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Development of an Izod Impact Test Machine for Non-Metals

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Abstract: Different type of tests that are conducted to know the various properties of metals and non-metals include tensile, compression, hardness, fatigue, flexural, torsional etc. There are many properties of metals and non-metals such as ductility, brittleness, toughness, hardness, fatigue strength, impact load etc. which are important for their uses. To identify metal or non-metals some characteristic properties are required. To differentiate any metal from another these characteristic properties should be known. Izod Impact test is one of them where the finding is the impact strength of the material. Izod impact testing is an ASTM standard method of determining the impact resistance of materials. A pivoting arm is raised to a specific height and then released. The arm swings down hitting a notched sample, breaking the specimen. A part or material sustainability can be defined by Izod Impact test. The ability to identify the characteristics of the product helps to prevent the failure of the material on sudden load. The optimum value of this parameter for maximum value of Impact energy absorbed can be determined. In plastics and non-metals Izod impact test is required for stability against sudden load and internal strength. In this project an Izod Impact Test machine for non-metals has been designed, fabricated and its performance was tested. The comparison of impact properties of Polycarbonate was made. The machine performance is satisfactory.

Key Words: Material properties, Impact test, Izod impact test, Charpy test, Non-metal test.

1. Introduction

Impact is an important phenomenon in governing the life of a structure. In case of an aircraft, impact can take place by a flying bird hitting the plane; while it is cruising or during take-off and landing, the aircraft may be struck by debris that is present on the runway, and similar other causes. It must also be calculated for roads if speed breakers are present, in bridge construction where vehicles punch an impact load, etc. [1].

Impact tests are used in studying the toughness of material. The toughness of a material is a factor of its ability to absorb energy during plastic deformation. Brittle materials have low toughness, as a result a small amount of plastic deformation that they can endure. The impact value of a material can also change with temperature. Generally, at lower temperatures, the impact energy of a material is decreased. The size of the specimen may also affect the value of the impact test because it may allow a different number of imperfections in the material, which can act as stress risers and lower the impact energy on the specimen [1]. Notched bar impact test of metals provides information on failure mode under high velocity loading conditions leading to sudden fracture where a sharp stress riser (notch) is present.

The energy absorbed at fracture is generally related to the area under the stress-strain curve which is termed as toughness in some references. Brittle materials have small area under the stress-strain curve (due to its limited toughness) and as a result, little energy is absorbed during impact failure. As plastic deformation capability of the materials (ductility) increases, the area under the curve also increases and absorbed energy and respectively toughness increase. Similar characteristics can be seen on the fracture surfaces of broken specimens. The fracture surfaces for low energy impact failures, indicating brittle behaviour, are relatively smooth and have crystalline appearance in the metals. On the contrary, those for high energy fractures have regions of shear where the fracture surface is inclined about 45° to the tensile stress, and have rough and more highly deformed appearance, called fibrous with increasing strain rate. A variety of testing methods are used to evaluate the toughness of a material, three of the most common are uniaxial tension, fracture toughness, and the Izod Impact test [1].

Two basic types of impact testing have been developed. One is bending which includes Charpy and Izod test; other one is Tension impact tests. Bending tests are most common and they use notched specimen that are supported as beams. In the Charpy test, the specimen is supported as a simple beam with the load at the centre. In the Izod Impact test, the specimen is supported as cantilever beam [1, 2].

Now-a-days, plastics, rubbers, glasses are using in many commercial purposes, so stress and impact analysis for such non-metals is essential for their sustainability against sudden load and stress conditions. For example, a plastic pipe, under the soil, need to absorb more pressure

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to sustain its durability. Izod Impact test is one of the basic tests for non-metals to check their durability against such condition.

Previous century was the initial time for realizing the impact test necessity. The impact test procedure seems to have become known as the Charpy test in the first half of the 1900’s for similarity of their testing procedure. Mechanics of Notched impact test for polycarbonate was related to impact test of non-metals. The Charpy V-notched impact test to determine the ductile-brittle transition was another work on impact test. Most of these works were basically on the analysis on the impact test of non-metals and are on the basis of design and construction of the machine. The outcome of these works are to check the metals and non-metals sustainability, striking angle, amount of force required to create impact. Using notched specimens, the specimen is fractured at the notch. Stress is concentrated and soft materials fail as brittle fractures. Both Charpy and Izod Impact testing utilize a swinging pendulum to apply the load. ASTM has standardized the impact test with two testing approaches: the Charpy and Izod.

It is said (Harvey, 1984) that ‘No man is civilized or mentally adult until he realizes that the past, the present, and the future are indivisible.’ This statement applies equally to all fields of science and technology, including material testing. This contribution focuses on the development of material testing using the Charpy test method, which is based on the use of a pendulum to apply an impact force to a specimen. Some of the milestones in the development of this technique have been outlined in a conference on Fracture Mechanics in Design and Service - Living with Defects by the Royal Society in 1979. According to the paper ‘Historical Background and Development of the Charpy Test’ by H. P. L. Tóth et. al. [3], the important role of the impact pendulum test machine was highlighted. The present history-oriented contribution illuminates the development of impact testing from a material toughness characterization point of view. Historically, the impact-pendulum test method and associated apparatus were suggested by S. B. Russell in 1898 and G. Charpy in 1901. G. Charpy presented his fundamental idea in France in the June issue of the Journal Soc. Ing. Civ. De Francais and in the Proceedings of the Congress of the International Association for Testing of Materials, which was held in Budapest in September 1901. The impact-test procedure seems to have become known as the Charpy test in the first half of the 1900’s, through the combination of Charpy’s technical contributions and his leadership in developing the procedures to where they became a robust, engineering tool [3].

Marshall et. al. [4] developed a fracture mechanical analysis to account for the observed dependence of W (energy per unit area) on notch size. A correction factor had been derived to accommodate notch effects and this allows for the calculation of the strain energy release-rate G directly from the measured fracture energies. Tests PMMA have shown that corrected results were independent of specimen geometry and the G_c for PMMA had been evaluated as 1.04 x 10^3 J/m^2. The experimental results showed that there was an additional energy term which must be accounted for and that had been interpreted there as being due to kinetic energy losses in the specimens. A conservation of momentum analysis had allowed a realistic correction term to be calculated to include kinetic energy effects and the normalized experimental results showed complete consistency between all the geometries used in the test series. It was concluded that the analysis resolved many of the difficulties associated with notched impact testing and provided for the calculation of realistic fracture toughness parameters.

Mcmillan and Tesh (1975) experimentally investigated the impact failure in a glass, a glass-ceramic and two conventional ceramics. This revealed the occurrence of complex dynamic effects during impact as a result of vibrations induced in the test specimen. These effects were studied by using strain gauges fitted to the impacter and the specimen. To aid understanding of the observations, computer simulations of impact behavior was undertaken and the results were compared with the experimental data. A conclusion was drawn concerning the design and limitations of impact testing machines of the pendulum type for investigating impact failure of brittle materials - the value of instrumentation of the pendulum and of computer calculations of the type described was emphasized.

Hine (1986) studied the impact behavior of polyether sulphone using a specially constructed instrumented impact testing machine. This machine was of the pendulum type and the samples were fractured in three-point bend loading. It was shown that accurate force/deformation curves could be obtained in spite of complications due to flexural vibrations of the test sample. Measurements were made on both sharp-notched and blunt-notched specimens over a range of crack lengths. It was found that the sharp-notched samples could be analyzed in terms of fracture toughness, whereas the blunt-notched samples corresponded to a constant critical stress at the root of the notch. The importance of multiple crazes at the crack tip in blunt-notched specimens was emphasized. It was also shown that ageing reduces the fracture toughness; while on the other hand, the critical stress observed in blunt-notched specimens, who had been associated with the craze initiation stress, was not affected by ageing [5].

Ajit et. al. [6] investigated the impact resistance of silicon containing modified Cr-Mo steels within a temperature regime of - 40 to 440°C using the Charpy method. The results indicated that the energies absorbed in fracturing the tested specimens were substantially lower at temperatures of - 40°, 25° and 75°C compared to those at elevated temperatures. Lower impact energies and higher ductile-to-brittle transition temperatures (DBTTs) were observed with the steels containing 1.5 and 1.9 wt. % Si. The steels containing higher Si levels exhibited both ductile and brittle failures at elevated temperatures. However, at lower temperatures, brittle failures characterized by cleavage and inter granular cracking were observed for all four tested materials.

Kinloch et. al. [7] conducted instrumented impact tests on both a simple unmodified and rubber-modified epoxy polymer over a range of impact velocities. Single-edge notched three-point bend and double-edge notched tensile specimens had been employed and from the measured force-time response, values of the fracture energy, G_{Ic}, and the fracture toughness K_{Ic} had been determined and shown to be independent of the geometry of the test specimen. However, the measured value of the toughness was found to be dependent upon the impact velocity of the pendulum-striker and this dependence appears to largely arise from dynamic effects presented in the test technique. The nature of these effects were discussed and modeled and the hue material impact resistance of the epoxy polymers determined. These studies clearly revealed that the multiphase microstructure of the rubber-modified epoxy leads to a significant improvement in the impact behavior of cross-linked epoxy polymers.

Giovanni [8] investigated the impact fracture toughness of sintered iron and high-strength sintered steels, with densities between 7.0 to 7.25 gm/cm^3, by means of instrumented impact testing on fatigue pre-cracked as well as 0.17 mm-notched specimens. Experimental results showed that the fracture behavior was controlled by the properties of the resisting necks at the cracked notch tip. The materials with impact yield strengths of up to 700 MPa display an increase in fracture toughness as the yield strength was increased. These materials undergo continuous yielding during loading, and ductile fracture took place once the critical plastic strain was attained within a large process zone. A process-zone model, physically consistent with the fracto-graphic observations, correctly rationalized their impact fracture toughness. The materials with higher impact yield strengths display an impact curve which was linear up to fracture and were characterized by a fracture toughness which was independent of the yield strength. For these materials, the process zone reduced to the first necks at the cracked notch tip and fracture took place once the local applied stress-intensity factor reached the fracture toughness of the matrix. Based on the above information, the objectives of the present project are as follows:

- To design and construct an Izod Impact test machine for non metals.
- To test the performance of Izod Impact test machine.
- To analyze the properties obtained from the Izod Impact test machine.

3. Impact Testing Features and Principles

Testing of materials can be carried for various purposes and it may be either destructive or non-destructive. In destructive test, the specimen either breaks or remains no longer useful for future use, e.g., tensile test, torsion test. But in non-destructive test, the specimen does not break and even after being tested, it can be used for the purpose for which it is made, e.g., radiography, ultrasonic test. Impact test is a dynamic test in which a selected specimen, usually notched, is struck and broken by a single blow in a specially designed machine. It signifies the toughness of the material; i.e., ability to deform plastically and to absorb energy in the process before fracture. The key to toughness is a good combination of strength and ductility. A material with high strength and high ductility will have more toughness than a material with low strength and high ductility. The essential features of impact test are: suitable specimen, an anvil or support, a moving mass of known kinetic energy and a device for seaming the energy absorbed by the broken specimen. The schematic of an Izod Impact test machine is shown in Fig. 1.

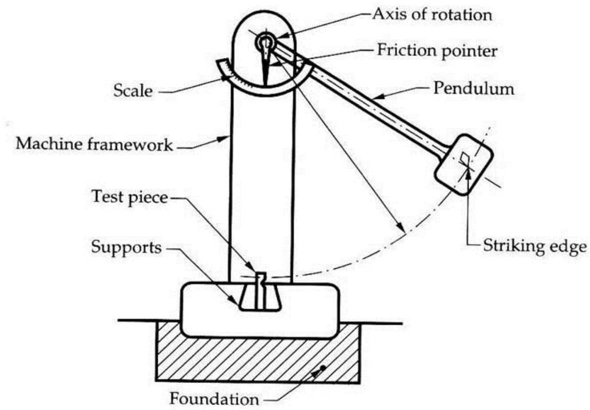

Fig.1: Schematic of Izod Impact Test Machine

4. Design of Izod Impact Testing Machine

The main objective of Impact test is to predict the likelihood of brittle fracture of a given material under impact loading. The test involves measuring the energy rammed in breaking a notched specimen when hammered by a swinging pendulum as shown in Fig.1. The energy can be calculated from the positions of the pendulum before and after struck the specimen. The detail of the calculations for designing the Izod Impact test machine is available in [9] but some of them are briefly described below:

Design of the Machine:

An MS base with dimensions of 46 × 30 × 9.5 cm was chosen to support the whole structure. The pendulum is chosen as a rectangular inverted U-shaped one as shown in Fig. 2. The gap between the two sides of the pendulum is 63.5 mm plus the clearance between clamp and sides. Assuming a clearance of 6.35 mm., the gap between two sides of the pendulum is = (63.5 + 2 × 6.35) mm = 76.2

mm. The pendulum sides are constructed from 12.7 mm thick MS plate. Hence, the dimension of the sides is 90 × 90 × 12.7 mm.

The pendulum arm is made of 25.4 mm dia pipe with a length of 170 mm from the centre of swing. The total mass of the pendulum arm is 3.43 kg.

The maximum angle the pendulum can swing is 90° with vertical and the maximum energy stored in this position = $mgh_1 = m\,g\,\times r\,(1-cos\alpha)$ = $3.43 \times 9.81 \times 0.382 \times\ (1 - cos\ 90°)$ N.m = 12.85 J.

Thus, the maximum velocity achieved, V = $\sqrt{2gh_1}$ $= \sqrt{2 \times 9.81 \times 0.382 \times\ (1 - cos\ 90°)}\ = 2.74\ m/s.$

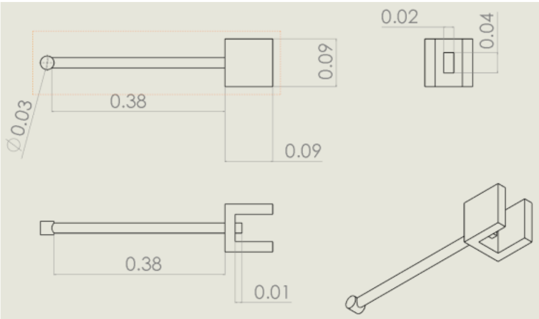

Fig 2: Schematic View of Rectangular Pendulum

After calculation of various parameters the specification of the designed Izod impact test machine is as follows and is shown in Fig.3: The clamp was purchased from the local market.

Machine Specification:
Base dimension = 46 cm × 30 cm × 9.5 cm
Clamp dimension = 10.1 cm × 6.35 cm × 7.5 cm
Pendulum cross-section = 9 cm × 1.27 cm
Pendulum mass, m = 3.43 kg
Pendulum radius, r = 382 mm
Range of pendulum swing angle = 0° to 90°
Tolerance angle or error angle = 2°.

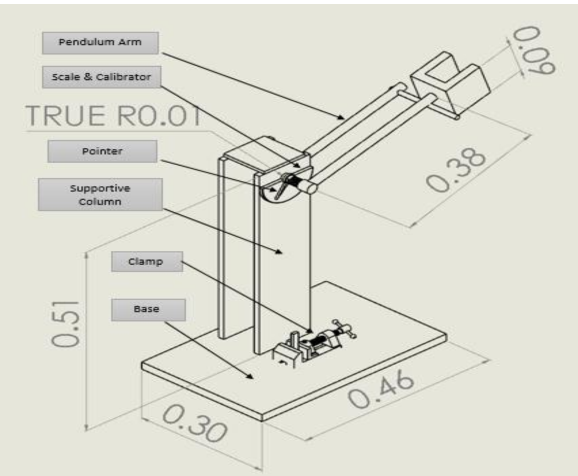

Fig. 3: Various Dimension of the Model.

5. Experimental Procedure

There are several standards for impact test. The ASTM standard for Izod Impact test for non-metals is ASTM D256. The result is expressed as energy lost per unit thickness (say, J/cm) at the notch. The dimension of a standard specimen for ASTM D256 is 63.5 × 12.7 × 3.2 mm. The test specimen varies on which material is being tested. Metallic samples are square in cross-section whereas polymeric specimens are often rectangular being struck parallel to the long axis of the rectangle. The specimen is held at one end and the other end is free. A 45^o V-notch of depth 2 mm is cut at the middle. The experimental setup depends on the setting up of two things of the specimen on the clamp and the angle of the pendulum where it is freed. These are (i) Setup on the clamp and (ii) Angle graduation.

Setup on the Clamp: The specimen is set on the clamp tightly and rigidly. The middle section of the V-notch is situated at the centre of the clamp. As suggested in [5], the striking edge must strike the specimen 22 mm above the clamp as shown in Fig. 4.

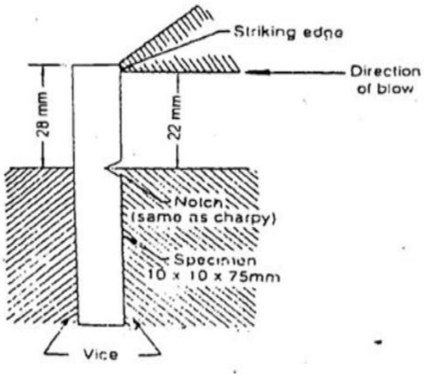

Fig. 4: Striking Edge and Striking Position

Angle graduation: First of all from an assumable angle, the pendulum is swung and then decreases it gradually onto the angle where the fracture actually occurred. The dial moves upward and the scale give the angle of the impact load. From the angular difference between initial angle and pointer angle absorbed energy and impact strength can be calculated. Fig. 5 and Fig. 6 show the photographic view of the experimental setup.

Fig. 5: Photo of Experimental setup from Front.

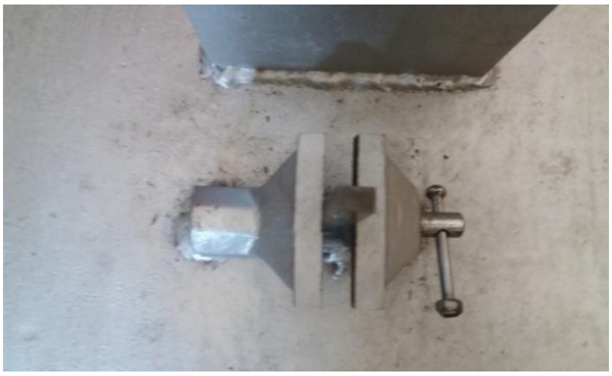

Fig. 6: Photo of Experimental setup from Top

6. Performance Test

The performance test was carried out with the constructed Izod Impact test machine with the following six samples whose specifications are as shown in Table 1.. For each test three samples were used and the average of the three results was taken.

Table 1: Specification of different samples for testing

Test No.	Specimen name	Length (mm)	Width (mm)	Thickness (mm)
01.	U-PVC pipe	63.5	12.7	2.0
02.	Thread pipe	63.5	12.7	3.2
03.	PPR pipe	63.5	12.7	6.0
04.	U-PVC pipe	63.5	12.7	6.3
05.	U-PVC pipe	63.5	12.7	8.0
06.	U-PVC pipe	63.5	12.7	10.0

The setting up of the specimens was closely monitored. It was ensured that the clamp should hold the specimen at the middle position and pendulum must be frictionless as much as possible. The free swing of the pendulum movement was ensured. The sensitivity of the dial was checked. In this experiment the specimen criteria follow the basic of ASTM D256 standard. For checking the experimental value of non-metals some polycarbonate characteristics were also examined.

7. Results and Discussion

The experimental data and some calculated parameters are presented in Table 2 to Table 3.

Table 2: Test Results for Minimum Fracture Angle and Absorbed Energy

Test No.	Specimen Material	Thickness (mm)	Minimum Fracture angle	Absorbed Energy (J)
01.	U-PVC pipe	2.0	10°	0.042
02.	Thread pipe	3.2	21°	0.333
03.	PPR pipe	6.0	30°	0.7524
04.	U-PVC pipe	6.3	24°	0.3090
05.	U-PVC pipe	8.0	29°	0.5164
06.	U-PVC pipe	10.0	43°	1.144

Table 3: Test Results for Minimum Impact Force and Impact Strength

Test No.	Specimen Material	Thickness (mm)	Force (N)	Impact strength (J/m)
01.	U-PVC pipe	2.0	18.20	92.48
02.	Thread pipe	3.2	79.43	239.41
03.	PPR pipe	6.0	160.28	204.37
04.	U-PVC pipe	6.3	103.60	97.72
05.	U-PVC pipe	8.0	150.18	104.37
06.	U-PVC pipe	10.0	322.64	115.21

To compare the results from the constructed machine, some tests were carried out with polycarbonate specimen. Table 4 shows the breaking and fracture energy for polycarbonate specimen. Four specimens of 63.5 × 12.7 × 6.35 mm were tested. The fracture energy is calculated by dividing the experimentally obtained breaking energy by the specimen thickness.

Table 4: Test Result for Polycarbonate Sample

Test No.	Maximum pendulum energy(J)	Breaking energy (J)	Fracture energy per thickness (J/m)
01.	2.82	0.7873	123.98
02.	2.82	0.7399	116.52
03.	2.82	0.7942	125..07
04.	2.82	0.7257	114.29

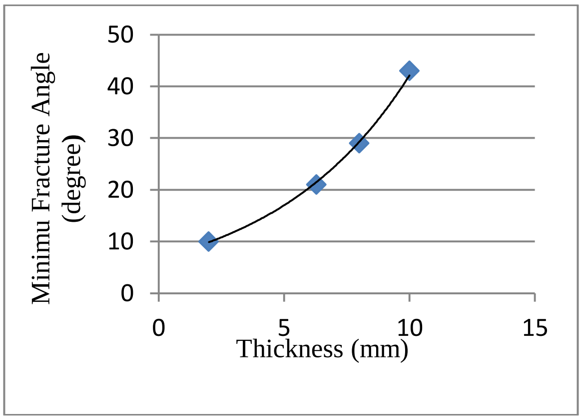

Fig 7: Best fit curve for thickness vs minimum fracture angle .

The equation from the best fit curve for Fig. 7 is an expotential line and the equation is: $Y = 6.860e^{0.1815X}$.

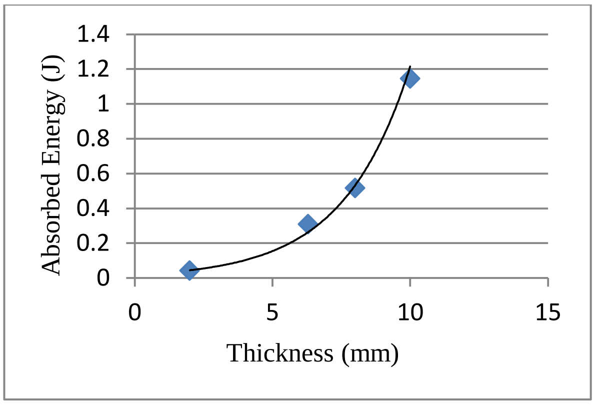

Fig 8: Best fit curve for thickness vs absorbed energy.

The equation from the best fit curve for Fig. 8 is an expotential line and the equation is: $Y = 0.0197e^{0.4215X}$.

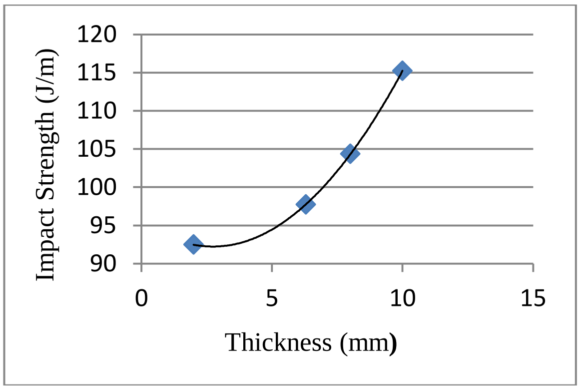

Fig.9: Best fitcurve for thickness vs Impact strength.

The equation from the best fit curve for Fig. 9 is a polynominal and the equation is:

$$Y = 0.4326\,X^2 + 2.3892X + 95.508$$

From the test results of Izod impact test and analyzing the properties of U-PVC specimen, it is clear that the toughness and minimum fracture angle, absorbed energy increases with the thickness of the specimen. The impact strength of non-metals gradually increases with the thickness as envisioned from Fig. 9.

The minimum fracture angles are 10°, 21°, 30°, 24°, 29° and 43° for 2-mm U-PVC, 3.2-mm Thread, 6-mm PPR, 6.3-mm U-PVC, 8-mm U-PVC and 10-mm U-PVC pipes respectively.

From Table 2, it is evident that the absorbed energy for various size specimens are: 0.04204 J, 0.333 J, 0.7524 J, 0.354 J, 0.5164 J and 1.114 J for 2-mm U-PVC, 3.2-mmThread, 6-mm PPR, 6.3-mm U-PVC, 8-mm U-PVC and 10-mm U-PVC pipes respectively; whereas, the absorbed energy for polycarbonate is 0.7617J as seen from Table 5. So, from the comparison of U-PVC and polycarbonate specimen it can be concluded that polycarbonate required two times more energy to breaking the similar specimen.

8. Conclusion

Izod Impact test machine is constructed for testing absorbed energy and material strength. The constructed machine will be used for checking absorbed energy and strength of non-metals (plastics) of various thicknesses. In this machine maximum 12.84J of energy could be achieved with the pendulum velocity of 2.73 m/s. Different types of U-PVC pipe samples were tested and compared with the corresponding values of polycarbonate. The polycarbonate specimen's absorbed energy, impact strength are greater than U-PVC pipe. The result of the tests are based on the thickness, minimum fracture angle, force required to break the specimen, absorbed energy, impact strength etc.

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