order to set the datum for the data to the y axis.

### *C. Swing Down Test*

The swing down test established the energy sinks in the pendulum. The impactor head was dropped from an angle of -1.494 rads (-85.6°). On the swing up, it came up to 1.425 rads (81.7°). The difference in height from the starting height and ending height was calculated to be 0.0484 m. This resulted in a potential energy loss of 1.09 J which is the energy loss due to non-conservative forces. (Table II).

TABLE II
SWING DOWN TEST DATA

| Data | Value |
|---|---|
| Starting Angle (rads) | -1.494 |
| Ending Angle (rads) | 1.425 |
| Starting Height (m) | 0.656 |
| Ending Height (m) | 0.607 |
| Change in Height (m) | 0.0484 |
| Starting PE (J) | 14.8 |
| Ending PE (J) | 13.7 |
| Change in PE (J) | 1.09 |

### *D. Fracture Impact Test (Brass Potential Energy Method)*

The fracture impact test for brass showed that the breaking energy was 6.47 J. The impactor head was dropped from an angle of -1.496 rads (-85.7°) and rose up to 0.988 rads (56.6°) on the swing up. The difference in height from the starting and ending height was calculated to be 0.338 m. This resulted in a gross potential energy loss of 7.62 J. However, the energy losses due to non-conservative forces still need to be tared from the total energy loss which resulted in a breaking energy of 6.47 J (Table III).

TABLE III
BRASS IMPACT TEST DATA

| Data | Value |
|---|---|
| Starting Angle (rads) | -1.496 |
| Ending Angle (rads) | 0.988 |
| Starting Height (m) | 0.657 |
| Ending Height (m) | 0.319 |
| Change in Height (m) | 0.338 |
| Starting PE (J) | 14.8 |
| Ending PE (J) | 7.21 |
| Change in PE (J) | 7.62 |
| Steady State Loss (J) | -1.09 |
| Breaking Energy (J) | 6.47 |

Fracture Impact Test (Marble Potential Energy Method)

### *E.*

The fracture impact test for marble showed a breaking energy of 5.74 J. The impactor head was dropped from an angle of -1.48 rads (-84.8°) and rose up to 1.02 rads (58.6°) on the swing up. The difference in height from starting and ending height was calculated to be 0.306 m. This resulted in a gross potential energy loss of 7.68 J. However, the energy losses due to non-conservative forces still need to be tared from the total energy loss which resulted in a breaking energy of 5.74 J (Table IV).

TABLE IV

MARBLE IMPACT TEST DATA

| Data | Value |
|---|---|
| Starting Angle (rads) | -1.481 |
| Ending Angle (rads) | 1.02 |
| Starting Height (m) | 0.646 |
| Ending Height (m) | 0.340 |
| Change in Height (m) | 0.306 |
| Starting PE (J) | 14.6 |
| Ending PE (J) | 7.68 |
| Change in PE (J) | 6.90 |
| Steady State Loss (J) | -1.09 |
| Breaking Energy (J) | 5.74 |

### F. *Fracture Impact Test (Brass Strain Estimation Method)*

Using the data from the ½ Wheatstone bridge/strain gauge system, the impact force over time was graphed (Fig 2).

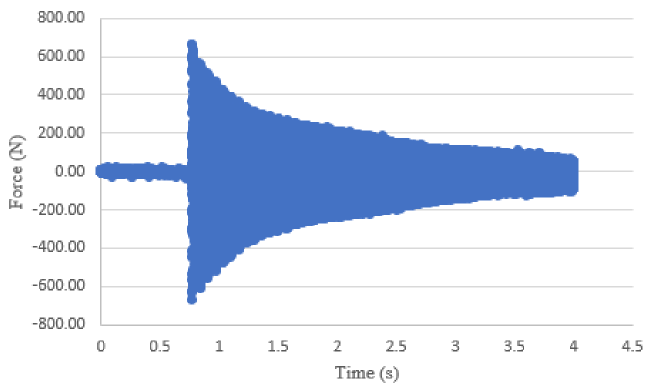


Fig 2. Force over time graph. As seen in the graph, the pendulum oscillated after impact.

The data was shown to be oscillatory and force over angle of the first oscillation was plotted onto a separate graph (Fig 3). The area under the curve of this force over angle graph times the length of the pendulum was the net work done to break the specimen. The work required to break the specimen was calculated as 3.70 J ± 0.142 J. The calculated impact force was 579 N.

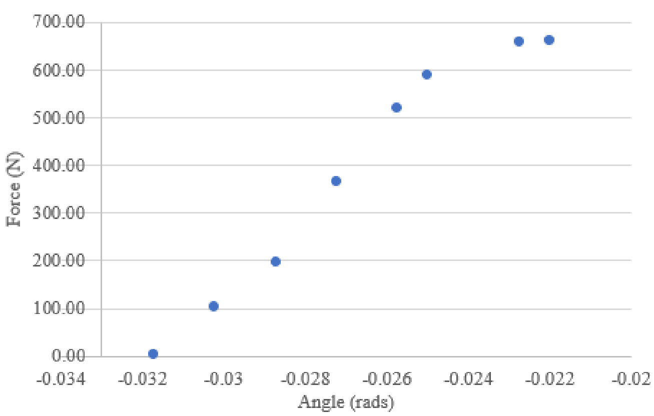


Fig 3. Force over angle graph. The area under this curve times the length of the pendulum is the net work done before fracture.

### G. *Fracture Impact Test (Marble Strain Estimation Method)*

Once again, using the data from the ½ Wheatstone bridge/strain gauge system, both the force over time and force over angle data was graphed like the brass specimen (Fig 4 & 5).

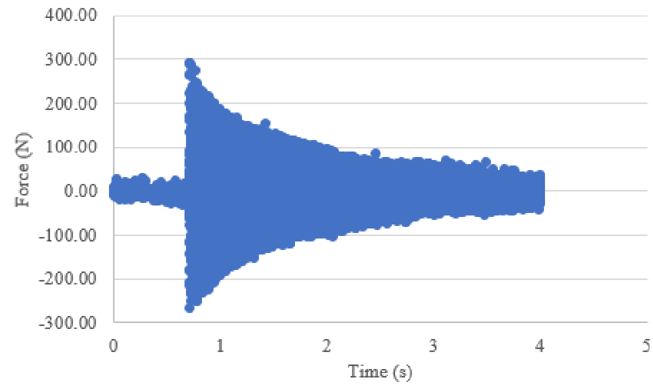


Fig 4. Force over time graph. As shown in the graph, the pendulum oscillated after impact the marble.

The work required to break the specimen was calculated as 2.47 J ± 0.07 J. The calculated impact force was 293 N.

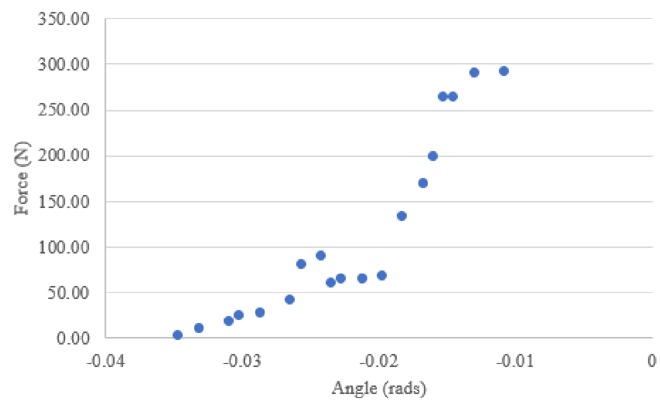


Fig 5. Force over angle graph. The area under the curve of this graph times the length of the pendulum is the net work done before fracture.

## IV. DISCUSSION

For both methods of calculating energy absorption, the brass specimen failure surface showed signs of necking before fracture. Plastic deformation before fracture is a characteristic of a ductile fracture. The marble specimen appeared to shatter before impact. This is a characteristic of a brittle fracture profile [2].

### A. *Energy Absorption (Potential Energy Method)*

The potential energy method for the calculation of absorption energy resulted in 6.47 J ± 1.28 J for the brass specimen and 5.74 J ± 1.05 J for the marble specimen. The higher energy absorption of the brass specimen is corelated with ductile fracture profiles. Ductile fracture profiles typically have larger energy absorption before fracture. Likewise, the lower energy absorption of the marble specimen is corelated with a brittle fracture profile. Brittle fracture profiles typically have lower energy absorption before fracture [2].

### B. *Work Done (Strain Estimation Method)*

The strain estimation method for the calculation of the work done resulted in 3.70 J ± 0.142 J for the brass specimen and 2.47 J ± 0.07 J for the marble specimen. The brass specimen was shown to have a higher absorption energy corelates with a ductile fracture profile. The marble specimen was shown to have a lower absorption energy which corelates with a brittle fracture profile [2].

As a side note, the graph of force over time revealed that the pendulum acted as a spring-mass-damper system and oscillating with a decreasing amplitude to trending to zero. This was the case with both the brass and marble specimens.

### C. Method Comparison

This lab procedure's variation of the potential energy method is slightly inaccurate. Since a student dropped the impactor head, it is impossible to know if any extra energy was added to the system that was unaccounted for. This could explain why the values for the potential energy were consistently higher than strain estimation method's values. This could be fixed by creating a rig to drop the pendulum impact head from the same height every time. This would effectively remove the human error of the release.

## V. Conclusion

This lab report attempted primarily to examine the difference between brittle and ductile fractures under a pendulum impact test. Secondarily, it compared the potential energy method results to the strain estimation results for energy absorption. Considering the plastically deforming failure surface of brass along with the higher absorption energy before fracture, the brass specimen fracture fell in line with a ductile fracture profile. On the other hand, the shattering failure surface of the marble along with its consistently lower energy absorption before fracture corelates with a brittle fracture profile.

## Appendix

TABLE V
UNCERTAINTY VALUES

| Value | Number | Value | Number |
|---|---|---|---|
| Brass Uncertainty | | | |
| $\theta$ (rads) | -1.496 | $\frac{\partial \Delta H}{\partial \theta}$ (m/rads) | -0.878 |
| $l$ (m) | 0.88 | $\frac{\partial PE}{\partial M}$ (J/rads) | 3.32 |
| $\Delta H$ (m) | 0.338 | $\frac{\partial PE}{\partial \Delta H}$ (J/m) | 22.6 |
| M (kg) | 2.3 | $\frac{\partial U_{break}}{\partial U_{osses}}$ (J/J) | 7.62 |
| g (N/kg) | 9.81 | $\frac{\partial U_{break}}{\partial PE}$ (J/J) | 1.09 |
| PE (J) | 7.62 | $U_{theta}$ (rads) | 0.000278 |
| $U_{losses}$ (J) | -1.09 | $U_{\Delta H}$ (m) | 0.000523 |
| $U_l$ (m) | 0.0005 | $U_M$ (kg) | 0.05 |
| $U_{PE}$ (J) | 0.165 | $U_{U_{Losses}}$(J) | 0.165 |
| $U_{U_{break}}$ (J) | 1.28 | $U_W$ (J) | 0.142 |
| $F_{im}$ (N) | | 579 | |
| Marble Uncertainty | | | |
| $\theta$ (rads) | -1.48 | $\frac{\partial \Delta H}{\partial \theta}$ (m/rads) | -0.876 |
| $l$ (m) | 0.88 | $\frac{\partial PE}{\partial M}$ (J/rads) | 3.00 |
| $\Delta H$ (m) | 0.306 | $\frac{\partial PE}{\partial \Delta H}$ (J/m) | 22.6 |
| M (kg) | 2.3 | $\frac{\partial U_{break}}{\partial U_{osses}}$ (J/J) | 6.90 |
| g (N/kg) | 9.81 | $\frac{\partial U_{break}}{\partial PE}$ (J/J) | 1.09 |
| PE (J) | 6.90 | $U_{theta}$ (rads) | 0.000278 |
| $U_{losses}$ (J) | -1.09 | $U_{\Delta H}$ (m) | 0.000516 |
| $U_l$ (m) | 0.0005 | $U_M$ (kg) | 0.05 |
| $U_{PE}$ (J) | 0.151 | $U_{U_{break}}$ (J) | 1.05 |
| $U_{U_{Losses}}$(J) | 0.151 | $U_W$ (J) | 0.0716 |
| $F_{im}$ (N) | | 293 | |

### A. Uncertainty Calculations (Potential Energy)

$$\Delta H = l - l\cos(\theta) \tag{6}$$

$$U_{\Delta H} = \sqrt{(l\sin(\theta)U_{\theta})^2 + (1-\cos(\theta)\, U_l)^2} \tag{7}$$

$$PE = Mg\Delta H \tag{8}$$

$$U_{PE} = \sqrt{(MgU_{\Delta H})^2 + (g\Delta H U_M)^2} \tag{9}$$

$$U_{break} = U_{losses} - \Delta PE \tag{10}$$

$$U_{U_{break}} = \sqrt{\left(\Delta PE U_{U_{energy\ loss}}\right)^2 + \left(U_{energy\ loss} U_{\Delta PE}\right)^2} \tag{11}$$

### B. Uncertainty Calculations (Strain Estimation)

$$W = I\int_{\theta_1}^{\theta_2} F_{im}\, d\theta \tag{12}$$

$$U_W = \sqrt{(lF_{im}U_{d\theta})^2} \tag{13}$$

## References

[1] Ghatu Subhash and Shannon Ridgeway. *Mechanics of Materials Laboratory Course*. Morgan & Claypool Publishers, San Rafael, California, 2018

[2] "What is a Ductile Fracture" – Definition from Corrosionpedia, https://www.corrosionpedia.com/definition/421/ductile-fracture