# Impact strength testing device

**Isaac Mugenyi**

Degree Thesis

Materials Processing Technology

2019

Isaac Mugenyi

| | |
|---|---|
| DEGREE THESIS | |
| Arcada | |
| | |
| Degree Programme: | Materials Processing Technology |
| | |
| Identification number: | 20794 |
| Author: | Isaac Mugenyi |
| Title: | Impact Strength Testing Device |
| Supervisor (Arcada): | Rene Herrmann |
| | |
| Commissioned by: | Arcada University of Applied Sciences |


Abstract:

The idea of this thesis to design and assemble the different manufactured components into an Impact Strength Testing Device (Izod). The machine will have four major components to it; frame, clamp, pendulum hammer and the scale or meter to read the data.

First, the individual parts of the of the test device are designed in SolidWorks software and brought together into a final assembly. The manufactured parts are assembled together and welded were needed.

Secondly, to use the test device, it must be calibrated to the standards and both the static and dynamic method were used. The dynamic method of calibration was preferred to the static because of its easy repeatability and accuracy.

In addition to the traditional dynamic method of calibration, which relies upon the measurement of angles, the alternative method in this thesis uses the Potentiometer to measure the voltage and periods as the pendulum oscillates freely with or without the hammer mass. Two distinctly different oscillations were recorded, getting periods that were used to calculate the centre of mass for the entire pendulum. Voltage has a linear relationship with the angles measured due to the ratio of division in Potentiometer corresponding with the angles.

Finally, sixty test specimens of composite material were tested and because of the stiffness of this material, an overall higher impact strength were recorded to break these specimens compared to polymers.




| | |
|---|---|
| Keywords: | Impact energy, impact strength, Izod pendulum test device, center of mass, pendulum hammer, oscillations |
| Number of pages: | 56 |
| Language: | English |
| Date of acceptance: | |

# TABLE OF CONTENTS

## FIGURES

## TABLES



## EQUATIONS

## LIST OF SYMBOLS

| | **Name** | **Symbol** | **Unit** |
|---|---|---|---|
| 1 | Acceleration due to gravity | g | $\left[\frac{m}{s^2}\right]$ |
| 2 | Velocity | v | $\frac{m}{s}$ |
| 3 | Mass | m | kg |
| 4 | Length | L | m |
| 5 | Diameter | D | m |
| 6 | Area | A | $m^2$ |
| 7 | Energy | E | J |
| 8 | Friction | f | - |
| 9 | Centre of mass of pendulum with hammer | $L_c$ | m |
| 10 | Height | h | m |
| 11 | Period | T | s |
| 12 | Angle | $\varphi$ | degrees |
| 13 | Centre of mass of pendulum without hammer | $l_1$ | m |
| 14 | Inertia | $I$ | $kg.m^2$ |
| 15 | Force | F | N |

# FOREWORD

A very special thank you to my thesis surpervisor, Mr Rene Herrmann for the guidance, knowledge and time invested throughout this whole process.

I would like to thank all the other academic staff for the knowlegde they have imparted to me throughout my studies at Arcada.

Lastly, I would like to thank my family for their continous support and encouragement during my studies and particulary during this thesis.

# 1 INTRODUCTION

“Impact strength is the ability of a material to resist failure when loaded suddenly high speed” [1] that is energy lost per cross sectional area, meaning that an impact strength test measures the exact energy that would cause a material to fail and it is reported as Joules per square meter ($J/m^2$). [2]

Impact strength of a material is determined by both internal factors and external factors. Internal factors include the actual mechanical properties of the material while the external factors include; temperature, rate of loading, geometry of the specimen and definition of failure. [1]

The tables below show some typical values of impact strength testing on common engineering materials:

*Table 1:Impact strength test (Izod) of polymers [3]*

| **Polymers** | **Impact energy** $\left[\frac{J}{m^2}\right]$ |
|---|---|
| **Engineering Polymers** | |
| ABS | 1.4 -14(1-10) |
| Polycarbonates | 19 (14) |
| Acetals | 3 (2) |
| Polytetrafluorethylene (Teflon) | 5 (4) |
| **General use polymers** | |
| Polyethylene<br>High density<br>Low density | <br>1.4 -16(1-12)<br>22(16) |
| Polyvinylchloride | 1.4(1) |
| Polypropylene | 1.4-15(1-11) |
| Polystyrene | 0.4(0.3) |
| Polyesters | 1.4 (1) |
| Epoxies | 1.1(0.8) |

*Table 2:Impact test (Charpy) of alloys [3]*

| **Alloy** | **Impact energy** $\left[\frac{J}{m^2}\right]$ |
|---|---|
| 1040 Carbon steel | 180(133) |
| 8630 Low alloy steels | 55(41) |
| c. 410 stainless steel | 34(25) |
| L2 tool steel | 26(19) |
| Ferrous super alloy (410) | 34(25) |
| a. Ductile iron, quench | 9(7) |
| b. 2048, plate aluminum | 10.3(7.6) |

There are several standard methods used in impact strength testing and these include;

- Pendulum type instruments i.e. Izod and Charpy test
- Drop weight or Falling weight method.

**Drop weight or Falling weigh method**

Drop weight or Falling weight method is simply a method used to determine whether a material will crack or fracture when a mass of a known weight is dropped on the material. The weight can be increased gradually or the height from which the mass falls can also be raised gradually. This method is well suited to testing material in sheet form. [1]

**Pendulum type method i.e. Izod and Charpy test**

The pendulum type method is a dynamic test in which a pendulum hammer of known mass is attached to a machine and in one swing of the hammer it causes the specimen to fracture or fail. The specimen is usually notched or unnotched though notching the specimen causes a concentrated stress increases the likely hood of the specimen breaking with a brittle fracture rather than a ductile fracture. [4]

The Izod and Charpy test also measure the bending impact strength of a specimen though in the Charpy test the specimen is supported at both ends, while in the Izod test the specimen is supported as a cantilever. [2] [1]

*Table 3:Stardard methods of measuring unnotched Charpy impact strength [2]*

| **Standard** | **ISO 179-1 and ISO 197-2** |
|---|---|
| Specimen | 80mm $^{x}$ 10mm$^{x}$ 4mm cut from the center of an ISO 3167 Type A specimen, also referred to as an ISO 179/1Eu specimen. |
| Conditioning | Specimen conditioning, including any post molding treatment, shall be carried out at 23ºC±2ºC and 50 ± 5% R.H for minimum length of time of 88h except where special conditioning is required as specified by the appropriate material standard. |
| Apparatus | The machine shall be securely fixed to a foundation having a mass at least 20 times that of the heaviest pendulum in use and capable of being leveled. |

## 1.1 Relevance

The study of impact strength of materials is motivated by a desire to understand the behavior of common engineering materials under dynamic loading. With new materials, such as composites, being widely adopted by the automobile and aerospace industry continuous study is required. An understanding of their behavior under static and dynamic loading is crucial as materials are sensitive to different testing variables. Impact strength tests are an important part of determining performance, service life and service safety of materials and products.

There are currently two methods that are used to test impact strength of materials; drop weight method and pendulum type methods as described above.

The focus of this thesis is on the Izod pendulum impact strength test which measures the amount of energy absorbed by a material. In order to calculate the energy absorbed, the indicated energy is first determined by measuring the difference between the initial angle and the final angle of the pendulum hammer. Once the indicated energy is determined, it is divided by the cross-sectional area of the specimen resulting in the absorbed energy.

# 2 BACKGROUND

The history of impact strength testing dates to the 19th century. It was highly driven by the building of the railways, when it was discovered that impact loads affect materials differently to static loads. At this time, the development of impact strength testing was mostly driven by the British. In 1857 Rodman designed and made a drop weight machine which was used to test finished products like pipes and ankles. [5]

The test was simple in the way it worked, the weight was dropped on the material and it either broke or it didn’t break. The data produced was used in the manufacture of other products and Rodman’s machine was used for 30years to test steel and steel products. [5]

But this was not the first documentation of impact strength testing. In fact, the very first documentation of impact strength testing was back in 1824 by a man called Tredgold who published about the theory of cast iron to resist impact forces. [5]

The drop impact test was improved due to the introduction of the notch on the rectangle samples. The improvement was important because some ductile material just bent without breaking but with a notch the material become more fragile. [5]

More work needed to be done on the impact strength test to improve the test and develop the it to produce consistent data. Between the years of 1895 to 1922 both national and international bodies were responsible for introducing the standardization of impact strength tests. These bodies included The American Society for Testing and Material (ASTM) and the International association for Testing materials. (IATM) [5]

In 1898 Russell built a Pendulum Impact Machine unlike the drop weight machine. Russell argued that the drop weight did not provide any more information apart from whether the material broke or not, but the Pendulum Impact Machine would provide more information on the amount of energy absorbed by the material on impact. Russell’s swinging pendulum machine was very big and could break large products. [5]

The design concept of the Russell’s swinging pendulum machine was detailed and well analyzed in its mechanics and accounted for the friction. This machine provided more consistent data and most importantly determined the amount of energy absorbed by the material when an impact force is applied. [5]

The American Society for Testing and Material and the International Association for Testing Materials continued with their research to improve impact testing and in 1905 Charpy, a member of the IATM, designed a new machine called the Charpy Method Test. It is a pendulum impact strength test like the one we used today. [5]

The Charpy method originally used specimen sizes of 10 mm by 10 mm and length of 53mm, with 40mm between the points and a notch of 2 mm to 5 mm.

The ASTM committee continued with their research and in 1922 to 1933 they developed standard methods for the pendulum impact strength test. The two approved pendulum impact strength tests were the Charpy and the Izod test. The standards detailed the geometry of the specimens, the size of specimens, notch, dimensions of the hammer, geometry of the striking edge and distance of striking. These and many more standards were detailed but over the years due to research and experience, they have been revised from time to time and in detail. [5]

## 2.1 Manufactures of Impact Testing Machine

There are various manufacturers and suppliers of Impact strength testing machines in the world The Zwick Roell company is one of the leading manufacturers and suppliers of different systems and testing machines including the Impact Strength Testing machines. Zwick Roell company produces an impact testing machine called the Pendulum Impact Tester PSW 750. [6]

The Pendulum Impact Tester PSW 750, can perform impact both as a Charpy and Izod testing machine by changing the fixture support. [6] “The PSW 750 can be used for tests to the following standards (among others): ISO 148- 1, ISO 14556, ASTM E23, JIS Z 2242, GOST 9454-78, DIN 50115.” [6] It is an automatic machine detecting errors during testing. It has potential energy of 750 joules and the results of impact energy and impact strength are recoded in joules and kilojoules per meter squared ($\frac{kJ}{m^2}$). Different pendulum hammers can be used and changed easily from 300 joules to 750 joules. Specimens varying in sizes of $55 \times 2.5 \times 10\ mm$ to $55 \times 10 \times 10\ mm$ can be tested in this machine which requires minimum specimen preparation and is normally done at room temperature. [6]

## 2.2 Methodology

My approach is to use an available steel frame to design and assemble the different manufactured components into an Izod Impact Strength Testing Device. The machine will have four major components to it; frame, clamp, pendulum hammer and the scale or meter to read of the data.

# 3 LITERATURE REVIEW

## 3.1 Izod Theory

The Izod impact test is a standardized test described by the ASTM-D 256, ISO 180 and is named after Edwin Gilbert Izod (1876–1946), who first described it 1903.

The Izod impact test measures the impact strength of a vertical cantilevered notched specimen hit by a swinging hammer. The Izod test exerts bending forces on the specimen and the absorbed energy is the measured. Impact energy is expressed in $\frac{kJ}{m^2}$ where impact energy is divided by the cross-sectional area for the ISO standard while ASTM standard expresses it in $\frac{J}{m}$.

The notch in the specimen causes a concentration of stress which makes the specimen more likely to have a brittle fracture. [2], [4]

### 3.1.1 Impact Energy

"Impact energy is a measure of the work done to fracture a test specimen." [7] when the hammer hits the specimen it will absorb energy until it yields. The specimen will be subjected to plastic deformation at the notch. The specimen will absorb energy and when it cannot absorb more energy it will fracture. Tougher materials will have higher impact strengths while brittle materials have low impact strength. [7]

**Major factors that affect impact strength of a specimen**

- Temperature
- Velocity
- Notch sensitivity

**Temperature**

Temperature affects the process of energy absorption during impact hence affecting the yield behavior of a specimen. Low temperature causes the specimen to be more brittle while higher temperature causes the specimen to be more ductile.

**Velocity**

The speed at which the specimen is hit or struck by the hammer determines the type of failure that will occur. Very high speeds will cause brittle failure in most materials of specimen while in low speeds, most materials will exhibit good impact strength.

**Notch sensitivity**

A notch is a sharp corner made in a specimen; this causes a localized concentration of stress higher than the stress imposed elsewhere in the specimen. A notch makes failure most likely and the radius and depth of the notch affects it even further. Different materials have different sensitivity to notches. [8]

### 3.1.2 Center of Mass/ Gravity

Center of mass is defined as; "a single point at which the whole mass of the body or system is imagined to be concentrated and all the applied forces acts at that point". [9] When an external force is applied on the body it is the center of mass that moves in the direction of the force. The center of mass is also that point where the distributed mass of the body balances.

Center of gravity is the other term that is used interchangeably with center of mass. The center of gravity of a body is the same as the center of mass in a uniform and parallel gravity field and so calculations are done using or referring to the center of gravity. [10]

## 3.2 Schematics of the Izod Test

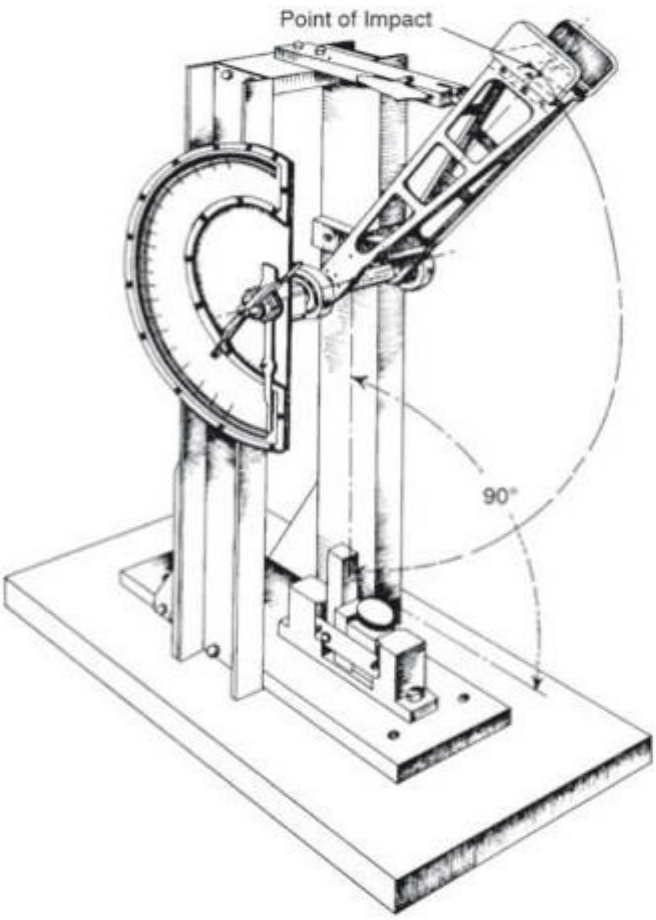



*Figure 1:Cantilever Beam Izod Impact Machine [2]*

## 3.3 Test Method of a Cantilever Izod Impact Test

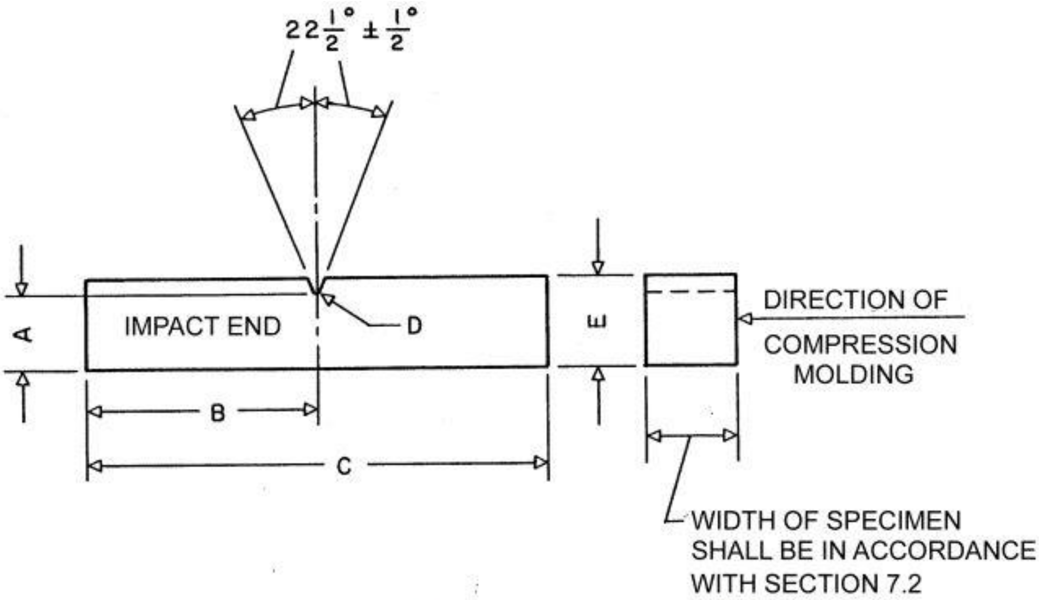
### 3.3.1 Apparatus

The machine consists of a rigid frame, pendulum hammer, a clamp or fixture to place the specimen, a massive base that is at least 20 times heavier than the hammer and a computer or dial used to measure the energy loss.

The clamp or fixture is mounted onto the base to which the frame is connected. The pendulum hammer is connected to the frame with a release mechanism and a dial or computer connected as well.

The pendulum hammer can have one or more arms which must be rigid enough to clear specimens and reduce vibrations. The head of the pendulum used to strike the specimens should be of hardened steel, with a cylindrical surface and a radius of $0.80 \pm 0.20mm$. The frame and pendulum should be rigid enough to maintain proper alignment of the hammer and specimen both in motion and at impact to reduce vibration and energy loss. [4]

### 3.3.2 Test Specimen




| | | |
|---|---|---|
| A | 10.16 ± 0.05 | 0.400 ± 0.002 |
| B | 31.8 ± 1.0 | 1.25 ± 0.04 |
| C | 63.5 ± 2.0 | 2.50 ± 0.08 |
| D | 0.25R ± 0.05 | 0.010R ± 0.002 |
| E | 12.70 ± 0.20 | 0.500 ± 0.008 |

*Figure 2:Dimensions of Izod-Type Specimen ASTM-D 256 [4]*

### 3.3.3 Notching Test Specimen

The test specimens are notched by milling with constant feed rate and cutting speed throughout the procedure. The notch is angle is $45 \pm 1°$ with a depth $10.16 \pm 0.05mm$ of material remaining on the specimen material. [4]

### 3.3.4 Conditioning

A temperature of $23 \pm 2$°C is ideal for storing test specimen and carrying out the Izod impact test and a $50 \pm 5$% relative humidity. [4]

### 3.3.5 Procedure

Ideally run three to five blank tests to determine the least frictional loss of energy and this should not be greater than 1% for a 2 J pendulum or 0.5% for the specified pendulums with a 4.0 J for greater energy pendulums.

Each material should have at least five to ten sample tests carried out in suitable conditions with each group of specimens having the same width.

Approximate the energy needed to break the specimen and select the lightest hammer available to break the specimen unless the impact energy needed to break the specimen is more than 85% and if this happens use the pendulum hammer with the highest energy.

Check that the pendulum hammer is in place properly and that the specimens conform to the standards.

Check to make sure that the dial or pointer on the impact machine works correctly, adjust and correct any excessive friction if detected in the machine.

Measure and record the width of the specimens and the width and depth of material remaining on the notching of the specimen.

Position and clamp the specimen as shown in the figure below;

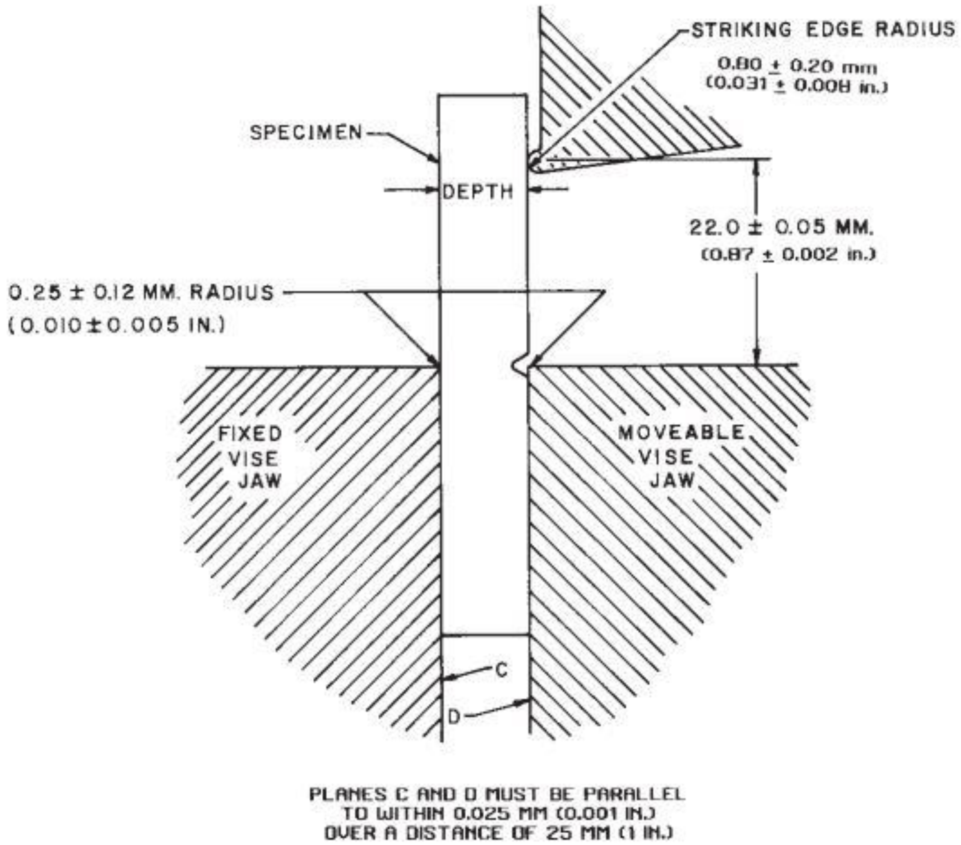



*Figure 3:Schematic of the Clamp, Specimen & Striking Hammer in Izod Impact Test* [11]

Release the pendulum hammer and record the impact energy that is taken to break the specimen as well as the appearance and condition of the specimen.

Calculate the correct impact energy by subtracting the friction from the indicated impact energy to break the specimen, record it and compare it with the energy specified for that hammer.

Divide the energy measured by the width of the specimen to get the impact resistance in joules per meter(J/m) or kilojoules per meter(kJ/m) if the energy is divided by the cross-sectional area of the specimen.

Lastly, using specimens of the same width and type of break, obtain the average impact strength excluding the specimens that did not break. [4] [2]

### 3.3.6 Specimen Types of Failures

"**C**- Complete Break—A break where the specimen separates into two or more pieces.

**H**- Hinge Break—An incomplete break, such that one part of the specimen cannot support itself above the horizontal when the other part is held vertically (less than 90° included angle).

**P-** Partial Break—An incomplete break that does not meet the definition for a hinge break but has fractured at least 90 % of the distance between the vertex of the notch and the opposite side.

**NB**. Non-Break—An incomplete break where the fracture extends less than 90 % of the distance between the vertex of the notch and the opposite side" [4]

## 3.4 Risk Assessment

The table shows the potential risks, source of risks, and consequences of these potential risks of operating the Impact Strength Testing Device to both the user and the bystanders. The risk assessment also puts control measures in place to avoid these accidents from happening.

Because this is a newly built machine the risk assessment will continually be reviewed and updated according to feedback provided by the users and according to the workshop or laboratory standards.

*Table 4:Risk assessment*

| **Lab;** Impact strength material testing | | **Machine;** Pendulum Impact Testing Device | | **Applicant;** Isaac Mugenyi | |
|---|---|---|---|---|---|
| **Risk** | **Risk group** | **Risk sources** | **Worst consequences** | **Risk level** | **Risk control** |
| Bruising injuries when loading the specimen and removing it. | User | Pendulum hammer and frame | Injuries to fingers and hand | Possible | • Correct set up of the machine<br>• Ensure the pendulum is at complete stop and secured before loading the specimen |
| Fracture injuries like broken fingers and arm | User and people very close proximity | swinging pendulum | Severe Fractures and bleeding | Unlikely | • Correct set up of the machine<br>• Ensure the pendulum is at complete stop and secured before loading the specimen<br>• Stay clear of the pendulum path<br>• Never stop the pendulum with any part of the body |
| Injuries from broken material debris | User and people around | Material debris | Injuries to eyes and body | Possible | • Wear protective clothing like, face mask, googles and lab coat<br>• Ask people around to stay away. |

## 3.5 Mathematical Pendulum

Mathematical pendulum is a mass point connected to a rigid massless rod of known length *l* at the upper end enabling it to move in the vertical plane. [12]

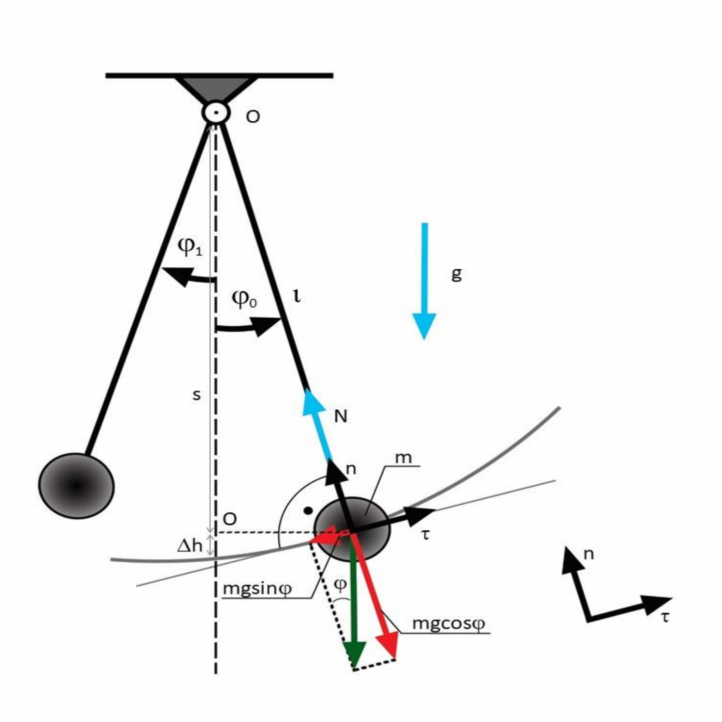



*Figure 4:Mathematical Pendulum*

Potential energy is

$$E_{pot} = mgh \ [13] \tag{1}$$

Kinetic energy is

$$E_{kin} = \frac{1}{2}mv^2 \ [13] \tag{2}$$

Where;

$$E_{p1} = mg\Delta h_1 = E_k = \frac{1}{2}mv^2 = E_{p2} = mg\Delta h_2 + E_f \tag{3}$$

$$\Delta h_1 - \Delta h_2 = \Delta h_3 \tag{4}$$

$$E_f = mg\Delta h_3 \tag{5}$$

**Note;** $E_f$ is friction energy

$$mg\Delta h_1 = \frac{1}{2}mv^2 = mg\Delta h_2 + E_f \tag{6}$$

**With no sample;**

$$mg\Delta h_1 - mg\Delta h_3 = E_d + E_{p4} \tag{7}$$

$$E_d = mg(\Delta h_1 - \Delta h_3 - \Delta h_4) \tag{8}$$

**Note:** $\boldsymbol{E_d} =$ is the Potential pendulum energy

### 3.5.1 Energy Analysis

To determine height changes (Δh) of the pendulum, small angle (φ) will be measured.

$$s = l - \Delta h \tag{9}$$

$$\Delta h + s = l \tag{10}$$

$$\cos\varphi = \frac{l - \Delta h}{l} = 1 - \frac{\Delta h}{l} \tag{11}$$

$$\frac{\Delta h}{l} = 1 - \cos\varphi \tag{12}$$

$$\Delta h = l(1 - \cos\varphi) \tag{13}$$

$\boldsymbol{E_f = 0}$

$$E_0 = mgh = mgl(1 - \cos\varphi_0) \tag{14}$$

$$E_1 = mgh_1 = mgl(1 - \cos\varphi_1) \tag{15}$$

$$\Delta W = E_0 - E_1 \tag{16}$$

$$\Delta W = gml(1 - \cos\varphi_0) - gml(1 - \cos\varphi_1) \tag{17}$$

$$\Delta W = gml(\cos\varphi_1 - \cos\varphi_0) \tag{18}$$

**Note;** Even if the hammer is very heavy it is still possible to measure small fracture energies by simply using a small initial angle ($\varphi_0$).

### 3.5.2 Motion Analysis

The simple pendulum is not dependent on the mass, nor is it dependent on amplitude for the period but for small angle displacement, the pendulum will go through a simple harmonic motion. [14]

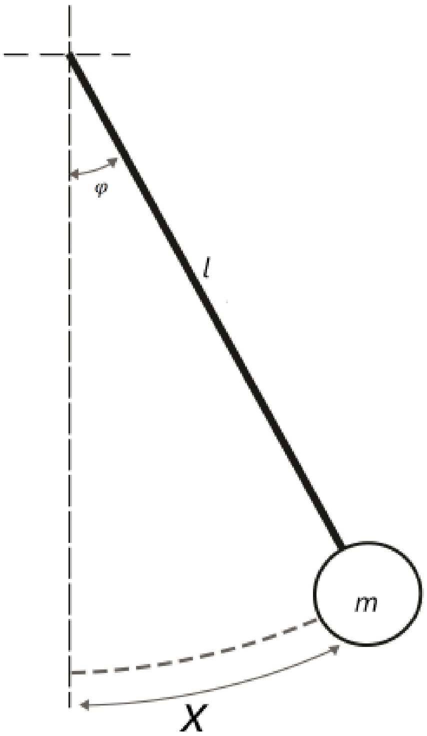



*Figure 5:Pendulum Motion*

$$\varphi = \frac{x}{l} = x = l\varphi \text{ [14]} \tag{19}$$

$$\sin\varphi \approx \varphi \tag{20}$$

Using the Newton's second law;

$$F = -mg\sin\varphi \text{ [14]} \tag{21}$$

$$F = -mg\sin\varphi \approx -mg\varphi = \frac{mgx}{l} \text{ [14]} \tag{22}$$

Since;

$$\omega = \sqrt{\frac{k}{m}} = \sqrt{\frac{\frac{mg}{l}}{m}} = \sqrt{\frac{g}{l}}\ [14] \tag{23}$$

$$T = \frac{2\pi}{\omega} = \frac{1}{f} = 2\pi\sqrt{\frac{l}{g}}\ [14] \tag{24}$$

## 3.6 Physical Pendulum

"A physical pendulum is any real pendulum that uses an extended body, as contrasted to the idealized simple pendulum with all of its mass concentrated at a point." [14]

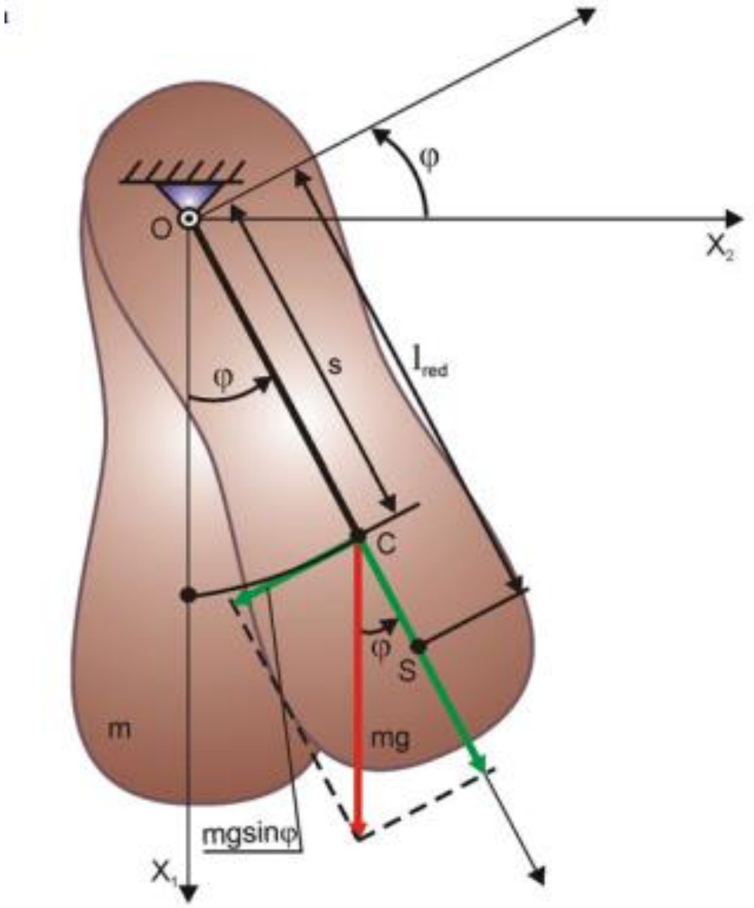



*Figure 6:Physical Pendulum of Mass [12]*

The physical pendulum is fixed at point O, with point C as the center of mass, and φ the angle rotation of the pendulum. To analyze this pendulum, we will assume that there is no friction at point O using small angle displacement. [12]

To calculate the energy in a physical pendulum we use the center of mass of the hammer instead of the change in height as a function of pendulum length and angle. This is because in a physical pendulum the mass is distributed. Where;

**Note;** In figure **5**, $S = l_c$ and $l_c$ refers to the length to the center of mass.

$$\Delta W = E_0 = E_1 \tag{25}$$

$$E_0 = mgh = mgl_c(1 - \cos\varphi_0) \tag{26}$$

$$E_0 = mgh = mgl_c(1 - \cos\varphi_1) \tag{27}$$

$$\Delta W = gml_c(1 - \cos\varphi_0) - gml_c(1 - \cos\varphi_1) \tag{28}$$

$$\Delta W = gm_{tot}l_c(\cos\varphi_1 - \cos\varphi_0) \tag{29}$$

## 3.7 Calibration Procedure

There are two types of methods used in the calibration of the pendulum arm namely;

1. Static method
2. Dynamic method

### 3.7.1 Static Method

To find the center of mass or the effective length of the pendulum arm, the pendulum arm is balanced on a single pivot point, then the pivot point is the position of the center of mass or the length L needed to calculate the energy of the physical pendulum.

### 3.7.2 Dynamic Method

The testing device is bolted on a firm base of at least 20 times heavier than the hammer being used. The base should be firm to prevent loss of energy through vibration.

Ensure that the pendulum arm is straight and insert it vertically, clamp it and check for alignment.

Check that the machine is well oiled and insert the pendulum arm in the vertical position and clamp it.

Swing the pendulum hammer freely without a specimen and record the height before the swing and the height it gets after the swing and the difference in height can be used to calculate the friction loss.

An angle meter is used to record the angle of the pendulum as a function of time, but the velocity of the pendulum will increase until the pendulum is vertical, and the velocity will be its derivative between two samples [11] [15]

$$v_{max} = \frac{s}{t} = \frac{2\pi R\varphi}{t} \tag{30}$$

R= real total length of the pendulum.

If the friction is zero

$$mg\Delta h - 0 = \frac{1}{2}mv^2 \tag{31}$$

Divide by mass (m) and get

$$\frac{1}{2}mv^2 = mgl_c(1 - \cos\varphi) \tag{32}$$

$$v = \sqrt{2gl_c(1 - \cos\varphi)} \tag{33}$$

Pendulum has a maximum velocity at $\varphi = 90$

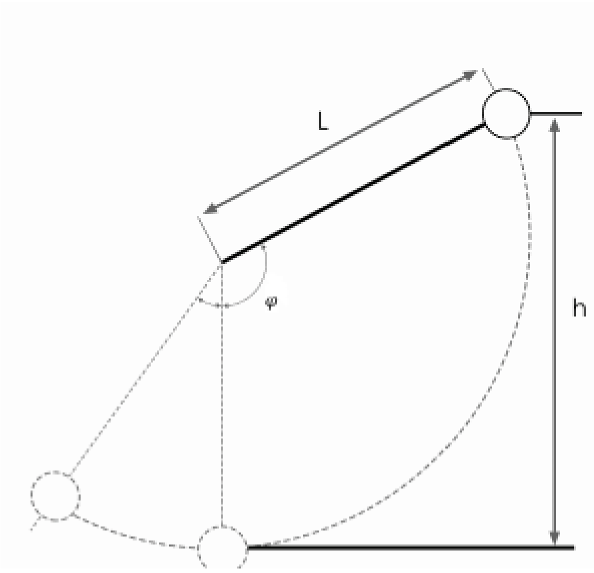



*Figure 7:Impact Velocity*

Pendulum has a maximum velocity at $\varphi = 90$ degrees.

Dynamic calibration is the preferred method of impact pendulum testing devices due to its accuracy and easy repeatability but to dynamically calibrate the impact pendulum device we must determine the center of mass of the pendulum with the hammer and without the hammer.

To determine the center of mass of the pendulum, two measurement of the period (T) were done with and without the hammer. This can be done because the mass of the hammer is known and pendulum mass without the hammer is also known. This allows us to measure the distance from suspension to the center of mass of the hammer. ($L_{hammer}$)

We know that:

**Kinetic energy;**

$$E_{kin} = \frac{1}{2} I\omega^2 \quad [16] \qquad (34)$$

**Period of oscillation;**

$$T = \frac{2\pi}{\omega} = \sqrt{\frac{I}{mg\, l_c}} \quad [14] \qquad (35)$$

**Note;** The inertia (*I)* and the center of mass ($l_c$) are unknown.

The center of mass of the pendulum with hammer can be calculated by:

$$l_c = \frac{m_1 l_c + m_2 L_{hammer}}{m_1 + m_2} \quad [17] \tag{36}$$

According to Steiner Satz (parallel axis theorem) [18], inertia can be calculated by:

$$I = I_0 + \ m_2 \, L_{hammer}^2 \tag{37}$$

**Period with no hammer;**

$$T_1 = 2\pi \sqrt{\frac{I_1}{m_1 g l_1}} \tag{38}$$

**Period with hammer;**

Because this is for finding the period of the pendulum and hammer, the mass and length of hammer is added to the inertia and inserted equation 36 to find the center of mass for the whole system.

$$T_2 = 2\pi \sqrt{\frac{I_1 + m_2 l_2}{(m_1 + m_2) g (\frac{m_1 l_1 + m_2 l_2}{m_1 + m_2})}} \tag{39}$$

The total mass cancels out remining with two equations:

$$\left(\frac{T_1}{2\pi}\right)^2 = \frac{I_1}{m_1 g l_1} \tag{40}$$

$$\left(\frac{T_2}{2\pi}\right)^2 = \frac{I_1 + m_2 l_2^2}{g(m_1 l_1 + m_2 l_2)} \tag{41}$$

**Approach;**

$$I_1 = I_1 \tag{42}$$

$$I_1 = \left(\frac{T_1}{2\pi}\right)^2 m_1 g l_1 \tag{43}$$

$$I_1 = \left(\frac{T_2}{2\pi}\right)^2 g(m_1 l_1 + m_2 l_2) - m_2 l_2^2 \tag{44}$$

$$\left(\frac{T_1}{2\pi}\right)^2 m_1 g l_1 = \left(\frac{T_2}{2\pi}\right)^2 g(m_1 l_1 + m_2 l_2) - m_2 l_2^2 \tag{45}$$

$$\left(\frac{T_1}{2\pi}\right)^2 m_1 g l_1 - \left(\frac{T_1}{2\pi}\right)^2 m_1 g l_1 = \left(\frac{T_2}{2\pi}\right)^2 g(m_2 l_2) - m_2 l_2^2 \tag{46}$$

$$l_1 g m_1 \left[\left(\frac{T_1}{2\pi}\right)^2 - \left(\frac{T_2}{2\pi}\right)^2\right] = m_2 l_2 \left[\left(\frac{T_2}{2\pi}\right)^2 g - l_2\right] \tag{47}$$

$$l_1 = \frac{m_2 l_2 \left[\left(\frac{T_2}{2\pi}\right)^2 - l_2\right]}{g m_1 \left[\left(\frac{T_1}{2\pi}\right)^2 - \left(\frac{T_2}{2\pi}\right)^2\right]} \tag{48}$$

**Note;** $\boldsymbol{l_1}$ is the center of mass for the pendulum without the hammer. Once the center of mass for the pendulum without the hammer $(\boldsymbol{l_1})$ is calculated, it allows us to calculate $(\boldsymbol{l_2})$ the center of mass with the hammer because all the other parameters are known.

# 4 METHOD

The impact testing device was designed and assembled using SolidWorks. Each part was designed individually, sent to be milled, assembled and then welded together.

SolidWorks is a computer design software used in product development i.e. Solid modelling, computer aided design and computer aided engineering and can be used on Microsoft Windows. It is issued by Dassault Systems company. [19]

## 4.1 The Frame

We used an already available rigid steel frame onto which all the other components were assembled, it was measured carefully, and the dimensions were used to draw the frame in SolidWorks. Sketch, boss extrude, and clearance holes are some of the commands used in the design of the frame.

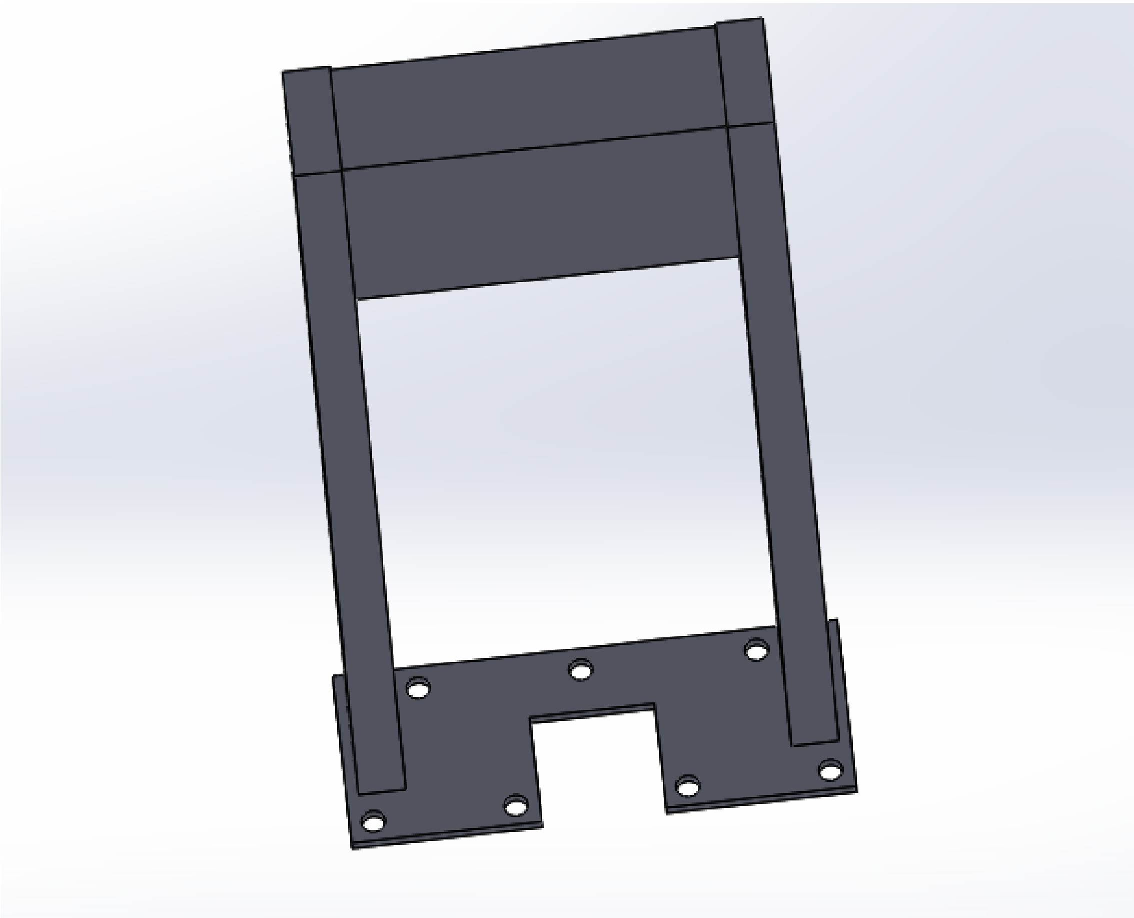


*Figure 8:The Frame*

## 4.2 The Clamp

The clamp will be used for securing the specimen securely with easy loading and removing of the test specimen during the impact testing. The clamp was designed in two parts and assembled together using some of these commands; extrude boss, extrude cut, holes and fillet.

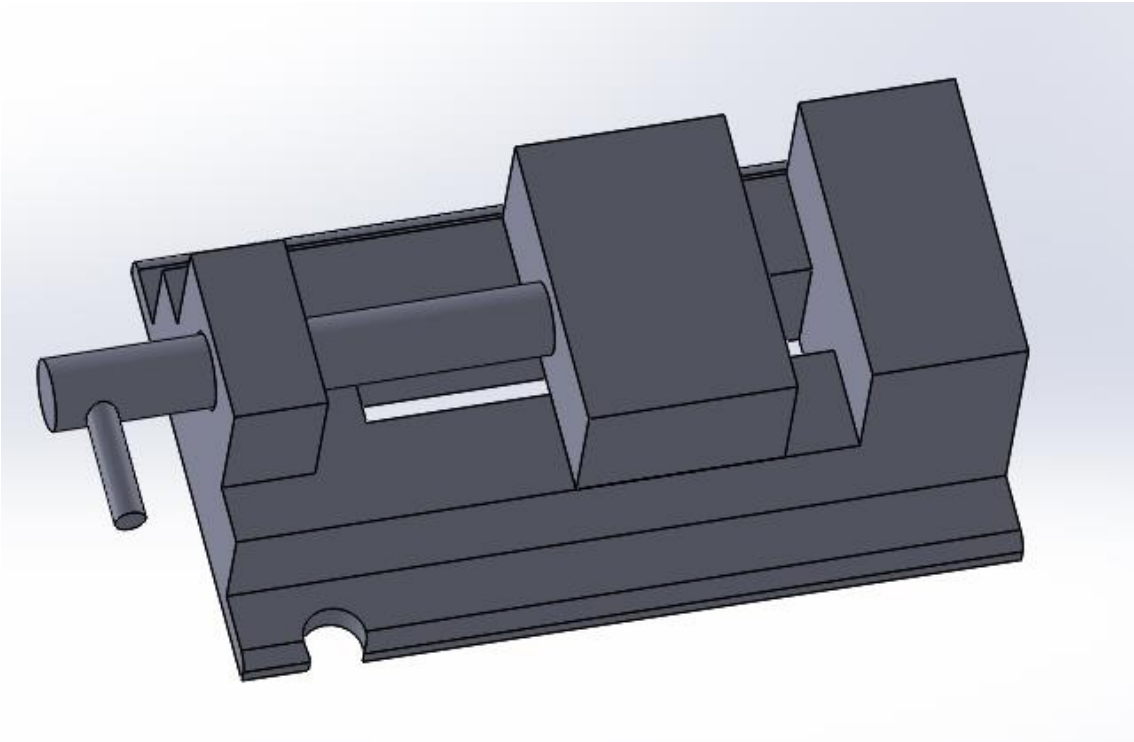


*Figure 9:The Clamp*

## 4.3 The Pendulum Arm

The pendulum arm is to hold and secure the pendulum hammer in position. It is rigid, made of steel and will be welded together using steel bars across to ensure there is less vibration when sample testing. It is designed for easy mounting of the hammer as well as easy mounting on the steel rod and fastening to the frame. Commands used are; extrude boss, extrude cut and fillet.

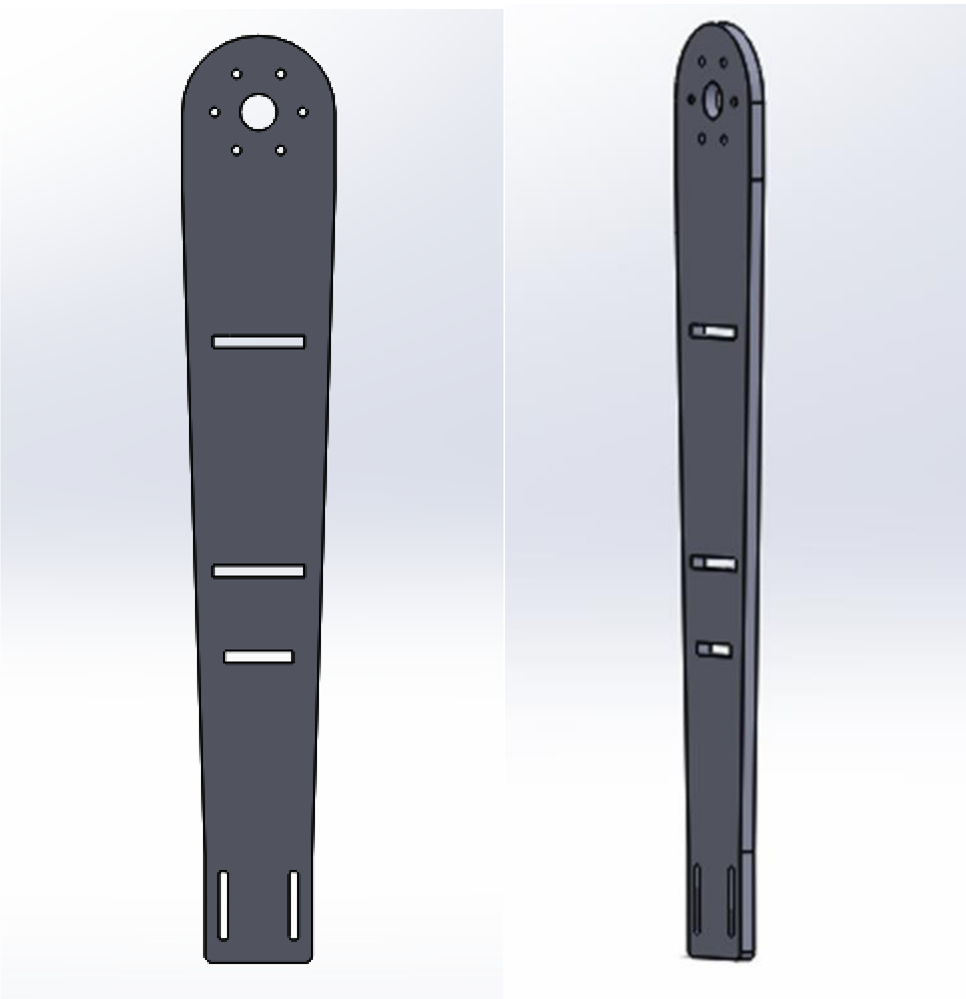


*Figure 10:Pendulum Arm*

## 4.4 Fixtures

This support will be connected to the support rod, pendulum arm to the frame. The two will experience a lot of friction during to the rotational movement of the support rod and pendulum arms. With proper oiling the friction should be reduced considerably. It was designed using extrude boss, cut and hole wizard.

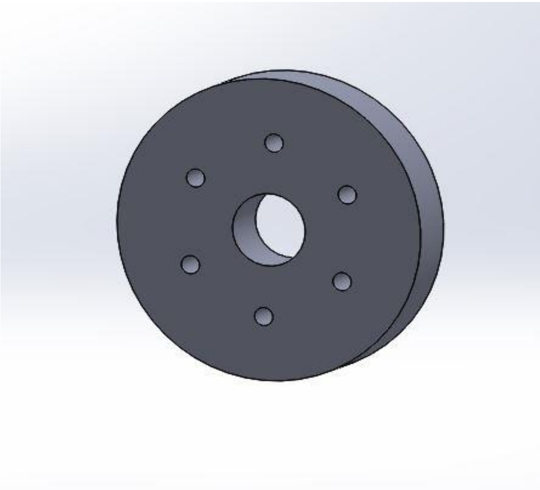


*Figure 11:Fixture*

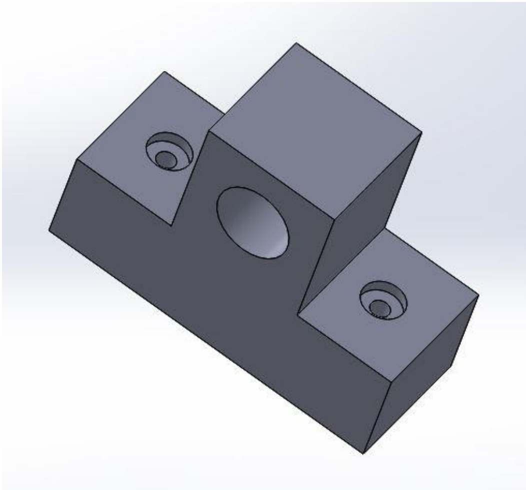


*Figure 12:Rod Support*

## 4.5 Hammer

The hammer is designed to be easily fitted and removed from the pendulum arms so hammers of different masses can be used in experiments. The hammer is also designed with a striking edge of hardened steel which is tapered at an angle of 45 degrees ∓ 2°. The hammer is designed with four holes so that it can be effectively mounted to the pendulum arm and rigid enough to avoid loss of energy through friction and instability. The hole will also help in adjusting the hammer's height as needed. It is designed using commands; extrude boss and cut.

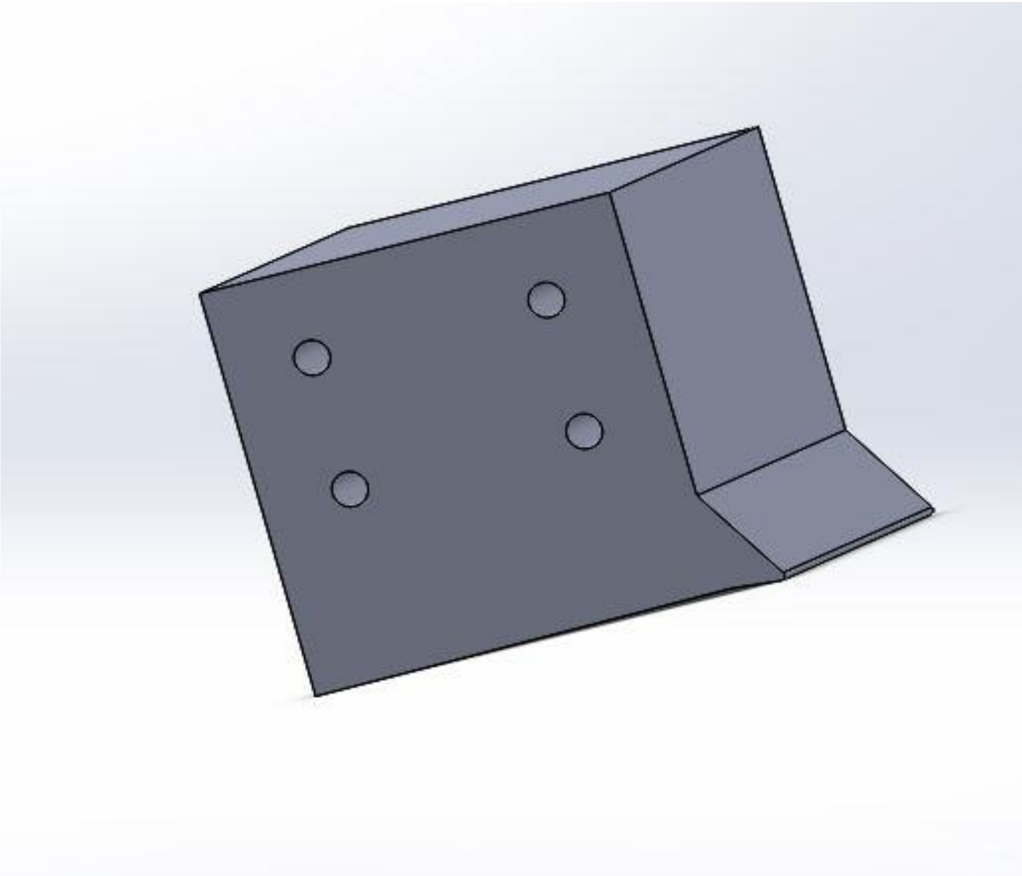


*Figure 13:Hammer*

## 4.6 Assembled Device

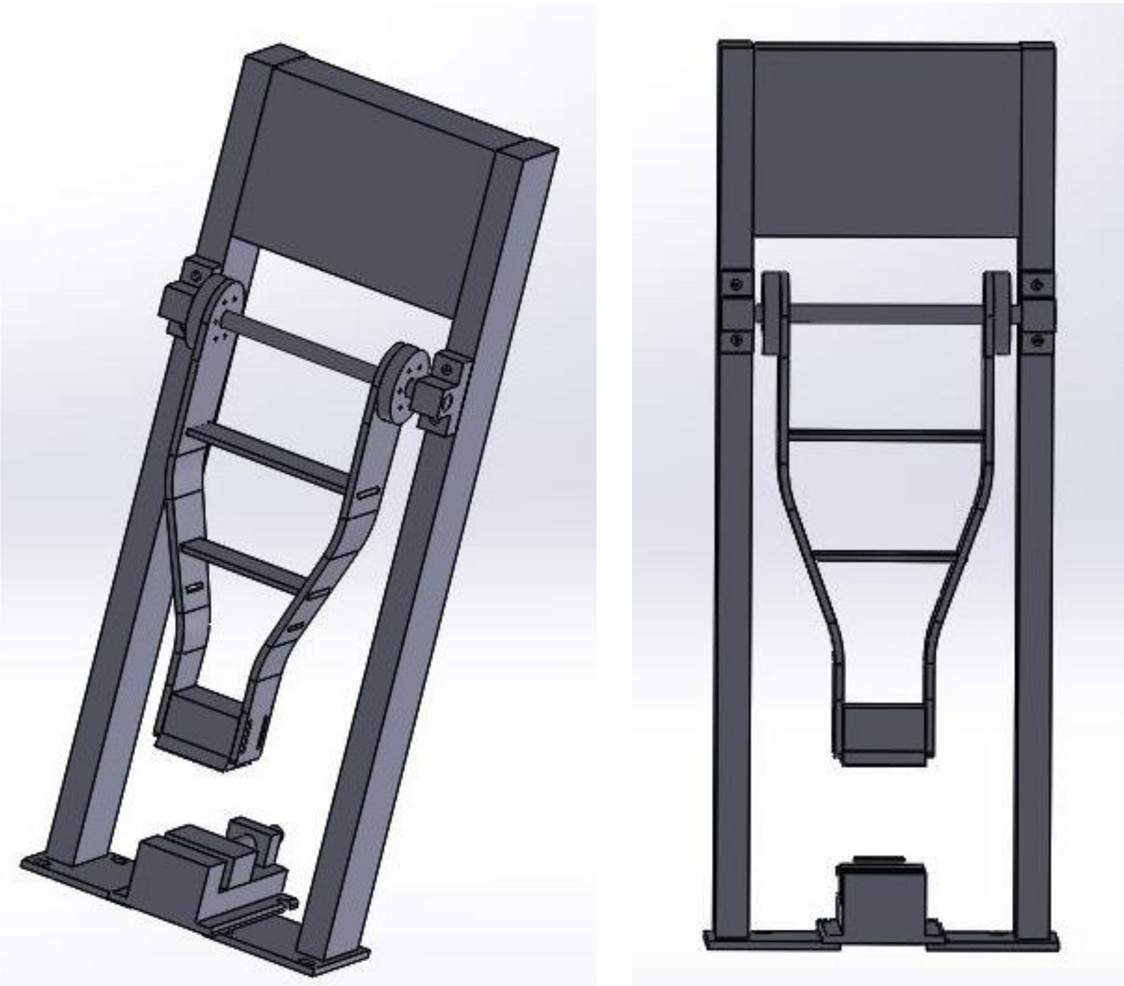


*Figure 14:Assembled Pendulum Impact Testing Device*

As shown in the figure above, the fully assembled Pendulum Impact Testing device with major components being the frame, clamp, hammer and pendulum arms.

The Pendulum arms are bent and will be welded together with horizontal rectangular rods. The purpose of this is to prevent any torsional motion.

## 4.7 Engineering Drawing

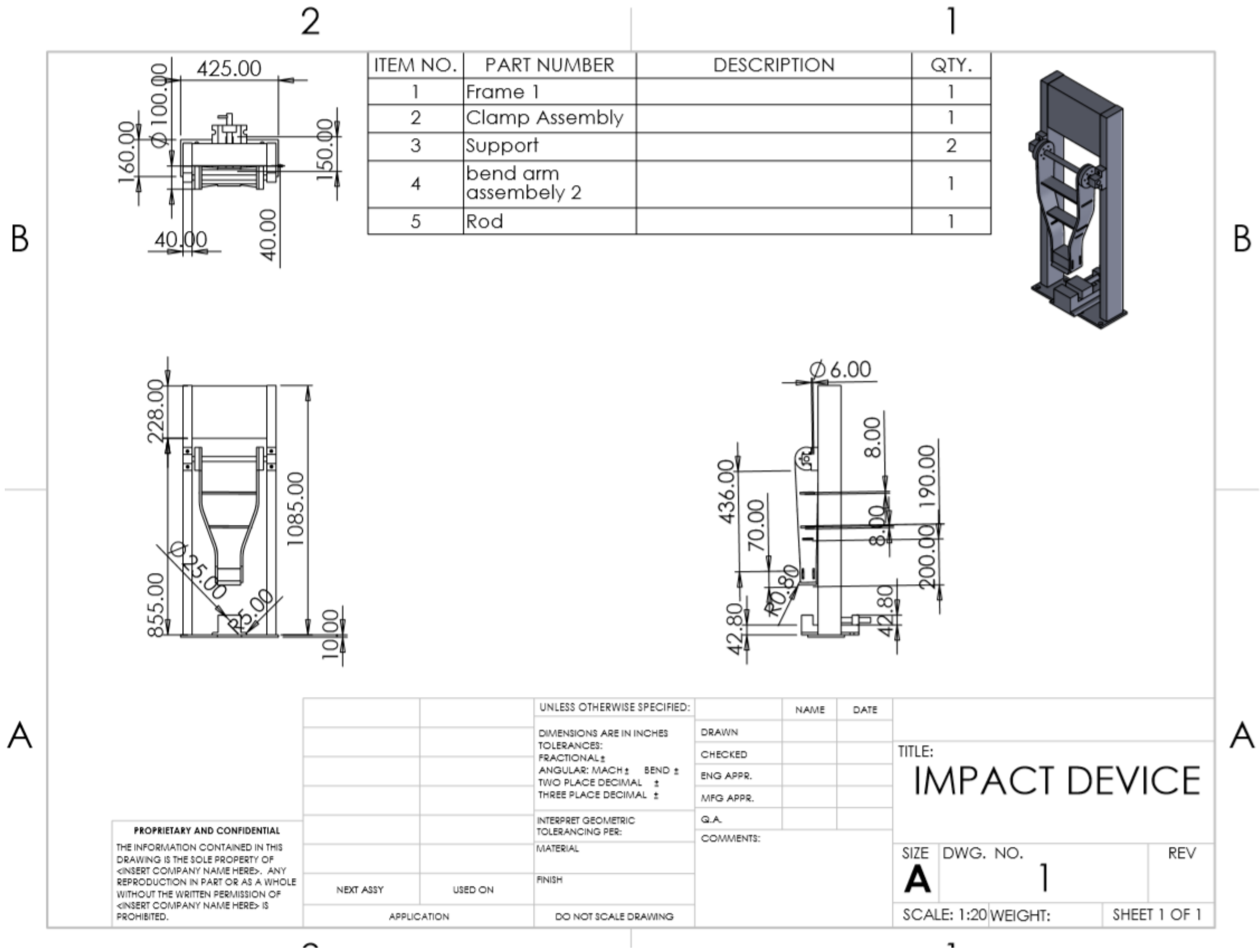



*Figure 15:Engineering Drawing*

The engineering drawing is showing details of the assembled impact testing device. The 2D views of the assembled, some of the dimensions used in modelling of various parts, a diametric view of the assembly and the bill of materials. Only a few dimensions are shown so as not to over crowd the drawing.

# 5 EXPERIMENTS

This chapter describes calibration of the Impact Pendulum Test Device (Izod) center of mass, set up in which experiments carried and the results of the sixty-impact tests carried out on the composite test specimens.

## 5.1 Setup

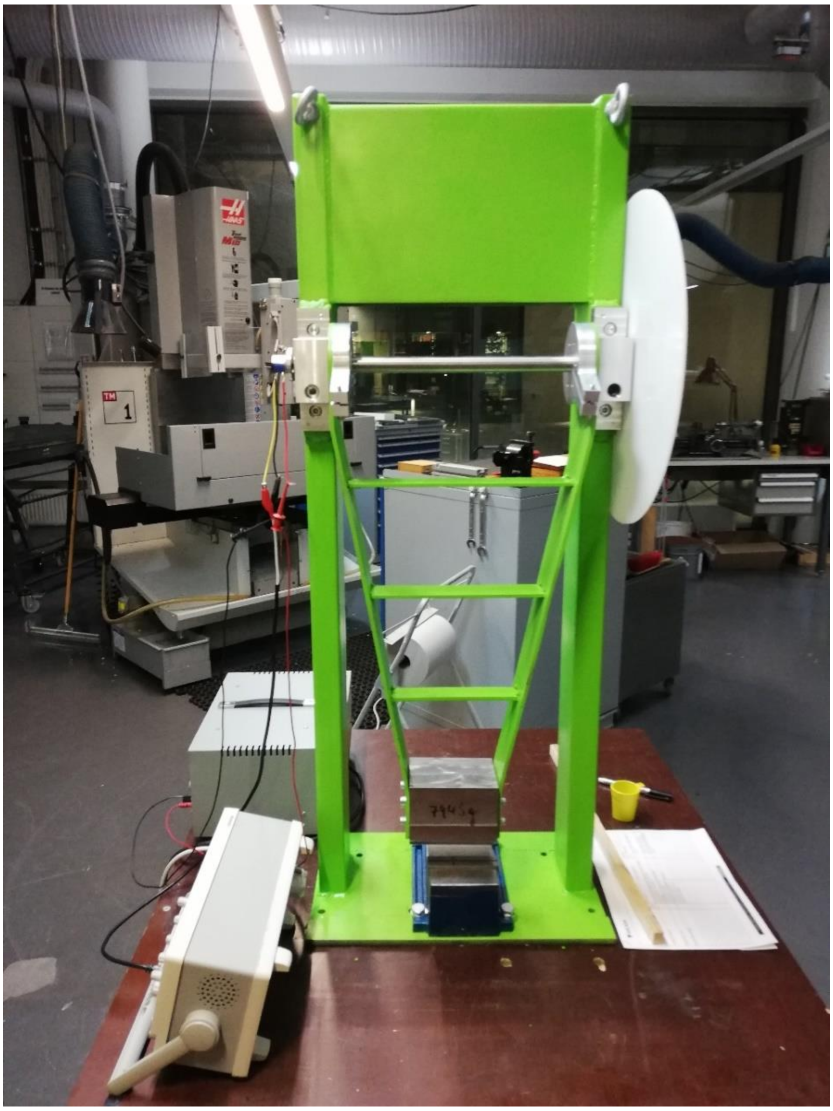


*Figure 16:Pendulum Impact Device*

As shown above in Figure 17, the main components of the pendulum impact device are; frame, pendulum hammer, clamp, angle measurement device and potentiometer to measure the voltage (electric potential). The device is firmly fixed on a large table giving it stability.

The operator of the device stands to the side of the machine while loading the sample and uses a straight simple bar to lock the pendulum hammer so that it does not swing back. After loading the sample, the operator will stand behind the machine, make sure there is no one in front or in close proximity. The pendulum is then raised to a vertical position of 90 degrees and let go freely.

### 5.1.1 Pointer and Dial Mechanism

*Figure 17:Point and Dial Mechanism*

The dial (white circular plate) made of polymer with angles engraved using a laser cutter for accuracy. The pointer, consisting of an arm and marker, is connected to the rod through which the pendulum arms are connected as well. This mechanism will help in determining the energy required to break the specimen or the energy remaining in the pendulum after breakage by indicating the initial angle at which the pendulum is released and the final angle beyond the point of breakage.

### 5.1.2 The Potentiometer

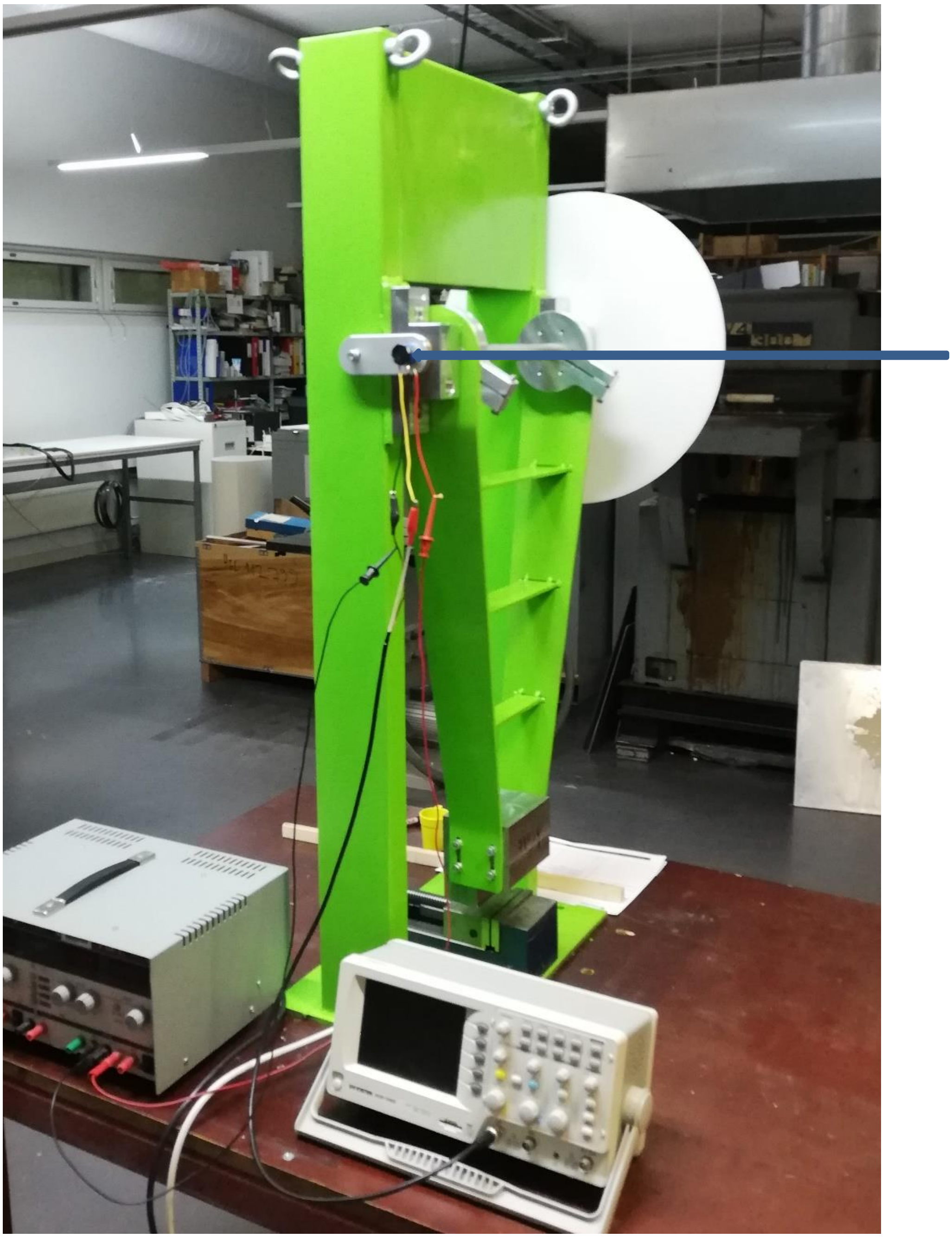


*Figure 18:Potentiometer*

The potentiometer is a voltage divider and used to measure voltage. It is mounted and connected to the rod where the pendulum arm is connected. As the pendulum is released to swing freely the potentiometer enables us to measure the angle, speed and displacement. As shown below in the graph the angles measured have a linear relationship with the voltage measure:

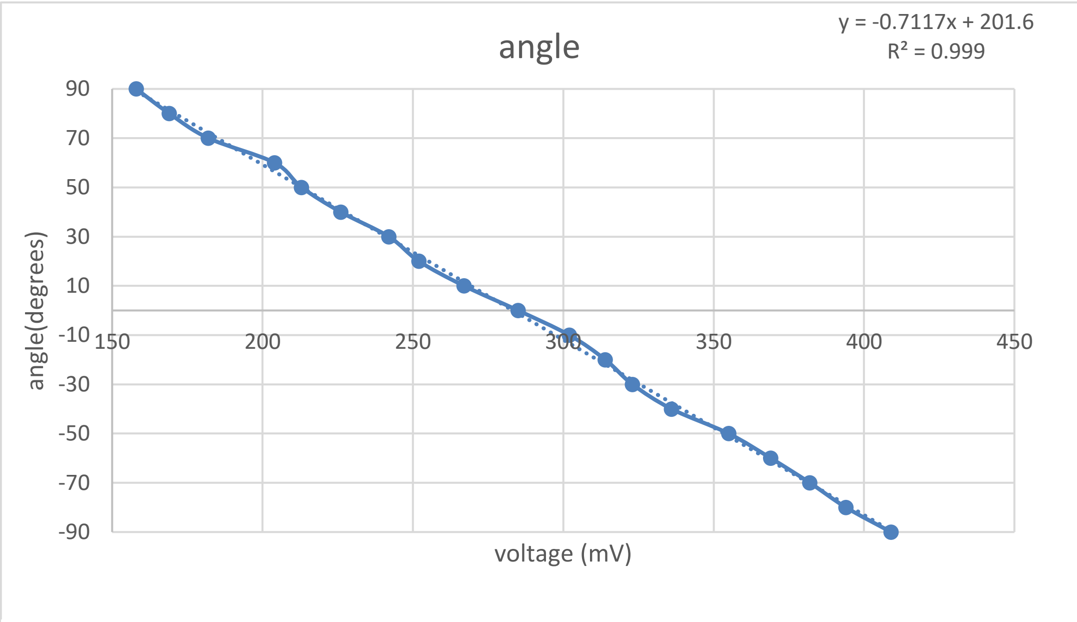



*Figure 19:Angle Voltage Relationship*

As the pendulum swings both the angle and voltage are measured simultaneously. The angles are measured using the pointer and dial mechanism while the voltage is measured using the potentiometer and values displayed on the monitor. As the outputs of the angle measurement and voltage are analyzed, they show a linear relationship between the angle and voltage measured, this is because the ratio of division in potentiometer corresponds to the angle. Unlike in the traditional method, where only angle measurements are relied upon to calibrate impact test device, we can also use the voltage to calibrate this Impact Pendulum Device.

## 5.2 Center of Mass of the Pendulum Hammer

The pendulum arm oscillates freely either with or without the hammer mass. This is used with the parallel axis theorem to define two equations containing polar moment of inertia $(I)$ and center of mass.

The center of mass is determined using the dynamic method. The pendulum was released to swing freely with and without the hammer. The pendulum oscillations were measured by the potentiometer and from the data collected the periods were extracted, which were used to calculate the center of mass.

The graph below (Figure 20) shows two distinctly different oscillations, one with the hammer and one without. From this data we extracted periods which we used to solve the first equation. This gives us the center of mass for the pendulum only. Once we know the center of mass for the pendulum only, we can use it to calculate the center of mass for the entire pendulum including the hammer.

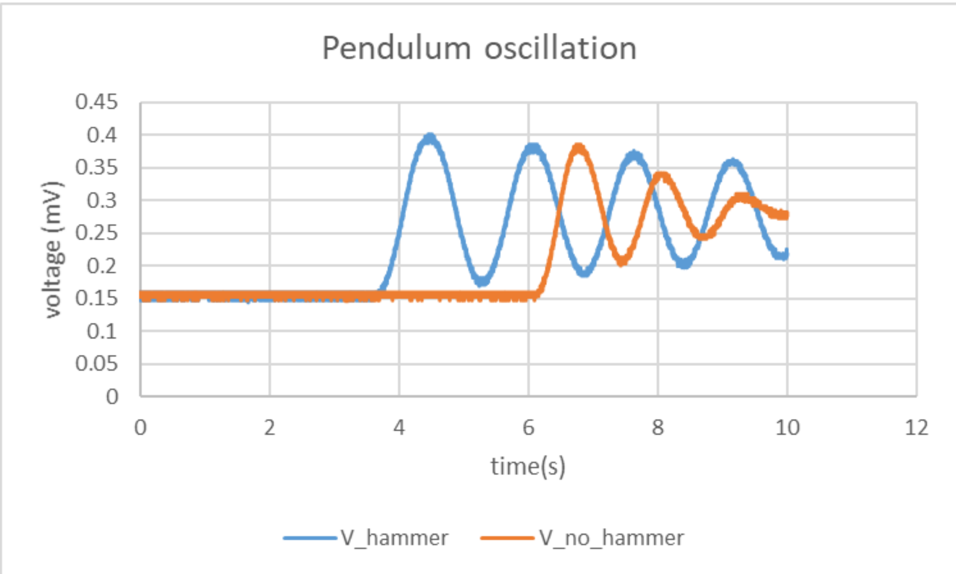



*Figure 20:Pendulum Oscillations with &without hammer*

Using *equation 39* the center of mass of mass was calculated;

$$T_2 = 2\pi \sqrt{\frac{I_1 + m_2 l_2}{(m_1 + m_2) g (\frac{m_1 l_1 + m_2 l_2}{m_1 + m_2})}} \qquad Eq\ (39)$$

*Table 5:Calculated $L_c$ using extracted periods*

| | **T_1 (s)** | **T_2 (s)** |
|---|---|---|
| **periods(s)** | 0.924221 | 1.4639 |
| **T/2/pi** | 0.147094 | 0.232987 |
| | 0.021637 | 0.054283 |
| | | |
| | | |
| $\boldsymbol{l_1}$ | 0.201583 | **m** |
| | | |
| | | |
| **L_C** | 0.438247 | **m** |

**Note;** the extracted periods from the data are slightly smaller than expected and this is because the friction is not considered.
With friction considered the center of mass = $\mathbf{0.476\ m}$

The alternative use of kinetic energy instead of potential energy demands velocity and the table below shows the calculated velocity. The pendulum oscillation had over a million points but only a few have been selected to demonstrate this;

*Table 6:Calculated velocity with &without hammer*

| t (s) | V_hammer(mV) | V_no_hammer (mV) | angle_H (degrees) | angle_no H (degrees) | distance_H (m) | distance_noH (m) | velocity_H ($\frac{mm}{s}$) | velecity_noH ($\frac{mm}{s}$) |
|---|---|---|---|---|---|---|---|---|
| 0 | 0.157 | 0.160 | 89.93 | 87.73 | 0.00 | 0.01 | -440.70 | -1308.32 |
| 9.5461E-06 | 0.154 | 0.154 | 92.21 | 92.21 | 0.00 | 0.00 | -440.70 | 440.70 |
| 1.9092E-05 | 0.154 | 0.157 | 92.21 | 89.93 | 0.00 | 0.00 | 881.40 | 0.00 |
| 2.8638E-05 | 0.157 | 0.157 | 89.93 | 89.93 | 0.00 | 0.00 | -881.40 | 0.00 |
| 3.8184E-05 | 0.154 | 0.157 | 92.21 | 89.93 | 0.00 | 0.00 | 881.40 | 0.00 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 4.773E-05 | 0.157 | 0.157 | 89.93 | 89.93 | 0.00 | 0.00 | -440.70 | 0.00 |
| 5.7276E-05 | 0.154 | 0.157 | 92.21 | 89.93 | 0.00 | 0.00 | 0.00 | 0.00 |
| 6.6822E-05 | 0.154 | 0.157 | 92.21 | 89.93 | 0.00 | 0.00 | -440.70 | 0.00 |
| 7.6369E-05 | 0.154 | 0.157 | 92.21 | 89.93 | 0.00 | 0.00 | 881.40 | 0.00 |
| 8.5915E-05 | 0.157 | 0.157 | 89.93 | 89.93 | 0.00 | 0.00 | -440.70 | 0.00 |
| 9.5461E-05 | 0.154 | 0.157 | 92.21 | 89.93 | 0.00 | 0.00 | 0.00 | 440.70 |
| 0.000105 | 0.154 | 0.157 | 92.21 | 89.93 | 0.00 | 0.00 | -867.63 | -881.40 |
| 0.000115 | 0.154 | 0.154 | 92.21 | 92.21 | -0.01 | 0.00 | 1294.55 | 440.70 |
| 0.000124 | 0.160 | 0.157 | 87.73 | 89.93 | 0.00 | 0.00 | -426.93 | 0.00 |
| 0.000134 | 0.157 | 0.157 | 89.93 | 89.93 | 0.00 | 0.00 | 440.70 | 0.00 |
| 0.000143 | 0.157 | 0.157 | 89.93 | 89.93 | 0.00 | 0.00 | -881.40 | 440.70 |
| 0.000153 | 0.154 | 0.157 | 92.21 | 89.93 | 0.00 | 0.00 | 881.40 | -881.40 |
| 0.000162 | 0.157 | 0.154 | 89.93 | 92.21 | 0.00 | 0.00 | -440.70 | 881.40 |
| 0.000172 | 0.154 | 0.157 | 92.21 | 89.93 | 0.00 | 0.00 | 0.00 | -440.70 |
| 0.000181 | 0.154 | 0.154 | 92.21 | 92.21 | 0.00 | 0.00 | -440.70 | 0.00 |
| 0.000191 | 0.154 | 0.154 | 92.21 | 92.21 | 0.00 | 0.00 | 440.70 | -440.70 |
| 0.000200 | 0.157 | 0.154 | 89.93 | 92.21 | 0.00 | 0.00 | 440.70 | 440.70 |
| 0.000210 | 0.157 | 0.157 | 89.93 | 89.93 | 0.00 | 0.00 | -440.70 | 0.00 |
| 0.000220 | 0.154 | 0.157 | 92.21 | 89.93 | 0.00 | 0.00 | -440.70 | 0.00 |
| 0.000229 | 0.154 | 0.157 | 92.21 | 89.93 | 0.00 | 0.00 | 881.40 | 0.00 |
| 0.000239 | 0.157 | 0.157 | 89.93 | 89.93 | 0.00 | 0.00 | -440.70 | 0.00 |
| 0.000248 | 0.154 | 0.157 | 92.21 | 89.93 | 0.00 | 0.00 | -440.70 | 440.70 |
| 0.000258 | 0.154 | 0.157 | 92.21 | 89.93 | 0.00 | 0.00 | 440.70 | -881.40 |
| 0.000267 | 0.157 | 0.154 | 89.93 | 92.21 | 0.00 | 0.00 | 0.00 | 440.70 |
| 0.000277 | 0.157 | 0.157 | 89.93 | 89.93 | 0.00 | 0.00 | 440.70 | 0.00 |
| 0.000286 | 0.157 | 0.157 | 89.93 | 89.93 | 0.00 | 0.00 | -440.70 | 0.00 |
| 0.000296 | 0.154 | 0.157 | 92.21 | 89.93 | 0.00 | 0.00 | -440.70 | 0.00 |
| 0.000305 | 0.154 | 0.157 | 92.21 | 89.93 | 0.00 | 0.00 | 881.40 | 440.70 |
| 0.000315 | 0.157 | 0.157 | 89.93 | 89.93 | 0.00 | 0.00 | -440.70 | -440.70 |
| 0.000325 | 0.154 | 0.154 | 92.21 | 92.21 | 0.00 | 0.00 | -440.70 | -440.70 |
| 0.000334 | 0.154 | 0.154 | 92.21 | 92.21 | 0.00 | 0.00 | 440.70 | 440.70 |
| 0.000344 | 0.157 | 0.157 | 89.93 | 89.93 | 0.00 | 0.00 | 0.00 | 0.00 |
| 0.000353 | 0.157 | 0.157 | 89.93 | 89.93 | 0.00 | 0.00 | 440.70 | 0.00 |
| 0.000363 | 0.157 | 0.157 | 89.93 | 89.93 | 0.00 | 0.00 | -881.40 | 0.00 |
| 0.000372 | 0.154 | 0.157 | 92.21 | 89.93 | 0.00 | 0.00 | 881.40 | 0.00 |
| 0.000382 | 0.157 | 0.157 | 89.93 | 89.93 | 0.00 | 0.00 | -881.40 | 0.00 |
| 0.000391 | 0.154 | 0.157 | 92.21 | 89.93 | 0.00 | 0.00 | 440.70 | 0.00 |
| 0.000401 | 0.157 | 0.157 | 89.93 | 89.93 | 0.00 | 0.00 | 0.00 | 0.00 |
| 0.000410 | 0.157 | 0.157 | 89.93 | 89.93 | 0.00 | 0.00 | 440.70 | 0.00 |
| 0.000420 | 0.157 | 0.157 | 89.93 | 89.93 | 0.00 | 0.00 | -440.70 | 440.70 |
| 0.000430 | 0.154 | 0.157 | 92.21 | 89.93 | 0.00 | 0.00 | -440.70 | -440.70 |
| 0.000439 | 0.154 | 0.154 | 92.21 | 92.21 | 0.00 | 0.00 | 881.40 | -440.70 |
| 0.000449 | 0.157 | 0.154 | 89.93 | 92.21 | 0.00 | 0.00 | -881.40 | 440.70 |
| 0.000458 | 0.154 | 0.157 | 92.21 | 89.93 | 0.00 | 0.00 | 881.40 | 0.00 |

The angle was calculated using the linear equation extracted from Figure 20; graph showing the Angle voltage linear relationship;

$$y = -0.7117 \times voltage + 201.6$$

## 5.3 Test Specimens

The test specimens were made of composite material that is; both fiber-reinforced polymers and bio-composites. The test specimens were unnotched and the experiments were carried out at room temperature. The width and thickness of each specimen was measured prior the experiment. These are some of the test specimens after the experiment;

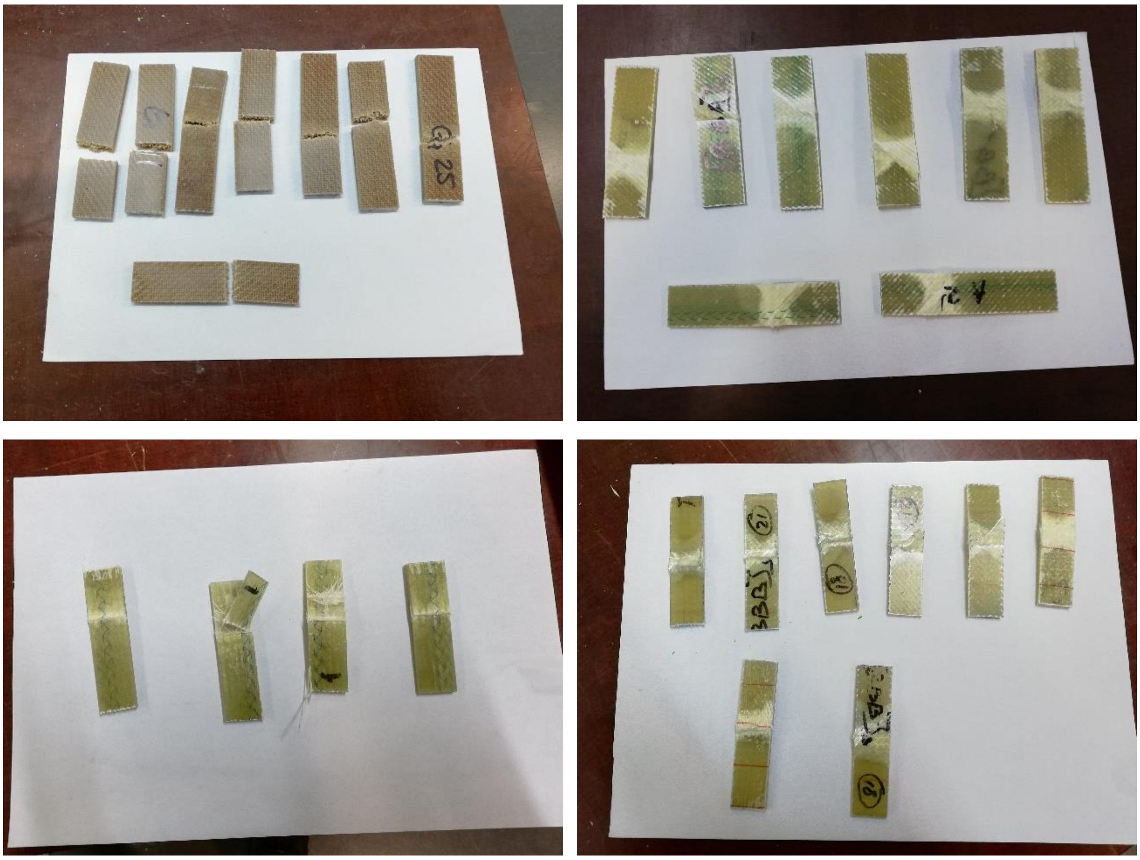


*Figure 21:Broken Test Specimens*

## 5.4 Calculations

The energy calculations were done using equation 29; -

$$\Delta W = gm_{tot}l_c(\cos\varphi_1 - \cos\varphi_0)$$

Parameters used for the calculations:

*Table 7:Parameters used for calculations*

| | |
|---|---|
| Mass_total(kg) | 13.772 |
| L_center of mass (m) | 0.476 |
| $g\left(\frac{m}{s^2}\right)$ | 9.81 |
| Angle offset (degrees) | 5.4 (accounts for friction) |

Table 9 below is showing the dimensions of the test specimens, energy lost due to friction and energy needed to break each individual test specimen. Sixty test specimens were test using the impact strength device.

**Note;** The Impact strength is given in $\frac{kJ}{m^2}$ because the test specimens were unnotched.

*Table 8:Calculated impact energy of test specimens*

| w(mm) | T(mm) | Area A ($mm^2$) | Area A ($m^2$) | Angle in | Out | Angle out | delta | E_pot[J] | E_indicated[J] | Friction loss | Energy absorbed[J] | Energy(kJ) | E/A $[\frac{kJ}{m^2}]$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 4 | 10 | 40 | 0.0000 | 90 | 260 | 80 | 10 | 64.31 | 53.14 | 0.29 | 10.88 | 0.011 | 272.04 |
| 20 | 4.2 | 84 | 0.0001 | 90 | 249 | 69 | 21 | 64.31 | 41.26 | 0.29 | 22.76 | 0.023 | 270.96 |
| 20 | 4.1 | 82 | 0.0001 | 90 | 248 | 68 | 22 | 64.31 | 40.22 | 0.29 | 23.81 | 0.024 | 290.31 |
| 20 | 4.1 | 82 | 0.0001 | 90 | 248 | 68 | 22 | 64.31 | 40.22 | 0.29 | 23.81 | 0.024 | 290.31 |
| 20 | 4.1 | 82 | 0.0001 | 90 | 249 | 69 | 21 | 64.31 | 41.26 | 0.29 | 22.76 | 0.023 | 277.57 |
| 20 | 5.2 | 104 | 0.0001 | 90 | 210 | 30 | 60 | 64.31 | 8.62 | 0.29 | 55.41 | 0.055 | 532.77 |
| 20 | 5.2 | 104 | 0.0001 | 90 | 230 | 50 | 40 | 64.31 | 22.97 | 0.29 | 41.05 | 0.041 | 394.73 |
| 20 | 5.3 | 106 | 0.0001 | 90 | 223 | 43 | 47 | 64.31 | 17.28 | 0.29 | 46.75 | 0.047 | 441.01 |
| 20 | 5.2 | 104 | 0.0001 | 90 | 217 | 37 | 53 | 64.31 | 12.95 | 0.29 | 51.07 | 0.051 | 491.10 |
| 20 | 4.2 | 84 | 0.0001 | 90 | 250 | 70 | 20 | 64.31 | 42.31 | 0.29 | 21.71 | 0.022 | 258.45 |
| 20 | 4.2 | 84 | 0.0001 | 90 | 252 | 72 | 18 | 64.31 | 44.44 | 0.29 | 19.59 | 0.020 | 233.18 |
| 20 | 4.2 | 84 | 0.0001 | 90 | 255 | 75 | 15 | 64.31 | 47.66 | 0.29 | 16.36 | 0.016 | 194.75 |
| 20 | 4.3 | 86 | 0.0001 | 90 | 252 | 72 | 18 | 64.31 | 44.44 | 0.29 | 19.59 | 0.020 | 227.76 |
| 20 | 4 | 80 | 0.0001 | 90 | 254 | 74 | 16 | 64.31 | 46.58 | 0.29 | 17.44 | 0.017 | 218.01 |
| 20 | 4.1 | 82 | 0.0001 | 90 | 250 | 70 | 20 | 64.31 | 42.31 | 0.29 | 21.71 | 0.022 | 264.75 |
| 25 | 3.8 | 95 | 0.0001 | 90 | 245 | 65 | 25 | 64.31 | 37.13 | 0.29 | 26.89 | 0.027 | 283.08 |

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 25 | 3.8 | 95 | 0.0001 | 90 | 245 | 65 | 25 | 64.31 | 37.13 | 0.29 | 26.89 | 0.027 | 283.08 |
| 25 | 3.7 | 92.5 | 0.0001 | 90 | 248 | 68 | 22 | 64.31 | 40.22 | 0.29 | 23.81 | 0.024 | 257.35 |
| 25 | 3.8 | 95 | 0.0001 | 90 | 247 | 67 | 23 | 64.31 | 39.18 | 0.29 | 24.84 | 0.025 | 261.50 |
| 25 | 3.8 | 95 | 0.0001 | 90 | 245 | 65 | 25 | 64.31 | 37.13 | 0.29 | 26.89 | 0.027 | 283.08 |
| 25 | 4 | 100 | 0.0001 | 90 | 249 | 69 | 21 | 64.31 | 41.26 | 0.29 | 22.76 | 0.023 | 227.61 |
| 25 | 3.8 | 95 | 0.0001 | 90 | 245 | 65 | 25 | 64.31 | 37.13 | 0.29 | 26.89 | 0.027 | 283.08 |
| 25 | 3.8 | 95 | 0.0001 | 90 | 245 | 65 | 25 | 64.31 | 37.13 | 0.29 | 26.89 | 0.027 | 283.08 |
| 25 | 6.8 | 170 | 0.0002 | 90 | 260 | 80 | 10 | 64.31 | 53.14 | 0.29 | 10.88 | 0.011 | 64.01 |
| 25 | 7 | 175 | 0.0002 | 90 | 259 | 79 | 11 | 64.31 | 52.04 | 0.29 | 11.99 | 0.012 | 68.49 |
| 25 | 7 | 175 | 0.0002 | 90 | 261 | 81 | 9 | 64.31 | 54.25 | 0.29 | 9.77 | 0.010 | 55.86 |
| 25 | 7 | 175 | 0.0002 | 90 | 260 | 80 | 10 | 64.31 | 53.14 | 0.29 | 10.88 | 0.011 | 62.18 |
| 25 | 7 | 175 | 0.0002 | 90 | 259 | 79 | 11 | 64.31 | 52.04 | 0.29 | 11.99 | 0.012 | 68.49 |
| 25 | 7.1 | 177.5 | 0.0002 | 90 | 260 | 80 | 10 | 64.31 | 53.14 | 0.29 | 10.88 | 0.011 | 61.31 |
| 25 | 6.9 | 172.5 | 0.0002 | 90 | 259 | 79 | 11 | 64.31 | 52.04 | 0.29 | 11.99 | 0.012 | 69.48 |
| 25 | 7 | 175 | 0.0002 | 90 | 260 | 80 | 10 | 64.31 | 53.14 | 0.29 | 10.88 | 0.011 | 62.18 |
| 20 | 4 | 80 | 0.0001 | 90 | 253 | 73 | 17 | 64.31 | 45.51 | 0.29 | 18.52 | 0.019 | 231.46 |
| 20 | 4.1 | 82 | 0.0001 | 90 | 253 | 73 | 17 | 64.31 | 45.51 | 0.29 | 18.52 | 0.019 | 225.81 |
| 20 | 4.2 | 84 | 0.0001 | 90 | 254 | 74 | 16 | 64.31 | 46.58 | 0.29 | 17.44 | 0.017 | 207.63 |
| 20 | 3.9 | 78 | 0.0001 | 90 | 255 | 75 | 15 | 64.31 | 47.66 | 0.29 | 16.36 | 0.016 | 209.73 |
| 20 | 4.1 | 82 | 0.0001 | 90 | 253 | 73 | 17 | 64.31 | 45.51 | 0.29 | 18.52 | 0.019 | 225.81 |
| 20 | 3.5 | 70 | 0.0001 | 90 | 254 | 74 | 16 | 64.31 | 46.58 | 0.29 | 17.44 | 0.017 | 249.15 |
| 20 | 3.6 | 72 | 0.0001 | 90 | 255 | 75 | 15 | 64.31 | 47.66 | 0.29 | 16.36 | 0.016 | 227.21 |
| 20 | 3.8 | 76 | 0.0001 | 90 | 256 | 76 | 14 | 64.31 | 48.75 | 0.29 | 15.27 | 0.015 | 200.95 |
| 20 | 4.9 | 98 | 0.0001 | 90 | 239 | 59 | 31 | 64.31 | 31.19 | 0.29 | 32.84 | 0.033 | 335.06 |
| 20 | 5 | 100 | 0.0001 | 90 | 238 | 58 | 32 | 64.31 | 30.23 | 0.29 | 33.79 | 0.034 | 337.93 |
| 20 | 5 | 100 | 0.0001 | 90 | 240 | 60 | 30 | 64.31 | 32.15 | 0.29 | 31.87 | 0.032 | 318.69 |
| 20 | 5 | 100 | 0.0001 | 90 | 235 | 55 | 35 | 64.31 | 27.42 | 0.29 | 36.60 | 0.037 | 366.01 |
| 20 | 5 | 100 | 0.0001 | 90 | 240 | 60 | 30 | 64.31 | 32.15 | 0.29 | 31.87 | 0.032 | 318.69 |
| 20 | 5 | 100 | 0.0001 | 90 | 238 | 58 | 32 | 64.31 | 30.23 | 0.29 | 33.79 | 0.034 | 337.93 |
| 20 | 5 | 100 | 0.0001 | 90 | 240 | 60 | 30 | 64.31 | 32.15 | 0.29 | 31.87 | 0.032 | 318.69 |
| 20 | 5 | 100 | 0.0001 | 90 | 238 | 58 | 32 | 64.31 | 30.23 | 0.29 | 33.79 | 0.034 | 337.93 |
| 20 | 4.1 | 82 | 0.0001 | 90 | 250 | 70 | 20 | 64.31 | 42.31 | 0.29 | 21.71 | 0.022 | 264.75 |
| 20 | 4.1 | 82 | 0.0001 | 90 | 250 | 70 | 20 | 64.31 | 42.31 | 0.29 | 21.71 | 0.022 | 264.75 |
| 20 | 4.2 | 84 | 0.0001 | 90 | 245 | 65 | 25 | 64.31 | 37.13 | 0.29 | 26.89 | 0.027 | 320.15 |
| 20 | 4.2 | 84 | 0.0001 | 90 | 251 | 71 | 19 | 64.31 | 43.37 | 0.29 | 20.65 | 0.021 | 245.85 |
| 20 | 4.1 | 82 | 0.0001 | 90 | 250 | 70 | 20 | 64.31 | 42.31 | 0.29 | 21.71 | 0.022 | 264.75 |
| 20 | 4.1 | 82 | 0.0001 | 90 | 253 | 73 | 17 | 64.31 | 45.51 | 0.29 | 18.52 | 0.019 | 225.81 |
| 20 | 4.2 | 84 | 0.0001 | 90 | 250 | 70 | 20 | 64.31 | 42.31 | 0.29 | 21.71 | 0.022 | 258.45 |
| 20 | 4.1 | 82 | 0.0001 | 90 | 249 | 69 | 21 | 64.31 | 41.26 | 0.29 | 22.76 | 0.023 | 277.57 |
| 20 | 5.5 | 110 | 0.0001 | 90 | 260 | 80 | 10 | 64.31 | 53.14 | 0.29 | 10.88 | 0.011 | 98.93 |
| 20 | 5.5 | 110 | 0.0001 | 90 | 262 | 82 | 8 | 64.31 | 55.36 | 0.29 | 8.66 | 0.009 | 78.77 |
| 20 | 5.5 | 110 | 0.0001 | 90 | 260 | 80 | 10 | 64.31 | 53.14 | 0.29 | 10.88 | 0.011 | 98.93 |
| 20 | 5.5 | 110 | 0.0001 | 90 | 259 | 79 | 11 | 64.31 | 52.04 | 0.29 | 11.99 | 0.012 | 108.96 |
| 20 | 5.5 | 110 | 0.0001 | 90 | 260 | 80 | 10 | 64.31 | 53.14 | 0.29 | 10.88 | 0.011 | 98.93 |

# 6 RESULTS

This section describes the various calculations and results of center of mass of the pendulum hammer and impact/absorbed energy of test specimens.

## 6.1 Center of Mass of Pendulum Hammer

Dynamic method was used to calibrate the impact strength. The pendulum was released to swing freely with and without the hammer. The pendulum oscillations were measured by the potentiometer and from the data collected the periods were extracted, which were used to calculate the center of mass.

Table 5 shows the calculated center of mass of the impact device using the extracted periods; $0.438\ m$

These extracted periods were slightly smaller than expected because friction was not considered. When friction was considered the center of mass was calculated to be $0.476\ m$

## 6.2 Impact/Absorbed Energy

Sixty composite specimens were tested. Impact energy ranging from $532.7\ \frac{kJ}{m^2}$ to $55.86\frac{kJ}{m^2}$ was calculated using known parameters shown in Table 7.

The test specimen requires a range of different impact energy to fail or fracture due to different reinforcing materials and different fiber arrangement.

# 7 DISCUSSION

The primary focus of this thesis to design and assemble the different manufactured components into an Impact Strength Testing Device (Izod). The machine has four major components to it; frame, clamp, pendulum hammer and the scale or meter to read the data. First, the individual parts of the of the test device are designed in SolidWorks software and brought together into a final assembly. The manufactured parts are assembled together and welded were needed.

Secondly, to use the test device, it must be calibrated to the standards and both the static and dynamic method were used. The dynamic method of calibration was preferred to the static because of its easy repeatability and accuracy.

In addition to the traditional dynamic method of calibration, which relies upon the measurement of angles, the alternative method in this thesis uses the Potentiometer to measure the voltage and periods as the pendulum oscillates freely with or without the hammer mass. Two distinctly different oscillations were recorded, getting periods that were used to calculate the center of mass for the entire pendulum. Voltage has a linear relationship with the angles measured due to the ratio of division in Potentiometer corresponding with the angles.

Friction was considered in both the center of mass and impact energy calculations as it affects the accuracy of the recorded periods and absorbed energy. Percentage error between center of mass calculated with friction considered and without friction considered is less than 10%.

# 8 CONCULSION

The basic idea of this thesis is to design, manufacture, assemble and calibrate the Impact Strength Testing Device (Izod) which will be able to carry out impact strength tests with easy repeatability and accuracy.

The Impact Strength Testing Device works well and accurately. According to the results shown in Table 8, composite materials over all require higher impact energy to break them compared to the polymers and metals as in Tables 1& 2. To further improve the accuracy of this test a wider range of test specimens could be used, conditioned and notched according to the standards.

The Impact Strength Testing Device can be calibrated dynamically on a regular basis even with a change of hammer size and mass. This makes the whole process of calibration, hammer change and testing of specimens relatively easy and accurate.

The designing, manufacturing and assembly of the Impact Strength Testing Device were economical compared to buying a new test device. This comes with safety concerns, which we addressed but this will be a continuous process of reviewing and implementing the safety control parameters regarding the device, user and bystanders.

The Impact strength test device works well but could also be improved by; a hold and release mechanism of the pendulum to ensure safety while loading and unloading of the test specimen, a jig for positioning of test specimen in the clamp, and a cage at the front of the device to provide safety.

Traditionally, calibration of pendulum impact device has relied on angle measurement. This Impact Strength Testing Device improved on the traditional method by successfully using the voltage to calibrate it. Further studies could explore the accuracy of using voltage or resistance in relationship to angle rotation in impact strength testing especially in the impact pendulum strength device (Izod).

# 9 REFERENCES


[1] Wiley, Properties and Behavior of Polymers, 2 Volume Set, New Jersey : John Willey & sons , 2016.

[2] T. O. M. d. P. N. A. R. A. J. D. S. Alberto Naranjo, Plastics Testing and Characterization, Munich : Hanser Gardner Publications Inc , 2008.

[3] J. F. Shackelford, Introduction to Materials Science for Engineers, New Jersey: Prentice Hall, 2000.

[4] A. International, Standard Test Methods for Determining the Izod Pendulum Impact Resistance of Plastics, West Conshohocken: ASTM International, 2004.

[5] M. P. M. T. A. Siewert, Pendulum Impact Testing: A Century of Progress, Issue 1380, West Conshohocken: American Society for Testing and Materials, 2000.

[6] Zwick Roell, "Zwick.com," Zwick Roell, 2017. [Online]. Available: https://www.zwick.com/impact-testing-machine/pendulum-impact-testers-up-to-750-j. [Accessed 29 November 2017].

[7] Azo Materials , "Charpy Test - Determination of Impact Energy Using the Charpy Test," Azo materials , [Online]. Available: https://www.azom.com/article.aspx?ArticleID=2763. [Accessed 26 03 2018].

[8] R. Brown, Handbook of Polymer Testing, Shrewsbury: Rapra Technology Limited, 2002.

[9] "City Collegiate," City Collegiate , [Online]. Available: http://www.citycollegiate.com/centre_of_mass.htm. [Accessed 14 05 2018].

[10] L. G. K. J. L. Meriam, Engneering Mechanics Statics, Wiley, 2012.

[11] ASTM International, "Standard Test Methods for Determining the Izod Pendulum Impact Resistance of Plastics," *ASTM International,* vol. 1, no. 10, pp. 5-25, 2015.

[12] J. Awrejcewicz, Classical Mechanics: Dynamics, New York: Springer , 2012.

[13] L. G. K. J. L. Meriam, Engineering Mechanics Dynamics, New Jersey : John Wiley $ Sons , 2013.

[14] R. A. F. A. L. Hugh D. Young, University Physics with Mordern Physics, Pearson Education, 2016.

[15] M. Toropov. A.I & Grosso, "Dynamic Calibration of Impact Test Instrument," *Journal of Testing and Evalution* , vol. 26, no. 4, pp. 315-319, 1998.

[16] R. G. Brown, "Applications of Mechanics," in *Introductory Physics 1*, Duke Univesity , 2013, pp. 511-514.

[17] J. Taylor, "Momentum and Angular Momentum," in *Classical Mechanics* , University Science Books , 2005, pp. 87-90.

[18] "Parallel axis theorem," [Online]. Available: https://en.wikipedia.org/wiki/Parallel_axis_theorem. [Accessed 08 02 2019].

[19] Dassault Systèmes, "SolidWorks," Dassault Systèmes, [Online]. Available: https://www.solidworks.com/category/3d-cad. [Accessed 21 08 2018].