EXPERIMENTAL STUDY AND PARAMETRIC DESIGN OF IMPACT TESTING METHODOLOGY

A thesis submitted in the partial fulfillment of requirement

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Master of Engineering

In

Production and Industrial Engineering

Submitted by

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CERTIFICATE

This is to certify that the thesis entitled **EXPERIMENTAL STUDY AND PARAMETRIC DESIGN OF IMPACT TESTING METHODOLOGY** submitted by **NARINDERPAL SINGH** in partial fulfillment of the requirement for the award of the degree of **Master of Engineering in Mechanical (Production and Industrial Engineering)** to **Thapar University, Patiala,** is a record of candidate's own work carried out by him under my supervision and guidance. The matter embodied in this report has not been submitted in part or full to any other university or institute for the award of any degree.

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ABSTRACT

Impact testing methodology is finding the applications for determining the impact strength of the different materials. The process implies hammering effect on the work material that determines how much mechanical energy is required for the failure of any material. A part or material's ability to resist impact often is one of the determining factors in the service life of a part, or in the suitability of a designated material for a particular application. Impact resistance can be one of the most difficult properties to quantify. The ability to quantify this property is a great advantage in product liability and safety. In addition to providing information not available from any other simple mechanical test, these tests are quick and inexpensive. This study explores the influence of work material, weight & height of hammer on impact values. The optimal values of these parameters for maximum value of impact energy absorbed have been determined. Taguchi methodology has been used to get optimal values of these parameters. The three levels of each of the factors (work material, weight and height of hammer) have been taken and experiments were designed by applying the taguchi methodology. The L27 Orthogonal array was used and experiments were performed as designed by taguchi method. The results of the experimentation were analyzed analytically as well as graphically using ANOVA and main effect - interaction plots, respectively. The ANOVA tables of the experimental data have been created to calculate the significance of all factors upon each response individually.

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CHAPTER 1

INTRODUCTION

Engineers use metallic materials in designing structures and machine elements which are almost always subject to external loadings and environmental conditions. Metallic materials fail in different modes depending on the type of loading (tensile, compressive, bending, shearing, or torsion) and on the service conditions (temperature and corrosivity of the environment). Let's first consider purely static tensile loading. Metallic structures that are properly designed to avoid plastic deformation (applied stresses are less than σy) may fail in a catastrophic way by fast fracture when defects such as micro-cracks are present. Fracture is caused by the growth of an existing crack (can be few microns in length) to a critical size where a total break down of the cracked piece takes place due to the externally applied stresses. Micro-cracks in stressed materials can grow either in a ductile or in a brittle manner.

Ductile crack growth involves excessive plastic deformation which consumes a lot of the energy associated with the applied stresses. Fracture due to ductile crack growth is described as ductile fracture. A fracture surface produced by ductile fracture is extremely rough which indicates that a great deal of plastic flow has taken place. Ductile crack growth can often be detected before final fracture and catastrophic consequences can be avoided. FCC metals (like copper, austenitic stainless steel, aluminum, and lead) are ductile at all temperatures.

Brittle crack growth, on the other hand, proceeds with little plastic deformation where cracks grow rapidly. Brittle fracture surfaces are flat and do not show evidence of plastic deformation. Brittle fracture takes place suddenly and often causes considerable economical and human lives losses. Therefore, design engineers must be aware of brittle fracture and take it into consideration during materials selection. Brittle fracture occurs in BCC and HCP metals (like iron and zinc) under certain conditions. Several factors may promote brittle fracture in BCC and HCP metallic alloys such as the presence of sharp notches and cracks in the structure, fast application of the external stresses (high strain rate loading), and most importantly low operating temperatures. Many times mixed fracture, with both crystalline and fibrous areas, is observed. The stress-strain curve for' a material gives some idea. What to expect in impact tests. Material with stress strain curve A (Figure 1.1), should give greater impact strength than material B because the area under curve A is greater than that under B, even though material B has greater tensile strength.

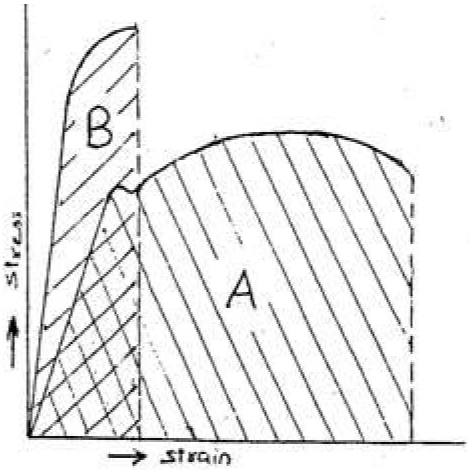


Figure 1.1: Stress-Strain Curves for Material A & B

Unlike other testing applications, impact testing involves the sudden and dynamic application of the load. Parts such as shafts, bolts, anvils and dies are examples of items subjected to impact loading. Impact is defined as the resistance of a material to rapidly applied loads. Experience has shown that some materials which offer considerable resistance to static stresses often shatter easily from a suddenly applied load, such as a hammer blow. An impact test signifies toughness of material that is ability of material to absorb energy (per volume) during plastic deformation. Static tension tests of unnotched specimens do not always reveal the susceptibility of a material to brittle fracture. This important factor is determined impact test. Several engineering materials have to withstand impact or suddenly applied loads while in service. Impact strengths are generally lower as compared to strengths under gradually applied loads. This applies to materials as cast iron, high carbon steel, glass and some plastics.

Two basic types of impact testing have evolved: (1) bending which includes Charpy and Izod tests, and (2) tension impact tests. Bending tests are most common and they use notched specimens that are supported as beams. In the Charpy impact test, the specimen is supported as a simple beam with the load applied at the center. In the Izod test, the specimen is supported as a cantilever beam. Using notched specimens the specimen is fractured at the notch. Stress is concentrated and even soft materials fail as brittle fractures. Bending tests allow the ranking of various materials and their resistance to impact loading. Additionally, temperature may be varied to evaluate impact fracture resistance as a function of temperature. Both Charpy and Izod impact testing utilize a swinging pendulum to apply the load. The tensile impact test avoids many of the pitfalls of the notched Charpy and Izod bending tests. The behavior of ductile materials can be studied without the use of notched specimens. Pendulum, drop-weights and flywheels can be used to apply the tensile impact load.

The notched bar tests are extensively used of all types of impact test. Therefore, the impact measures the energy necessary to fracture a standard notched bar (i.e. notch toughness) applying an impulse load or sudden load. The notch provided on the tension side in the specimen locates the point of fracture (i.e. acts as stress concentration point). All forms of the impact test depend upon the swinging pendulum. The height from which it drops is a measure of its inertia at the lowest point. There it collides with the specimen, breaking latter and continuing onward in its swing. The height to which the Pendulum rises is dependent upon the inertia left in the pendulum after breaking the specimen. The difference between height and the height to which it would have risen, had no specimen been present is a measure, the energy required to break the specimen. This, expressed in Joules (i.e. N-m), is the impact value of the specimen. A high impact value indicates better ability to withstand shock than an impact value.

CHAPTER 2

IMPACT TESTING

Testing of Materials can be done for the following purposes:

- To assess numerically the fundamental mechanical properties of ductility, malleability, toughness, etc.
- To determine data, i.e., force-deformation values to draw up sets of specifications upon which the engineer can base his design.
- To determine the surface or sub-surface defects in raw materials or processed parts.
- To check chemical composition.
- To determine suitability of a material for a particular application.

Testing on materials may be destructive tests and non-destructive tests. In destructive test, the components or specimen either breaks or remains no longer useful for future use. Examples of destructive tests are tensile test, impact test, bend test, torsion test, fatigue test, etc. A component or specimen does not break in non-destructive testing and even after being tested so, it can be used for the purpose for which it was made. Examples of non-destructive tests are radiography, ultrasonic inspection, etc.

Impact is defined as the resistance of a material to rapidly applied loads. An impact test is a dynamic test in which a selected specimen which is usually notched is struck and broken by a single blow in a specially designed machine. The purpose of impact testing is to measure an object's ability to resist high-rate loading. It is usually thought of in terms of two objects striking each other at high relative speeds. A part or material's ability to resist impact often is one of the determining factors in the service life of a part, or in the suitability of a designated material for a particular application. Impact resistance can be one of the most difficult properties to quantify. The ability to quantify this property is a great advantage in product liability and safety.

An impact test signifies toughness of material that is ability of a metal to deform plastically and to absorb energy in the process before fracture is termed toughness. The emphasis of this definition should be placed on the ability to absorb energy before fracture. Recall that ductility is a measure of how much something deforms plastically before fracture, but just because a material is ductile does not make it tough. 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. There are several variables that have a profound influence on the toughness of a material. These variables are Strain rate (rate of loading), Temperature, Notch effect. A metal may possess satisfactory toughness under static loads but may fail under dynamic loads or impact. Toughness decrease as the rate of loading increases. Temperature is the second variable to have a major influence on its toughness. As temperature is lowered, the ductility and toughness also decrease. The third variable is termed notch effect, has to due with the distribution of stress. A material might display good toughness when the applied stress is uniaxial; but when a multiaxial stress state is produced due to the presence of a notch, the material might not withstand the simultaneous elastic and plastic deformation in the various directions.

The essential features needed to perform Impact test are:

- A suitable specimen (specimens of several different types are recognized),
- An anvil or support on which the test specimen is placed to receive the blow of the moving mass,
- A moving mass of known kinetic energy which must be great enough to break the test specimen placed in its path, and
- A device for measuring the energy absorbed by the broken specimen.

The main objective of the impact test is to predict the likelihood of brittle fracture of a given material under impact loading. The test involves measuring the energy consumed in breaking a notched specimen when hammered by a swinging pendulum. The presence of a notch simulates the pre-existing cracks found in large structures. Note that both impact loading and the presence of a notch increase the probability of brittle fracture. The energy absorbed can be calculated by measuring the change in the potential energy of the pendulum before and after breaking the specimen.

ASTM has standardized the impact test with two testing approaches: the Charpy and the Izod. The two tests differ mainly in how the specimen is support during the impact loading. In the Charpy test the specimen is supported as a simple-beam while in the Izod test the specimen is supported as a cantilever-beam. Both tests use square bar specimens with machined notches taking the shape of the letter V hence giving other common names for these tests as Charpy V-notch (CVN) or Izod V-notch. Using an impact machine, the energy absorbed while breaking the specimen is measured. The energy quantities determined are qualitative comparisons on a selected specimen and cannot be converted to energy figures that would serve for engineering design calculations. The purpose of the impact test is to measure the toughness, or energy absorption capacity of the materials. In addition to providing information not available from any other simple mechanical test, these tests are quick and inexpensive. The data obtained from such impact tests is frequently employed for engineering purposes. It is usually thought of in terms of two objects striking each other at high relative speeds. It is usually used to test the toughness of metals, but similar tests are used for polymers, ceramics and composites.

Pendulum impact machines consist of a base, a pendulum of either single-arm or "sectorial" design, and a striker rod (also called a hammer), whose geometry varies in accordance with the testing standard. The mass and the drop height determine the potential energy of the hammer. Each pendulum unit has provisions to add extra weight. There is also a specimen support—a vise for the Izod test and an anvil for the Charpy test. The principal measurement from the impact test is the energy absorbed in fracturing the specimen. After breaking the test bar, the pendulum rebounds to a height which decreases as the energy absorbed in fracture increases. The energy absorbed in fracture, usually expressed in joules, is rending directly from a calibrated dial on the impact tester.

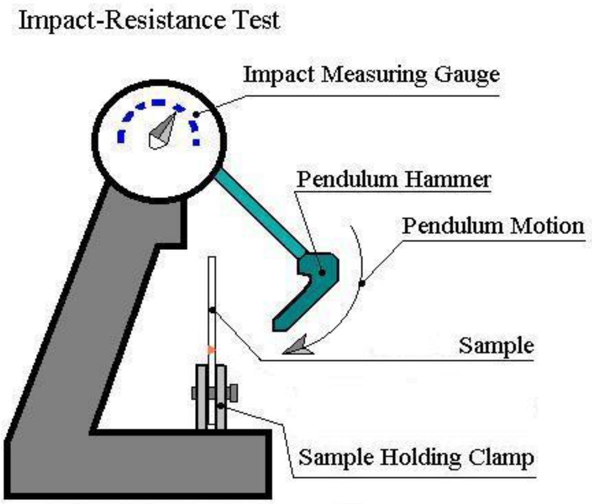


Figure 2.1: Pendulum Impact Machine

Izod and Charpy impact tests are similar in many respects. Both use test specimens that are either molded to size or cut from a larger "dog-bone" tensile-test sample. The test specimens have different dimensions.Specimen size for Izod testing is 10 x10 x 75 mm, while Charpy uses 10 x 10 x 60 mm specimens. In both tests, sample thickness depends on the specifications for the material being tested (typically 1/8 in. for Izod tests). Specimens are notched and conditioned with temperature and humidity before testing. At least 3 specimens are tested and the results are averaged. The test notches for the impact specimens for the tests have different dimensions. The Izod test is a V-notch; the Charpy test has three different specimen types: Key-hole, U-notch, and V-notch. However, other specimen types may be specified as required for both tests. The specimens are held differently. The Izod specimen is held in a cantilevered manner; the Charpy test is held such that the specimen rests against two supports on either side of the test notch. The impact location is different. The Izod test impact is against the end of the exposed cantilever; the Charpy test is struck directly behind the test notch such that the specimen undergoes three point bending.

Notchers cut away a V-shaped section of the sample. The notch size and shape are specified by the test standard. The purpose of the notch is to mimic part-design features that concentrate stress and make crack initiation easier under impact loads. Notch toughness is the ability that a material possesses to absorb energy in the presence of a flaw. In the presence of a flaw, such as a notch or crack, a material will likely exhibit a lower level of toughness. When a flaw is present in a material, loading induces a triaxial tension stress state adjacent to the flaw. The material develops plastic strains as the yield stress is exceeded in the region near the crack tip. However, the amount of plastic deformation is restricted by the surrounding material, which remains elastic. When a material is prevented from deforming plastically, it fails in a brittle manner. The units of this property are reported in the literature as foot-pounds (ft-lb) in the English system and joules (J) in the metric system. ISO and ASTM standards express impact strengths in different units. ISO standards report impact strengths in kJ/m^2, where the impact energy is divided by the cross sectional area at the notch. ASTM standards call for values to be reported in J/m, where the impact energy is divided by the length of the notch. Units are ft-lb/in. for Izod and joule/m^2 for Charpy.

2.2 IMPACT ENERGY

Impact energy is a measure of the work done to fracture a test specimen. When the striker impacts the specimen, the specimen will absorb energy until it yields. At this point, the specimen will begin to undergo plastic deformation at the notch. The test specimen continues to absorb energy and work hardens at the plastic zone at the notch. When the specimen can absorb no more energy, fracture occurs. Notched impact data cannot be compared with unnotched. Brittle materials generally have lower impact strengths, while those registering higher impact strengths tend to be tougher.

Drop Weight Testing -this test is conducted to determine the nil ductility transition temperature (NDT) of materials. Dynamic Tear Testing has a wide range of Research and Development applications. Used to study the effects of metallurgical variables like heat treatment, composition, and processing methods on the dynamic tear fracture resistance of material. Manufacturing processes, such as welding, can be effectively evaluated for their effect on dynamic tear fracture resistance. Additional uses for this test include evaluating the appropriateness of selecting a material for an application where a baseline correlation between Dynamic Tear energy and actual performance has been developed.

2.3 IMPACT SPECIMENS

The testing of full sized parts or structures in impact is very difficult because of the magnitude of the force required to produce failure. Generally, notch type specimens are used for impact tests. The presence of a notch on the surface of the test area of the specimen creates a concentration of stress or localization of strain during test. The effect of the localized strain at the base of the notch causes the specimen to fail through the plane at relatively low values of energy. Since the effect of the notch localizes the strain at its base, any change in the shape of the notch at its base will influence the impact value obtained. Therefore, the accuracy in the manufacturing of test specimen is most important. A high degree of precision is required in shaping the notch and locating the bottom of the notch with respect to the opposite surface of the specimen. The accuracy surface of the maintained in the manufacture of any type impact test specimen is plus or minus 0.001 inch.

There are two general types of notches used in the Izod and Charpy impact tests (bending impact tests). These are classified as the keyhole notch and the V- notch. The keyhole notch is used only in the Charpy impact specimens and chief characteristic is the large radius at the root of the notch (0.039 inch radius). The V-notch has a small radius at the root of the notch (0.010 inch radius) and is used in both Charpy and Izod impact specimens. Another difference is the depth of the notch. In any notch-tough material, the V-notch specimens will give higher Charpy impact values than are obtained for the keyhole notched specimens because of the larger cross section of the material under test. However, when the material is not notch-tough, both types of specimens will give the same approximate Charpy impact values. According to ASTM A370 (Standard Test Method and Definitions for Mechanical Testing of Steel Products) Standard specimen for Charpy impact test is:

10mm×10mm×55mm. Sub size specimens are: 10mm×7.5mm×55mm, 10mm×6.7mm ×55mm, 10mm×5mm× 55mm, 10mm×3.3mm×55mm, 10mm×2.5mm×55mm.

2.4 THE MAJOR FACTORS THAT AFFECT THE RESULTS OF AN IMPACT TEST ARE

- Velocity
- Specimen
- Temperature

2.4.1 Velocity

The velocity at impact does not appear to appreciably affect the results. However, experiments conducted with machines that develop velocities above certain critical values, impact resistance appears to decrease markedly. In general, the critical velocities are much less for annealed steels than for the same steels in the hardened condition.

2.4.2 Specimen

In some cases it is not possible to obtain a specimen of standard width from the stock that is available. Decreasing either the width or the depth of these specimens decreases the volume of metal subject to distortion, and thereby tends to decrease the energy absorption when breaking the specimen. The effect of the notch is to concentrate stresses at the root of the notch, embrittle the material in the vicinity of the notch and, at the same time, raise the elastic limit of the material in this area. When a crack forms at the root of the notch the stress is greatly intensified and the crack quickly progresses across the section. Without the notch, many compositions would simply bend without fracture, and their total capacity to absorb energy could not be detected. The sharper the notch (i.e. the smaller the included angle) the more pronounced are the effects noted above. The specimen sizes have been standardized so that results can be compared with reasonable confidence

2.4.3 Temperature

In contrast to the relatively small effect of temperature on the static strength and ductility of metals, at least within the atmospheric range, temperature has a very markedly effect on the impact resistance of the notched bars. Figure 2.2 shows the effect of temperature on the impact energy absorbed.

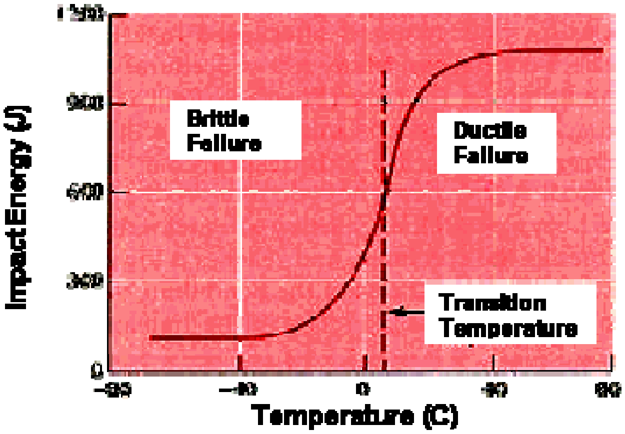


Figure 2.2: Effect of Temperature on the Impact Energy Absorbed

For a particular metal and type of test, below some critical temperature the failures are brittle, with low energy absorption. Above some critical temperature, the failures are ductile, with energy absorption that may be many times that in the brittle fracture range. Between these temperatures is what has been termed as transition-temperature range, where the character of the fracture may be mixed. With the standard notch, the critical range for many steels appears to occur between the freezing point and room temperature; in some metals it may be extended to temperatures well below the freezing point. Impact strength can be affected by temperature. This is especially true or carbon steels and other metals with a body-centered cubic (BCC) or hexagonal crystal (HCP) structure. Metals with a face-centered cubic (FCC) structure (such as austenitic stainless steel, copper, and aluminum) strengthen slightly at low temperatures, but there is not a significant lowering of impact strength as can be the case with carbon steels.

2.5 THEORETICAL EXPLANATION OF PENDULUM TEST

In a typical Pendulum machine, the mass of the hammer (striking edge) mass (m) is raised to a height (a). Before the mass (m) is released, the potential energy will be:

$$E_p = m\,g\,a \qquad \text{------------------------ (1)}$$

After being released, the potential energy will decrease and the kinetic energy will increase. At the time of impact, the kinetic energy of the pendulum:

$$E_k = 1/2\ m\,v^2 \qquad \text{------------------------- (2)}$$

And the potential energy:

$$E_p = m\,g\,a$$

Will be equal. $E_k = E_p$

$$m\,g\,a = 1/2\ m\,v^2$$

$$v^2 = 2\,g\,a$$

And the impact velocity will be:

$$v = (2\,g\,a)^{1/2} \qquad \text{-----------------------(3)}$$

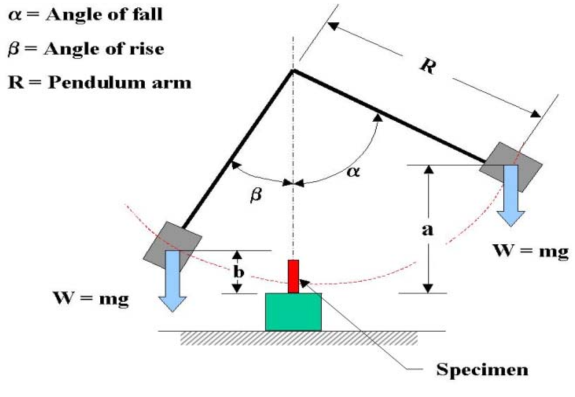


Figure 2.3: Typical Pendulum Machine

$a = R\,(1 - \cos\alpha)$

$b = R\,(1 - \cos\beta)$

Initial energy = $E_i = m\,g\,R\,(1 - \cos\alpha) = W\,R\,(1 - \cos\alpha)$

Energy after the rupture = $E_r = m\,g\,R\,(1 - \cos\beta) = W\,R\,(1 - \cos\beta)$

Energy absorbed by the specimen = $E_{abs} = W\,R\,(\cos\beta - \cos\alpha)$

Or

Initial energy = $m\,g\,a = W\,a = E_i$

Energy after rupture = $m\,g\,b = W\,b = E_r$

Energy absorbed during impact = $m\,g\,(a - b) = W\,(a - b) = E_{abs}$

2.6 IZOD IMPACT TEST

The Izod Impact Test was invented by Edwin Gilbert Izod (1876-1946).A test specimen, usually of square crossed section is notched and held between a pair of jaws, to be broken by a swinging or falling weight. When the pendulum of the Izod testing machine is released it swings with a downward movement and when it reaches the vertical the hammer makes contact with the specimen which is broken by the force of the blow. The hammer continues its upward motion but the energy absorbed in breaking the test piece reduces its momentum. A graduated scale enables a reading to be taken of the energy used to fracture the test piece. To obtain a representative result the average of three tests is used and to ensure that the results conform to those of the steel specification the test specimens should meet the standard dimensions. This test can also used to determine the notch sensitivity.

Figure 2.4: Impact Testing Machine (Izod & Charpy)

This impact testing machine is capable of performing both Izod and Charpy impact test. This has separate hammer for both tests, a vice for Izod test and an anvil for the Charpy test to hold the specimen according to standard specimen size, height of hammer, separate scale and other accessories to perform both impact test. It is used for the purpose of performing Izod test in solid mechanics lab at Thapar University. Where separate impact testing machine is used to perform Charpy impact test. Izod testing can be done up to 0 to 164 Joules or N-m. The testing equipment is the Impact Testing shown in figure No. 2.4 where the fracture energy in Joules can be read directly from the dial on the tester for both Izod and Charpy impact test. The test specimen is machined to a square or round section, with either one, two or three notches. The specimen is clamped vertically on the anvil with the notch facing the hammer. The Izod test is has become the standard testing procedure for comparing the impact resistances of plastics. While being the standard for plastics it is also used on other materials. The Izod test is most commonly used to evaluate the relative toughness or impact toughness of materials and as such is often used in quality control applications where it is a fast and economical test. It is used more as a comparative test rather than a definitive test. This is also in part due to the fact that the values do not relate accurately to the impact strength of moulded parts or actual components under actual operational conditions. When releasing the pendulum and make sure to clear the way and stand back away from the swinging pendulum. Do not try to stop the pendulum once it has been released. It can cause serious injury.

2.7 IZOD IMPACT TEST SPECIMENS

Izod test specimens vary depending on what material is being tested. Metallic samples tend to be square in cross section, while polymeric test specimens are often rectangular, being struck parallel to the long axis of the rectangle. In the Izod test, the specimen is held on one end and is free on the other end. This way it forms a cantilever beam. Izod test sample usually have a V-notch cut into them, although specimens with no notch as also used on occasion. Figures 2.5 and 2.6 shows the dimensions of the Izod test specimen and the positions of the striking edge of the pendulum and the specimen in the anvil. In this case the notch is just at the edge of the supporting vise and facing into the direction of impact.

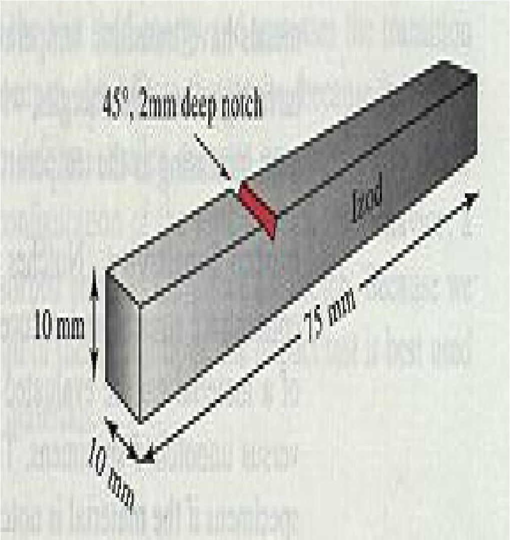
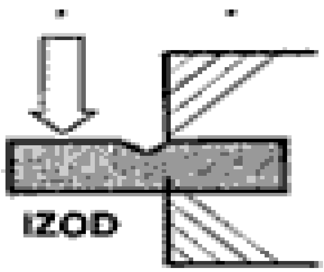


Figure 2.5: Izod Test Specimens



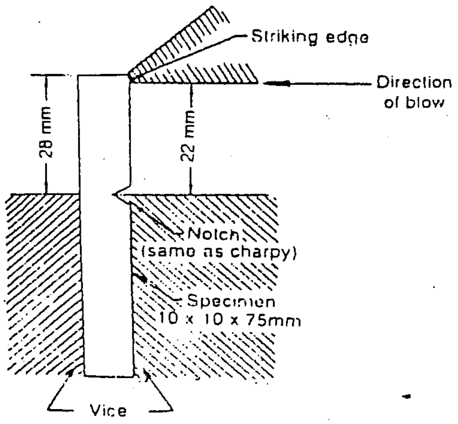


Figure 2.6: Izod test specimen and its position in the anvil

The Izod test involves striking a suitable test piece with a striker, mounted at the end of a pendulum. The test piece is clamped vertically with the notch facing the striker. The striker swings downwards impacting the test piece at the bottom of its swing. Some Izod impact testers are equipped to be able to utilize different sized strikers, which impart different amounts of energy. Often a series of strikers may be used to determine the impact energy, starting with small strikers and working up until failure occurs.

Tests are often performed at different temperatures to more closely simulate the actual service conditions. In the case of low temperature tests, specimens may are kept in a freezer until their temperature has equilibrated. They are then immediately removed and tested within seconds of removal from the freezer. At the point of impact, the striker has a known amount of kinetic energy. The impact energy is calculated based on the height to which the striker would have risen, if no test specimen was in place, and this compared to the height to which the striker actually rises. Tough materials absorb a lot of energy, whilst brittle materials tend to absorb very little energy prior to fracture.

2.8 CHARPY IMPACT TEST

The Charpy Impact Test was developed in 1905 by the French scientist Georges Charpy (1865-1945). The Charpy test measures the energy absorbed by a standard notched specimen while breaking under an impact load. The Charpy impact test continues to be used as an economical quality control method to determine the notch sensitivity and impact toughness of engineering materials. The Charpy Test is commonly used on metals, but is also applied to composites, ceramics and polymers. With the Charpy test one most commonly evaluates the relative toughness of a material, as such; it is used as a quick and economical quality control device. It was pivotal in understanding the fracture problems of ships during the Second World War, Today it is used in many industries for testing building and construction materials used in the construction of pressure vessels, bridges and to see how storms will affect materials used in building.

Figure 2.7: Charpy Impact Testing Machine

Charpy pendulum impact testing machine has eighteen numbers of teeth. The pendulum can be raised up to fifteen teeth. It measures impact energy absorbed in Kg-m. The potential energy of hammer is increased 2.5 Kg-m by increase in each teeth. A Charpy pendulum impact test is a variation of Izod. In a Charpy test, a sample is laid horizontally on two supports against an anvil. The sample is notched in the center and the notch side is positioned away from the pendulum. When the pendulum swings through the gap in the anvil, it impacts the center of the sample with a hammer. The energy to break is measured and reported in the same way as with an Izod test. The principal difference between two tests is the manner in which the specimen is supported. This position places the notch at the location of the maximum tension.

We will use the Charpy impact test configuration. The standard test specimen is 10 x 10 x 55 mm, with a v-notch 2 mm deep on one side at the center. The specimen is placed exactly midway between two anvils such that the pendulum strikes opposite to the notch. The pendulum is lifted to the initial release position and then released. The pendulum must be allowed to swing freely after striking the specimen. When releasing the pendulum and make sure to clear the way and stand back away from the swinging pendulum. Do not try to stop the pendulum once it has been released. It can cause serious injury. The standard Charpy Test specimen consist of a bar of metal, or other material, 55x10x10mm having a notch machined across one of the larger dimensions. Figure 2.8 and 2.9 show the dimensions of the Charpy test specimen and the positions of the striking edge of the pendulum and the specimen in the anvil.

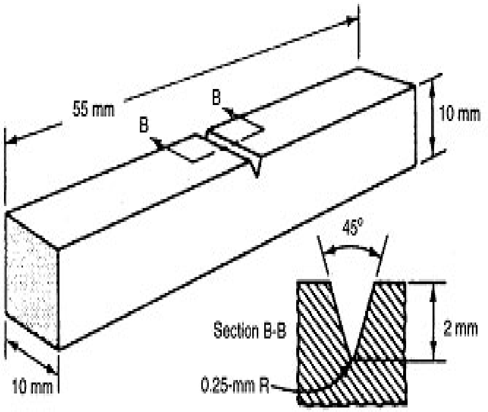


Figure 2.8: Charpy Impact Test specimens

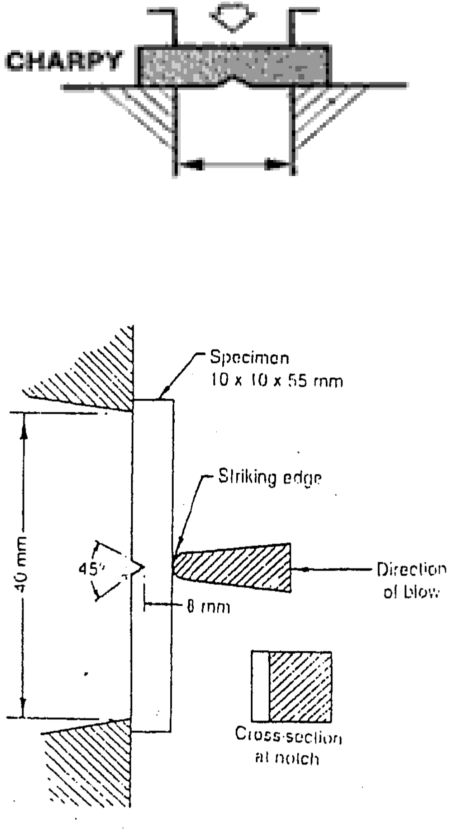


Figure 2.9: Position of the Charpy test specimen on the impact test machine

V-notch: 2mm deep, with 45° angle and 0.25mm radius along the base. **U-notch and keyhole notch:** 5mm deep notch with 1mm radius at base of notch.

The Charpy tests are conducted on instrumented machines capable of measuring less than 1ft.lb. to 300ft. lbs. at temperatures ranging from - 320°F(0^{o}C) to over 2000°F. Specimen types include notch configurations such as V-Notch, U-Notch, Key-Hole Notch, as well as Un-notched and ISO (DIN) V-Notch, with capabilities of testing sub size specimens down to 1/4 size. A test specimen is machined to a 10mm x 10mm (full size) cross-section, with either a "V" or "U" notch. Sub-size specimens are used where the material thickness is restricted. Specimens can be tested down to cryogenic temperatures.

2.9 QUANTITATIVE AND QUALITATIVE RESULTS

The quantitative result of the impact test—the energy needed to fracture a material—can be used to measure the toughness of the material and the yield strength. Also, the strain rate may be studied and analyzed for its effect on fracture. The ductile-brittle transition temperature (DBTT) may be derived from the temperature where the energy needed to fracture the material drastically changes. However, in practice there is no sharp transition and so it is difficult to obtain a precise transition temperature. An exact DBTT may be empirically derived in many ways: a specific absorbed energy, change in aspect of fracture (such as 50% of the area is cleavage), etc.

The qualitative results of the impact test can be used to determine the ductility of a material. If the material breaks on a flat plane, the fracture was brittle, and if the material breaks with jagged edges or shear lips, then the fracture was ductile. Usually a material does not break in just one way or the other, and thus comparing the jagged to flat surface areas of the fracture will give an estimate of the percentage of ductile and brittle fracture.

2.10 FACTORS AFFECTING IZOD AND CHARPY IMPACT ENERGY

Factors that affect the Charpy impact energy of a specimen will include:

- Yield strength and ductility
- Notches
- Temperature and strain rate
- Fracture mechanism

2.10.1 Yield strength and Ductility

For a given material the impact energy will be seen to decrease if the yield strength is increased, i.e. if the material undergoes some process that makes it more brittle and less able to undergo plastic deformation. Such processes may include cold working or precipitation hardening.

2.10.2 Notches

The notch serves as a stress concentration zone and some materials are more sensitive towards notches than others. The notch depth and tip radius are therefore very important.

2.10.3 Temperature and Strain rate

Most of the impact energy is absorbed by means of plastic deformation during the yielding of the specimen. Therefore, factors that affect the yield behavior and hence ductility of the material such as temperature and strain rate will affect the impact energy. This type of behavior is more prominent in materials with a body centered cubic structure, where lowering the temperature reduces ductility more markedly than face centered cubic materials.

2.10.4 Fracture mechanism

Metals tend to fail by one of two mechanisms, micro void coalescence or cleavage. Cleavage can occur in body centered cubic materials, where cleavage takes place along the {001} crystal plane. Micro void coalescence is the more common fracture mechanism where voids form as strain increases, and these voids eventually join together and failure occurs. Of the two fracture mechanisms cleavage involved far less plastic deformation ad hence absorbs far less fracture energy.

CHAPTER 3

LITREATURE REVIEW

Taguchi methods are most recent additions to the tool kit of design, process, and manufacturing engineers and quality assurance experts. In contrast to statistical process control which attempt to control the factors that adversely effect the quality of production The significance of beginning quality assurance with an improved process or product design is not difficult to gauge .Taguchi method systematically reveal the complex cause and effect relationship between design parameter and performance . These lead to building quality performance into process and product before actual production begins .Taguchi method have rapidly attained prominence because wherever they have been applied, they lead to the major reductions into process and products before actual production begins .The foundation of quality depend upon two premises :

- Society incurs a loss any time the performance of product is not on target.
- Product and process design require a systematic development, progressing stepwise through system design, parametric design and finally tolerance design.

The first point suggests that whenever the performance of a product deviates from its target performance, society suffer loss. Such a loss has two components: The manufacture incurs a loss when he repairs or rectified return or rejected product. The second point aims at quality engineering , a discipline that aims at engineering not only function but also quality performance into products and process .The following seven points highlight the distinguish feature of taguchi’s approach which aimed at assuring quality :

Taguchi defined the term quality as the deviation from on target performance which appears to be first paradox. According to him the quality of a manufactured product is the total loss generated by that product to the society from the time it is shipped.

In a competitive economy continuous improvement (CQI) and cost reduction are necessary.

A CQI programmed include continuous reduction in the variation of product performance characteristic in their target values.

Customer loss attribute to the product performance variation is often proportional to the square of the deviation performance characteristic from its target value.

The finally quality and cost of a product manufactured depends primarily on the engineering design of the product and its manufacturing process.

Variation in the product depends primarily on the engineering design of the product and its manufacturing process. Statically planned experiments can efficiently and reliably identify the settings of the product and process parameters that reduce performance variations.

Design of Experiments (DOE) is a powerful statistical technique introduced by R.A. fisher in England in 1920s to study the effect of multiple variables simultaneously DOE can highly effective when:

Optimize product and process design; study the effect of multiple factor on process. Study the influence of individual factors on the performance and determine which factor has more influence, which one has less. It can also find which factor should have higher tolerance and which tolerance should be relaxed.

Marshall (1973) developed a fracture mechanical analysis to account for the observed dependence of w (energy/unit area) on notch size. A correction factor (ø) 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 on PMMA have shown that "corrected" results were independent of specimen geometry and the Gc for PMMA had been evaluated as 1.04 x 103 J m^{-2}. The experimental results showed that there was an additional energy term which must be accounted for and this had been interpreted here 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 resolves many of the difficulties associated with notched impact testing and provides 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 were reported. 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 simulation of impact behavior was undertaken and the results were compared with the experimental data. Conclusions were 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 in this paper was emphasized.

Hine (1986) studied the impact behavior of polyethersulphone 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, Gc 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.

Kinloch (1987) conducted instrumented impact tests on both a simple unmodified and a 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, Glc, and the fracture toughness, Klc, 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 true 'material' impact resistance of the epoxy polymers determined. These studies clearly reveallled that the multiphase microstructure of the rubber-modified epoxy leads to a significant improvement in the impact behavior of cross-linked epoxy polymers.

Dear (1991) conducted a test on impact of materials, because it was becoming increasingly important as a wide range of new materials were being developed for demanding high loading-rate working conditions. Charpy pendulum and many other impact-testing machines were being better instrumented to provide more information about the forces acting on a specimen up to and during fracture. Mostly, the force sensors were near the points of contact on the striker or the support and these could provide well for recording the overall forces acting on the specimen to be monitored. Of increasing interest was the distribution of stress and strain within the specimen during the initiation and propagation of fracture. This paper reported research using on-specimen strain-gauge sensors for impact testing of non-metallic specimens. Comparisons were made between force time traces from sensors on the specimen and those located on the striker. Observations were made as to how the stresses related to the fast crack in the core of the material specimen and those acting on the surface of the material about the crack, and also those acting on the plastic hinge formed on the compression side of the specimen. Optical and scanning electron microscopic studies were made of the crack surfaces and high-speed photography was used to observe the crack propagation in specimens with and without side-grooves to guide the crack and increase constraint.

Folkes (1992) carried out Charpy impact tests on specimens removed from the joint region in butt fusion-welded polyethylene pipe. In order to ensure that crack initiation occurs precisely at the weld line, a novel method of notching had been used. Gc data had been derived from these tests, which were conducted at temperatures of - 150 and 23 ^{o}C Results obtained from pendulum impact and instrumented falling weight tests showed consistent differences, probably attributable to the speed of impact. Data had also been obtained for the parent unwelded material.

Giovanni (1998) investigated the impact fracture toughness of sintered iron and high-strength sintered steels, with densities between 7.0 And 7.25 g/cm^3, by means of instrumented impact testing on fatigue precracked 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 crack/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 fractographic 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 crack/notch tip, and fracture took place once the local applied stress-intensity factor reached the fracture toughness of the matrix.

Srivatsan (1999) presented and discussed the influence of notch acuity and test temperature on the impact behavior of aluminum alloy 6061. Notch angles of 45^{o}, 60^{o}, 75^{o} and 90^{o} were chosen for a standard Charpy impact test specimen containing two such notches positioned at right angles to the applied load. For a given angle of the notch the dynamic fracture toughness increased with an increase in test temperature. At a given test temperature, the impact toughness of a ductile microstructure decreased with an increase in notch severity. For the least severe notch dynamic fracture surfaces revealed the occurrence of localized mixed-mode deformation at the elevated temperature. An increase in notch severity resulted in essentially Mode-I dominated fracture at all test temperatures. The results were discussed in light of alloy microstructure, fracture mechanisms and deformation field ahead of the advancing crack tip.

Rita (2001) studied that impact fatigue had been made for the first time on 63.5% glass fibre reinforced vinylester resin notched composites. The study was conducted in a pendulum type repeated impact apparatus especially designed and fabricated for determining single and repeated impact strengths. A well-defined impact fatigue (S–N) behavior, having a progressive endurance below the threshold single cycle impact fracture stress with decreasing applied stress had been demonstrated. Fractographic analysis revealed fracture by primary debonding having fibre breakage and pullout at the tensile zone, but a shear fracture of fibre bundles at the compressive zone of the specimen. The residual strength, modulus and toughness showed retention of the properties at high impact stress leveled up to 1000 impacts followed by a sharp drop. Cumulative residual stresses with each number of impacts not withstanding the static fatigue failure at long endurances had been ascribed for the composite failures under the repeated impact stresses.

Rita (2001) examined two types of unidirectional carbon fibre, one of high strength (DHMS) and another of medium strength (VLMS) reinforced vinylester resin composites for their impact fatigue behavior over 10^4 impact cycles for the first time. The study was conducted using a pendulum type repeated impact apparatus specially designed and constructed for the purpose. A well-defined impact fatigue behavior (S–N type curve) curve had been demonstrated. It showed a plateau region of $10–10^2$ cycles immediately below the single cycle impact strength, followed by progressive endurance with decreasing impact loads, culminating in an endurance limit at about 71% and 85% of the single impact strength for DHMS-48 and VLMS-48, respectively. Analysis of the fractured surfaces revealed primary debonding, fibre breakage and pull-out at the tensile zone of the samples and a shear mode of fracture with breakage of fibre bundles at the compressive zone of the samples. The occurrence of a few major macrocracks in the matrix with fibre breakage at the high load–low endurance region and development of multiple microcracks in the matrix, coalescing and fibre breakage at the low-load–high endurance region had been inferred to explain the fatigue behaviour of the composites examined.

Talukdar, Sen and Ghosh (2001) Studied the effect of fatigue damage in En-8–grade heat treated steel (annealed and hardened and tempered), under different cyclic loading conditions at room temperature (25 ^{0}C), on the impact and dynamic fracture-toughness properties. The results indicate higher fracture toughness and impact toughness in hardened-and-tempered steel than in annealed steel. Cyclic hardening and softening occurs in both the hardened-and-tempered as well as the annealed steel. With the increase of peak stress and number of fatigue cycles, the *KID* and CVN values decrease in hardened-and-tempered steels. The results are discussed in terms of dislocations, slip bands, and their density, microstructure, and fracture morphology.

Fernandez et al. (2002) studied the dynamic behavior of three different fiber fabric composite laminates by testing notched specimens in an instrumented Charpy machine. The registered impact force and displacement at the specimen hammer contact point were used to evaluate Mode-I fracture energy and dynamic fracture toughness. The changes in fracture toughness due to impact velocity, crack size and stacking sequence of the specimen were investigated with different degrees of aging conditions. Aging was found to significantly affect the dynamic fracture toughness, but had less effect on the static fracture toughness.

Bimal and Surendra (2002) evaluated that Charpy V-notch impact toughness of 600 MPa yield stress TMT rebars alloyed with copper, phosphorus, chromium and molybdenum. Subsize Charpy specimens were machined from the rebar keeping the tempered martensite rim intact. The copper–phosphorus rebars showed toughness of 35 J at room temperature. The toughness of copper–molybdenum and copper–chromium rebars was 52 J. The lower toughness of phosphorus steel was attributed to solid solution strengthening and segregation of phosphorus to grain boundaries. Due to superior corrosion resistance, copper–phosphorus TMT rebar was a candidate material in the construction sector.

Rittel (2002) reported their methodology and resulted for the assessment of the dynamic fracture energy of notched Charpy A508 steel specimens. The fracture tests consist of one-point bend impact applied to the specimen in contact with an instrumented bar. Fracture was caused by the inertia of the unsupported specimen only. The fracture energy was determined from the incident, reflected and single wire fracture gage signals. High-speed photographic recordings showed that for all the specimens investigated in the "lower shelf" temperature regime, fracture occurs relatively early and prior to "taking off" of the bar by rigid body motion. It also confirmed that the fracture gage readings indeed coincide with the formation of a crack from the notch tip. The present methodology was relatively easy to implement, and it allows the investigation of the fracture properties of materials at loading rates (and velocities) that were substantially higher than those achieved in a conventional Charpy test. Moreover, this test was attractive for modeling purposes since its boundary conditions were simple and well defined.

Kalthoff (2004) used instrumented Charpy impact testing to investigate the strength and failure properties of a glass-fiber/vinyl-ester composite. The test technique, originally developed for testing of steel specimens, was presented in its basic aspects; reported the conventional procedures for determining load, displacement and energy absorption that a specimen experiences, over the entire phase of loading and subsequent failure of the specimen. Techniques were described for generating data of sufficient accuracy when applying the test to composites. In particular, the necessity of utilizing measurement chains of sufficiently high frequency response and striker tups of sufficiently high sensitivity was emphasized. Tests were performed with glass-fiber/vinyl-ester specimens, provided with notches oriented in two different directions with respect to the plies of woven glass fiber rovings. Two different types of failure result: fiber breakage ahead of the notch due to tensile stresses, and delaminations of the interface planes between the plies of woven glass fiber rovings due to shear stresses. Specifically, energies absorbed by the specimen over the entire failure process and values of maximum load occurring during the impact process were measured over a large range of temperatures. The data were correlated with the observed failure phenomena. The high level of information obtained in characterizing the failure behavior by means of a test which requires limited technical effort proves the instrumented Charpy impact test to be a simple but effective tool for quantifying the quality of a composite in practical applications, as e.g. in surveillance programs for controlling processes such as manufacturing or aging of the material.

Valeria (2004) deals with the influence of the testing equipment on impact load measurements. A previously developed method of analysis and processing of the experimental data based on a refined analogical model of the impact event and inverse problem techniques was used. This method made it possible to obtain the mechanical response of the material, notwithstanding the disturbance of the dynamic effects associated to the test. Results from tests carried out both on falling weight and swing pendulum instrumented testing machines were compared. It was shown that this method could give an accurate estimation of the actual bending force in impact testing independent of the testing equipment.

Anton (2005) studied experimentally dynamic responses of the standard Charpy impact machine were using strain gauges and accelerometer attached to the striker and the rotary position sensor fixed at the rotating axis and numerically with the finite element analysis. The fracture propagation was simulated with the cellular automata finite element approach developed earlier. A series of low velocity as well as full capacity Charpy tests were analyzed. It was found that the strain gauge signal recorded close to the tup edge and the acceleration recorded at the back of the striker does not match. The energy calculated with the strain gauge data agreed well with the dial reading, while the energy calculated with the accelerometer signal was never near it. Frequencies closed to the first natural frequency of the Charpy sample had high modal magnitudes in the acceleration signal but were effectively damped in the strain gauge response. Vibrations of the striker arm had highest modal magnitudes in the rotary position sensor. A low-pass filter was used to obtain the striker movements. The finite element analysis partly supported the experimental observations but also suggested that acceleration at the tup edge suffers higher oscillations than strain.

Tvergaard and Needleman (2005). Investigated full three dimensional transient analyses of Charpy V-notch specimens. The material response was characterized by an elastic-viscoplastic constitutive relation for a porous plastic solid, accounting for adiabatic heating due to plastic dissipation and the resulting thermal softening. The onset of cleavage was taken to occur when the average of the maximum principal stress over a specified volume attains a critical value. Typically, the material parameters in the weld material differ from those in the base material, and the heat affected zone (HAZ) tends to be more brittle than the other material regions. He analyzed that the effect of weld strength under match or overmatch was an important issue. Some specimens, for which the notched surface is rotated relative to the surface of the test piece, have so complex geometry that only a full 3D analysis was able to account for the interaction of failure in the three different material regions, whereas other specimens could be approximated in terms of a planar analysis.

Tamer (2006) evaluated impact fatigue properties of unidirectional carbon fibre-reinforced polyetherimide (PEI) composites by subjecting standard izod impact samples to low velocity impact loading at energy levels ranging 0.16–1.08 J by using Ceast Model Resil 25, a pendulum type instrumented impact test system. The effect of the previous low velocity impacts on the impact properties of the laminates was investigated. On the other hand materials were subjected to repeat low velocity impact tests up to fracture. Results of repeated impact study were reported in terms of peak load, absorbed energy and number of impacts. Fractographic analysis revealed the fracture by primary debonding, with fibre breakage and pullout in the tensile zone, but a shear fracture of fibre bundles in the compressive zone of the specimen.

H. Nishi (2006) performed an instrumented Charpy impact test and slow-bend Charpy test of the DB (diffusion-bonded) joints to clarify the degradation of Charpy absorbed energy. Elasto-plastic analyses were also carried out in order to study the deformation behavior of the tensile and Charpy V-notched specimens for the DBjoints. As a result, the fracture behavior of the impact and slow-bend tests was almost the same. Elasto-plastic analyses showed that the maximum strain occurred at the DS Cu apart from the interface for tensile specimen, however, the strain concentrated at the DS Cu near the interface for the Charpy notched specimen. This strain concentration arose from the mechanical heterogeneity between stainless steel and DS Cu in the bonded zone and could be attributed to the degradation of the absorbed energy of the DB joints.

V. M. Maslyuk (2006) organize and made more effective use of the large number of impact-toughness characteristics which currently exist, it is proposed that the type (KCU, KCV, KCT) and numerical values of the acceptance characteristics used for this property be chosen with allowance for their relationship to criterional values of the main characteristic IT0 employed in the univariate system described by the authors for evaluating impact toughness. It is not necessary to observe strict conditions on the method of application or geometry of the notch on impact specimens in order to construct working graphs of the function $IT = f(\alpha)$ used in the system.

Borkova (2007) proposed a procedure for determining the impact resistance of composite materials based on glass- and carbon-reinforced plastics and adhesive materials used as binders. Characteristics of the impact resistance were determined using a pendulum tester upon impact by a spherical steel indenter. It was shown that the most informative characteristic for estimating the impact resistance of composites was the work absorbed by the material upon impact. For comparative estimation of the impact resistance of different materials, whose specimens might have different thicknesses, it was convenient to use relative rather than absolute values of impact resistance. The relative value was calculated by dividing the maximum contact force by the specimen thickness. Glass-fiber laminates based on adhesive prepregs 1.9 and 2.1 mm thick and three-layer honeycomb panels were tested. Materials based on KMKS 2.120.T10 adhesive prepreg possess the best impact resistance.

Yakovleva (2007) studied the effects of testing conditions on the mechanical properties and fracture of a material in the course of impact loading. Using steels of various phase compositions (ferritic steel 08Kh18T1 and austenitic steel 10Kh18AG19) tested in a wide temperature range (from 20 to –196 °C), the advantage of layered structures had been established as compared to monolithic. It had been shown that the testing of composite samples simulated the loading-affected behavior of the ferritic steel 08Kh18T1 with an inhomogeneous layered microstructure obtained during repeated hot rolling with a reduction of no less than 65%.

Stolyarov (2007) studied the temperature dependence of the impact toughness of commercial purity titanium in coarse-grained and nano structured states. The method of transmission electron microscopy was used to investigate the structure of the initial nano structured titanium. Results of comparative fractographic analysis of fracture surfaces of impact specimens in coarse-grained and nano structured states at room and low temperatures were presented. The causes of elevated impact toughness of nano structured titanium at low temperatures were discussed.

Tvergaard and Needleman (2008) analyzed the Izod impact test numerically using a polymer constitutive relation with material parameters qualitatively representative of a polycarbonate. The computations were full 3D transient analyses using explicit time integration and accounting for finite strains. The main purpose of the analyses was a comparison of the stress and strain fields that develop for the various specimen geometries that were used in practice, ranging from a specimen with a square cross-section to a specimen with a width about a quarter of that value. It was shown that the response varies from something close to a plane strain response to something close to a plane stress response. The results illustrated the effect of the stress–strain behavior of polymers, which involved attaining a stress peak, followed by softening and then by the gradual evolution of a very stiff response resulting from increasing network stiffness.

Hufenbach (2008) after careful tailoring, composite structures could provide a reasonable well response to impact loads with the additional advantages of weight savings and structural stiffness. In order to efficiently design composite structures for impact loads, reliable numerical models were required and sufficiently accurate material codes were necessary. This paper deals with the experimental investigation of carbon reinforced composites under low-velocity impact and its numerical modeling with an orthotropic continuous damage-based material approach available in LSDYNA-3D. Experimental investigations in a Charpy test rig were conducted in order to identify key parameters influencing the impact damage resistance of composite structures. Using the experimental results, a numerical study of the impacted specimens was performed in LSDYNA-3D. Solid elements in conjunction with a damage-based composite material model were used to perform the calculations. A good correlation between experimentally and numerically obtained forces and failure modes had been achieved. Furthermore, the practical numerical modeling of composite materials under low-velocity impact, together with recommendations and achievements towards the effort to model their complex behavior under high dynamic impact was discussed.

Juraj (2008) deals with the fracture analysis of thermally exposed 9Cr–1Mo ferritic steel after tensile and impact testing at room temperature. The temperatures of the thermal expositions were 580, 620, and 650 ^{o}C, respectively. The duration of annealing experiments varied from 500 to 5000 h. The influence of thermal expositions on Vickers hardness as well as tensile properties was found to be negligible. On the other hand, remarkable effects of the annealing on room temperature impact toughness were observed. Fracture behavior of the 9Cr–1Mo steel was strongly affected by the presence of precipitates of secondary phases. Fracture surfaces of tensile samples indicated mainly transgranular dimple fracture mechanism. By contrast, the fracture mode of the samples after impact testing was more complex. It showed both – ductile dimple tearing as well as inter-lath decohesion.

Goglio and Rossetto (2008) reported the results of an experimental study on bonded joints, carried out by means of an instrumented impact pendulum, equipped to load overlap specimens in shear. Such testing configuration was the most adequate and natural to study the possible modifications of the behavior of the joint, changing from static to dynamic loading condition, keeping the same specimen type. The specimens were steel strips bonded by an epoxy adhesive (Hysol 3425). Several values of lap length, adhesive and adherends thickness were adopted, to achieve rupture under different peel and shear stress combinations. The stress state at rupture had been calculated by means of a structural solution. The results showed that the failure points, in a chart having as axes the maximum values of peel and shear structural stress, lie outside the rectangular limit zone previously obtained under static conditions. Therefore, in spite of the concerns associated with the impact condition, the strength of the tested adhesive did not decrease with respect to the case of static loading. In alternative, also the evaluation of the stress intensity factor proveed to be effective to predict failure in the considered cases.

Mustafa (2008) investigated the impact-fatigue properties of unidirectional carbon fibre reinforced polyetherimide (PEI) composites. Low velocity repeated impacts were performed by using pendulum type instrumented impact tester (Ceast, Resil 25) at energy levels ranging 0.54–0.94 J. Samples were prepared according to ISO 180 and subjected to repeat low velocity impacts up to fracture by the hammer. Results of repeated impact study were reported in terms of peak load (Fmax), absorbed energy (Emax) and number of repeated impacts. An analytical model to describe the life time of composite materials subjected to repeated impact loadings was presented.

Ajit (2008) investigated the impact resistance of silicon (Si)-containing modified 9Cr-1Mo steels within a temperature regime of -40 to 440 ^{o}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 ^{o}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.

CHAPTER 4

EXPERIMENTAL DESIGN

4.1 METHODOLOGY

The experimental analysis was conducted using the design of experiments techniques. Although full factorial designs could be used wherein all the possible combinations could be tested, we had used fractional factorial analysis methods for this experimental work. The Taguchi method was used to overcome the limitations of full factorial analysis by simplifying and standardizing the fractional factorial design (Roy, 1990). In the present work, the effects of various factors of the impact value parameters were varied and their interactions were studied using a parameterization approach developed by Taguchi. Experimental design based on Taguchi methodology is a powerful and effective approach to achieving this goal. The methodology involves identification of controllable and uncontrollable parameters and the establishment of a series of experiments to find out the optimum combination of the parameters which has the greatest influence on the performance and the least variation from the target of the design.

4.2 INTRODUCTION OF TAGUCHI METHOD

The orthogonal array forms the basis for the experimental analysis in the Taguchi method (Roy, 2001). First the experiment parameter factors and their corresponding levels are selected. Next, the experimental results are manipulated by the ANOVA method to determine the effect of each parameter versus the objective function. The experiment procedures are described as follows:

- Establishment of objective function
- Based on the required quality objective the parameter factors and/or interactions are selected.
- Based on the variable factor layout of the orthogonal array, the practical experiment can then proceed.
- Execution of experiments according to trail conditions in the orthogonal array

- Experimental results are obtained and then the ANOVA for signal-to-noise ratio (S/N ratio) and the contribution are computed.
- Next the optimal parameter factor level combination is selected.
- Finally, the optimal parameter level combination is used to proceed with the confirmation experiment.

4.3 DESIGN OF EXPERIMENTS AND SELECTION OF ORTHOGONAL ARRAY SYSTEM

Degrees of Freedom: Degree Of Freedom in statistics is a very important value because it determines the minimum number of treatment conditions.

Degree of freedom for each factor is

$$v_A = k_A - 1$$

Where k_A is the number of levels of factor A

Degree of freedom for interaction is

$$v_{A\times B} = (v_A)(v_B)$$

In this experiment, there are three parameters at three levels each. Values of variables at different level for izod impact testing as shown in the Table No. 4.1 and Values of variables at different level for Charpy Impact Testing as shown in the Table No. 4.2

Table 4.1: Values of variables at different level for Izod Impact Testing

Factors	**Levels**		
	Level-1	**Level-2**	**Level-3**
Specimen material(mm),A	EN-8	EN-24	EN-31
Weight(kg),B	14.15	15.15	16.15
Height(inch.),C	46.5	43.4	40.7

Table 4.2: Values of variables at different level for Charpy Impact Testing

Factors	Levels		
	Level-1	Level-2	Level-3
Specimen material(mm),A	EN-8	EN-24	EN-31
Weight(kg),B	14.9	15.9	16.9
Height(inch.),C	61.5	70.5	78.5

The degree of freedom (DOF) of a three level parameter is 2 (number of levels-1), hence total DOF for the experiment is 6. There are three interactions (between work materials (A), weight of hammer (B) and height of hammer (C) which are to be studied in the experiment. The minimum required degree of freedom in the experiment is the sum of all factor and interaction degrees of freedom. The interactions were:

1. A x B – Material Vs. Weight
2. A x C – Material Vs. Height
3. B x C – Weight Vs. Height

Table 4.3: Degree of Freedom

Factor	A	B	C	A x B	A x C	B x C	Total
Degree of Freedom	2	2	2	$2\times2=4$	$2\times2=4$	$2\times2=4$	18

The selection of which Orthogonal Array to use depends upon:

- The number of factors and interactions of interest.
- The number of levels for the factors of interest.

Total DOF of the interactions is 12. Total DOF for this experiment is 18 as shown in Table No.4.3. As the degree of freedom required for the experiment is 18 so the orthogonal array that is to be selected should have degree of freedom higher than 18. The most suitable orthogonal array that can be used for this experiment is L27.

In this experiment, the assignment of factors was carried out using MINITAB 15 Software. The Standard L27 Orthogonal Array as suggested by MINITAB using Taguchi Linear Graphs for the particular experiment are listed in Table No. 4.4

Table 4.4: Standard L27 Orthogonal Array (Taguchi Design)

Experiment No.	**Specimen material (mm), A**	**Weight (kg), B**	**Height (inch.), C**
1	1	1	1
2	1	1	2
3	1	1	3
4	1	2	1
5	1	2	2
6	1	2	3
7	1	3	1
8	1	3	2
9	1	3	3
10	2	1	1
11	2	1	2
12	2	1	3
13	2	2	1
14	2	2	2
15	2	2	3
16	2	3	1
17	2	3	2

18	2	3	3
19	3	1	1
20	3	1	2
21	3	1	3
22	3	2	1
23	3	2	2
24	3	2	3
25	3	3	1
26	3	3	2
27	3	3	3

4.4 EXPERIMENTAL SET UP

The effect of three different parameter (work material, weight of hammer and height of hammer) and impact energy absorbed (impact value) was studied using L27 taguchi orthogonal design in the solid mechanics lab(SM LAB) of Thapar University workshop . In proposed work, EN-8, EN-24 and EN-31 steel alloys were selected for specimen material. These alloy steel were cheaply available and widely used. Generally, EN-8 alloys were used for moderately stressed parts of motor vehicles and general engineering works like crank shafts, automobile axle beams, connecting rods, etc. EN-24 preferred to be applied for heat treated components having large sections and subjected to exacting requirements like air craft and heavy vehicle crank shafts, connecting rods, gear shafts, chain parts, clutches and camshafts. EN31 had high resisting nature against wear and can be used for components which were subjected to severe abrasion, wear or high surface loading like ball and roller bearing, punches and dies. Taguchi method using design of experiments approach was used to optimize a process. The various input parameters were taken under experimental investigation and then model were prepared then again experimentation work would be performed. The experiment selected the taguchi orthogonal array L27. Therefore, 27 trails were conducted on Izod and Charpy impact testing machine. The results obtain were analyzed and the models were produced by using MINITAB 15 software. The output is impact value had been selected as response parameters for this research work. The effect of the variation in input process parameter was studied on response parameters and the experimental data was analyzed as per Taguchi method to find out the optimum condition and significance of each factor. The composition of selected alloys as shown in Table No.4.5:

Table 4.5: Materials composition

Material	Carbon %	Silicon %	Nickel %	Chromium %	Molybdenum %
EN8	0.40	0.25	1.25	1.65	-
EN 24	0.40	0.30	1.50	1.20	0.25
EN31	1.00	0.20	-	1.40	-

4.5 Signal-to-Noise ratio(S/N ratio)

Noise factors are those that are either too hard or uneconomical to control even though they may cause unwanted variation in performance. It is observed that on target performance usually satisfies the user best, and the target lies under acceptable range of product quality are often inadequate. If Y is the performance characteristic measured on a continuous scale when ideal or target performance is T then according to Taguchi the loss caused L(Y) can be modeled by a quadratic function as shown in equation (1)

$$\mathrm{L(Y) = K(Y - T^2)} \ldots\ldots\ldots (1)$$

The objective of robust design is specific; robust design seeks optimum settings of parameters to achieve a particular target performance value under the most noise condition. Suppose that in a set of statistical experiment one finds a average quality characteristic to be μ and standard deviation to be σ. Let desired performance be μ1 .Then one make adjustment in design to get performance on target by adjusting value of control factor by multiplying it by the factor (μ_0/μ) . Since on target is goal the loss after adjustment is due to variability remaining from the new standard deviation. Loss after adjustment shown in equation (2):

$$\mathbf{k(\mu_0|\mu)^2\ \sigma^2} \ldots\ldots\ldots (2)$$

The factor $\frac{\mu^2}{\sigma^2}$ reflects the *ratio of average performance* μ^2(which is the signal) and σ^2(*the variance* of performance) the noise. Maximizing $\frac{\mu^2}{\sigma^2}$ or S/N ratio therefore become equivalent to minimizing the loss after adjustment. Finding a correct objective function to maximize in an engineering design problem is very important. Depending upon the type of response, the following three types of S/N ratios are employed in practice:

Higher the Better

If the nominal value for a characteristic Y is best then designer should maximize the S/N ratio i.e:

$(S/N)_{HB} = -10 \log (MSD_{HB})$

Where

$$MSD_{HB} = \frac{1}{R}\sum_{j=1}^{R}\frac{1}{{Y_j}^2}$$

Lower the Better:

If the nominal value for a characteristic Y is best then designer should maximize the S/N ratio i.e.:

$(S/N)_{LB} = -10 \log (MSD_{LB})$

Where

$$MSD_{HB} = \frac{1}{R}\sum_{J=1}^{R} Y_J^2$$

- In proposed work, *larger is better* is considered. Value of Impact energy absorbed by the specimen was measured by difference between initial(without specimen) and final(with specimen) reading in Izod impact test in J or N-m and direct reading from scale in Charpy impact test in kg-m.

4.6 ANALYSIS OF VARIANCE

The knowledge of the contribution of individual factors is critically important for the control of the final response. The analysis of variance (ANOVA) is a common statistical technique to determine the percent contribution of each factor for results of the experiment. The initial techniques of the analysis of variance were developed by the statistician and geneticist R. A. Fisher in the 1920s and 1930s, and are sometimes known as Fisher's ANOVA or Fisher's analysis of variance, due to the use of Fisher's *F-distribution* as part of the test of statistical significance. It calculates parameters known as sum of squares (SSs), pure SS, degree of freedom (D.O.f), variance, F-ratio and percentage contribution of each factor. The analysis required for this purpose was done by the Software MINITAB15. Since the procedure of ANOVA is very complicated and employs a considerable of statistical formulae, only a brief description is given as following:

The Sum of Squares (SS) is a measure of the deviation of the experimental data from the mean value of the data. The total deviation equals SS of all results minus correction factor (CF), are expressed as:

Before the test data is collected some notation in order to simplify the mathematical discussion is:

Let ‘A’ be a factor under investigation

$$SS_T = \sum_{i=1}^{N} (y_i - \overline{T})^2$$

Where

N = Number of response observations, $\overline{T}$ is the mean of all observations y_i is the i, *th* response

Factor Sum of Squares (SS_A) - Squared deviations of factor (A) averages from overall average

$$SS_A = \left[\sum_{i=1}^{k_A} \left(\frac{A_i^2}{n_{Ai}} \right) \right] - \frac{T^2}{N}$$

Where

A_i =Average of all obseravtions under A_i level = A_i / n_{Ai}

T = sum of all observations

$\overline{T}$ = Average of all observations = T / N

n_{Ai} = Number of obsernations under A_i level

k_A= Number of levels of factor A

Error Sum of Squares (SS_e) - Squared deviations of observations from factor (A) averages

$$SS_e = \sum_{j=1}^{k_A} \sum_{i=1}^{n_{Ai}} \left(y_i - \overline{A}_j\right)^2$$

4.7 EXPERIMENTATION DETAIL

The values of the input process parameters for the Izod impact test are as under:

Material	:	EN 8, EN 24, EN 31
Weight	:	14.15, 15.15. 16.15
Height	:	46.5, 43.4, 40.7

Table 4.6: Control Log for Izod Impact Test – L27 Orthogonal Array

Experiment No.	**Specimen material (mm)**	**Weight (kg)**	**Height (inch.)**
1	EN 8	14.15	46.5
2	EN 8	14.15	43.4
3	EN 8	14.15	40.7
4	EN 8	15.15	46.5
5	EN 8	15.15	43.4
6	EN 8	15.15	40.7
7	EN 8	16.15	46.5
8	EN 8	16.15	43.4
9	EN 8	16.15	40.7
10	EN 24	14.15	46.5
11	EN 24	14.15	43.4
12	EN 24	14.15	40.7
13	EN 24	15.15	46.5
14	EN 24	15.15	43.4
15	EN 24	15.15	40.7
16	EN 24	16.15	46.5
17	EN 24	16.15	43.4
18	EN 24	16.15	40.7
19	EN 31	14.15	46.5
20	EN 31	14.15	43.4
21	EN 31	14.15	40.7
22	EN 31	15.15	46.5
23	EN 31	15.15	43.4
24	EN 31	15.15	40.7
25	EN 31	16.15	46.5
26	EN 31	16.15	43.4
27	EN 31	16.15	40.7

The values of the input process parameters for the Izod impact test are as under:

Material : EN 8, EN 24, EN 31

Weight : 14.9, 15.9, 16.9

Height : 61.5, 70.5, 78.5

Table 4.6: Control Log for Charpy Impact Test – L27 Orthogonal Array

Experiment No.	Specimen material (mm)	Weight (kg)	Height (inch.)
1	EN 8	14.9	61.5
2	EN 8	14.9	70.5
3	EN 8	14.9	78.5
4	EN 8	15.9	61.5
5	EN 8	15.9	70.5
6	EN 8	15.9	78.5
7	EN 8	16.9	61.5
8	EN 8	16.9	70.5
9	EN 8	16.9	78.5
10	EN 24	14.9	61.5
11	EN 24	14.9	70.5
12	EN 24	14.9	78.5
13	EN 24	15.9	61.5
14	EN 24	15.9	70.5
15	EN 24	15.9	78.5
16	EN 24	16.9	61.5
17	EN 24	16.9	70.5
18	EN 24	16.9	78.5
19	EN 31	14.9	61.5
20	EN 31	14.9	70.5
21	EN 31	14.9	78.5
22	EN 31	15.9	61.5
23	EN 31	15.9	70.5
24	EN 31	15.9	78.5
25	EN 31	16.9	61.5
26	EN 31	16.9	70.5
27	EN 31	16.9	78.5

CHAPTER 5

EXPERIMENTAL ANALYSIS

The factors (Material, weight and height) were varied at three levels for both Izod impact test. The measured response was impact energy absorbed by the material. Analysis of the results was carried out analytically as well as graphically. All the statistical calculations and plots were generated by MINITAB 15 software. ANOVA plots of the experimental data have been created to calculate the significance of each factor for each response. Energy absorbed by specimen was calculates results for all the 27 trial runs. $\alpha = 0.05$ was selected for all statistical Calculations.

5.1 ANOVA OF IZOD IMPACT TEST

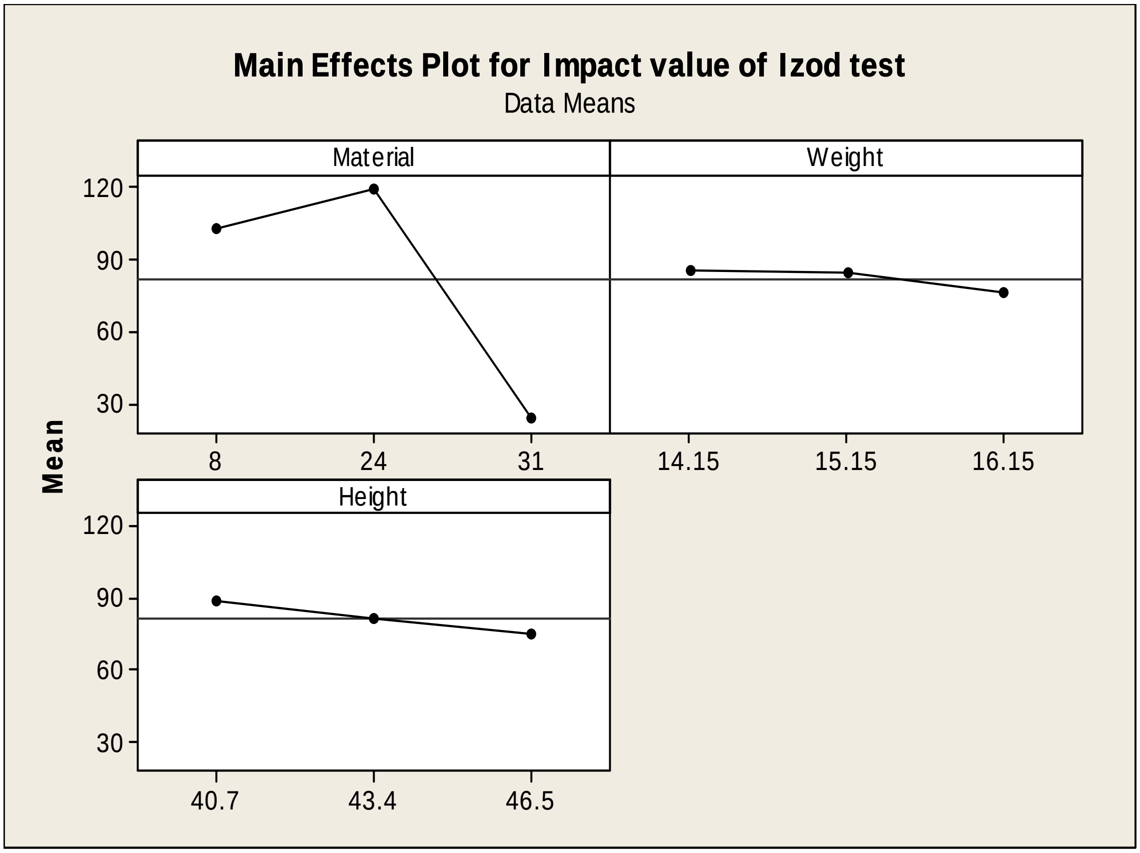
Table No.5.1 shows the results of 27 experimental trail runs for Izod impact test. Table No.5.2 shows ANOVA Table of Izod Impact Test. Figure No. 5.1 shows Main effect and Interaction plots for Izod Impact Test. F value for all the factors and their interaction was obtained. ANOVA Table No. 5.2 of Izod impact test shows Material (F= 2756.26) was the signify
cant. Weight (25.56) and height (49.94) were the factors found insignificant. None of the interaction was found to be significant. Main effect plot for impact value shows maximum impact value for EN-24 and minimum impact value for EN-31.Maximum impact value was observed at lower height levels.

Table 5.1: Results of Experimental Trail Runs for Izod Impact Test

Experiment No.	Specimen material (mm)	Weight (kg)	Height (inch.)	Impact value of Izod test (joules or N-m)
1	EN 8	14.15	46.5	98
2	EN 8	14.15	43.4	108
3	EN 8	14.15	40.7	115
4	EN 8	15.15	46.5	101
5	EN 8	15.15	43.4	102.5
6	EN 8	15.15	40.7	110
7	EN 8	16.15	46.5	84.5
8	EN 8	16.15	43.4	95
9	EN 8	16.15	40.7	106
10	EN 24	14.15	46.5	114
11	EN 24	14.15	43.4	123.5
12	EN 24	14.15	40.7	130
13	EN 24	15.15	46.5	120
14	EN 24	15.15	43.4	122
15	EN 24	15.15	40.7	130
16	EN 24	16.15	46.5	97
17	EN 24	16.15	43.4	110
18	EN 24	16.15	40.7	125
19	EN 31	14.15	46.5	22
20	EN 31	14.15	43.4	25
21	EN 31	14.15	40.7	26.5
22	EN 31	15.15	46.5	20
23	EN 31	15.15	43.4	24
24	EN 31	15.15	40.7	30
25	EN 31	16.15	46.5	19
26	EN 31	16.15	43.4	22
27	EN 31	16.15	40.7	26

Table 5.2: ANOVA Table of Izod Impact Test

Parameters	DOF	Sum of Square	Mean Square	F
Material	2	46486.4	23243.2	2756.26
Weight	2	431.0	215.5	25.56
Height	2	842.4	421.2	49.94
Material*Weight	4	132.6	33.1	3.93
Material*Height	4	98.9	24.7	2.93
Weight*Height	4	78.9	19.7	2.34
Error	8	67.5	8.4	
Total	26	48137.6		



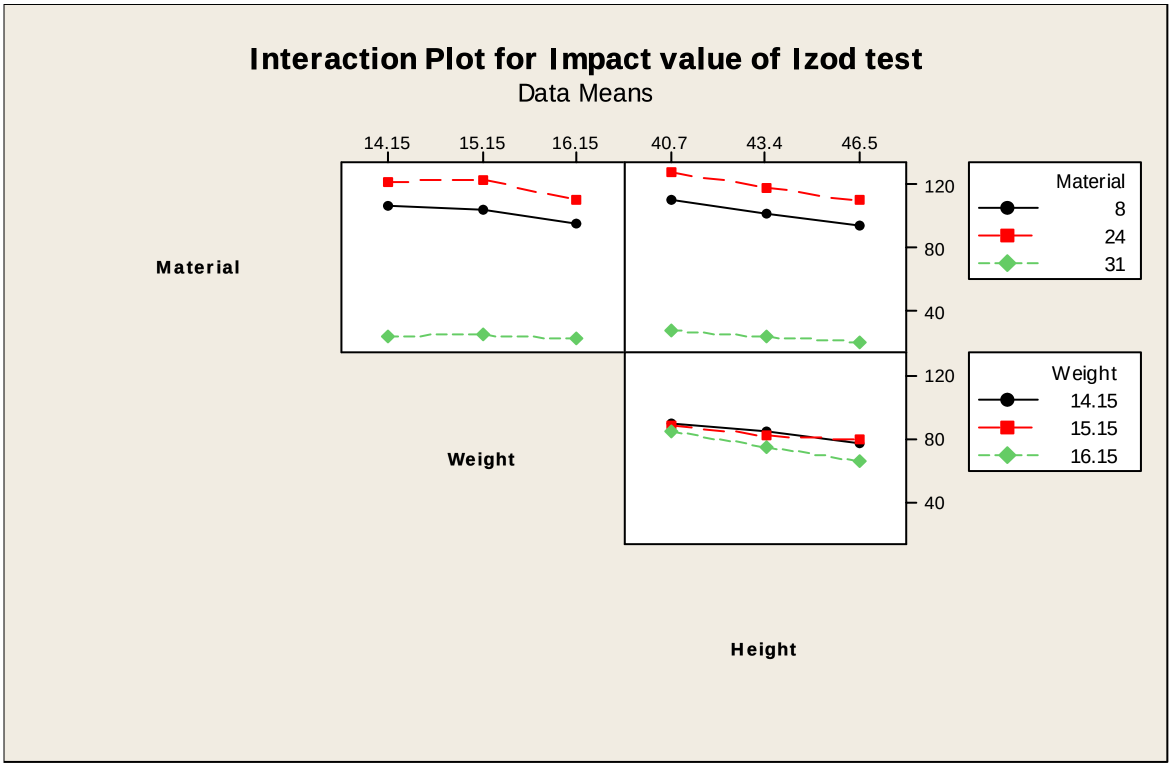


Figure 5.1: Main Effects and Interaction Plots for Izod Impact Test

5.2 SIGNAL TO NOISE RATIO OF IZOD IMPACT TEST

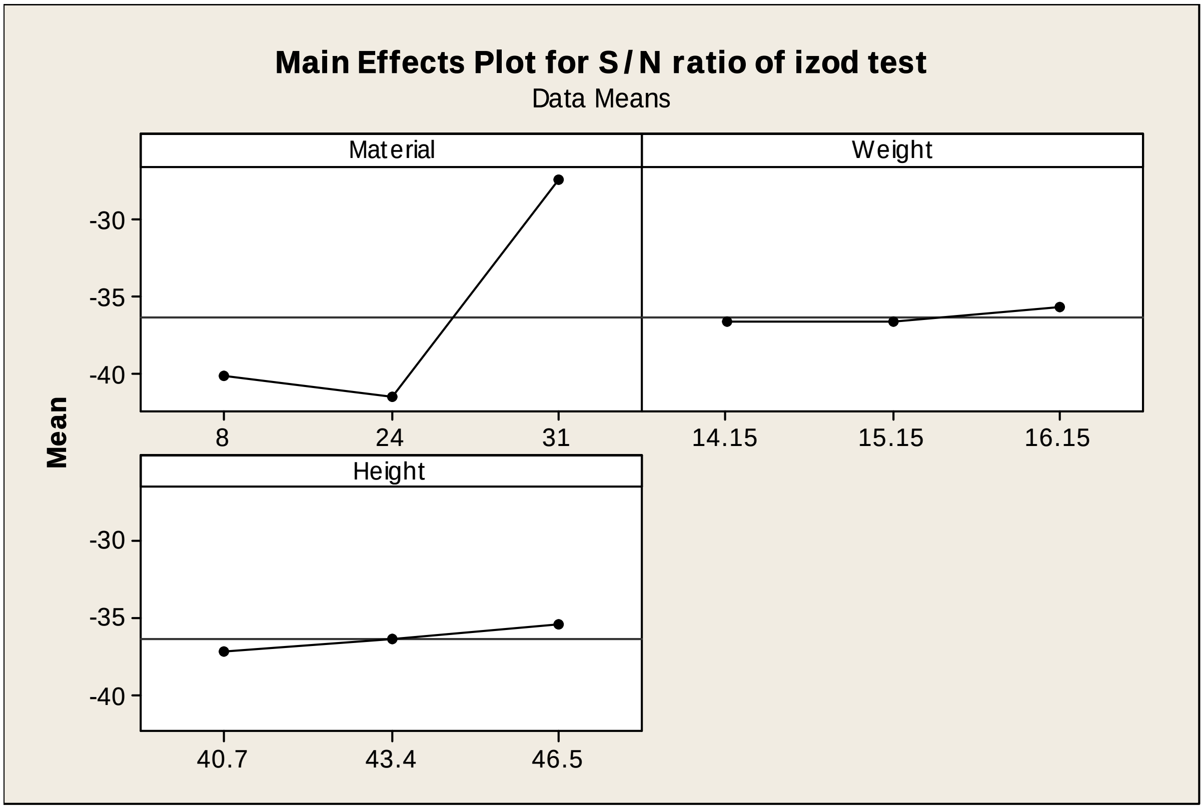
The Taguchi method uses the signal-to-noise ratio (S/N) to express the scatter around a target value. A high value of S/N implies that the signal is much higher than the random effects of the noise factors. The noise is usually due to the uncontrollable factors, which exist in the environment, often cannot be eliminated and cause variations in the output. Hence, in the context of this study, the noise is attributed to different subjects used for experimental analysis. Table No.5.3 shows the results of Signal-to-Noise ratio for Izod Impact Test. Table No. 5.4 shows ANOVA Table for Signal-to-Noise ratios. F value for all the factors and their interaction was obtained. ANOVA Table for Signal-to-Noise ratio shows Material (F= 3465.80) was the significant. Weight (F= 16.20) and height (F= 45.65) were the factors found insignificant. None of the interaction was found to be significant.

Table 5.3: Signal-to-Noise Ratio of Izod Impact Test

Experiment No.	Specimen material (mm)	Weight (kg)	Height (inch.)	Impact value of Izod test(joules or N-m)	S/N ratio of Izod test
1	EN 8	14.15	46.5	98	-39.82
2	EN 8	14.15	43.4	108	-40.66
3	EN 8	14.15	40.7	115	-41.21
4	EN 8	15.15	46.5	101	-40.08
5	EN 8	15.15	43.4	102.5	-40.21
6	EN 8	15.15	40.7	110	-40.82
7	EN 8	16.15	46.5	84.5	-38.53
8	EN 8	16.15	43.4	95	-39.55
9	EN 8	16.15	40.7	106	-40.50
10	EN 24	14.15	46.5	114	-41.13
11	EN 24	14.15	43.4	123.5	-41.83
12	EN 24	14.15	40.7	130	-42.27
13	EN 24	15.15	46.5	120	-41.58
14	EN 24	15.15	43.4	122	-41.72
15	EN 24	15.15	40.7	130	-42.27
16	EN 24	16.15	46.5	97	-39.73
17	EN 24	16.15	43.4	110	-40.82
18	EN 24	16.15	40.7	125	-41.93
19	EN 31	14.15	46.5	22	-26.84
20	EN 31	14.15	43.4	25	-27.95
21	EN 31	14.15	40.7	26.5	-28.46
22	EN 31	15.15	46.5	20	-26.02
23	EN 31	15.15	43.4	24	-27.60
24	EN 31	15.15	40.7	30	-29.54
25	EN 31	16.15	46.5	19	-25.57
26	EN 31	16.15	43.4	22	-26.84
27	EN 31	16.15	40.7	26	-28.29

Table 5.4: ANOVA Table for Signal to Noise Ratios of Izod Impact Test (Larger is better)

Parameters	DOF	Sum of Square	Mean Square	F
Material	2	1078.449	539.224	3465.80
Weight	2	5.042	2.521	16.20
Height	2	14.205	7.103	45.65
Material*Weight	4	0.091	0.023	45.65
Material*Height	4	1.602	0.401	2.57
Weight*Height	4	0.822	0.205	1.32
Error	8	1.245	0.156	
Total	26	1101.456		



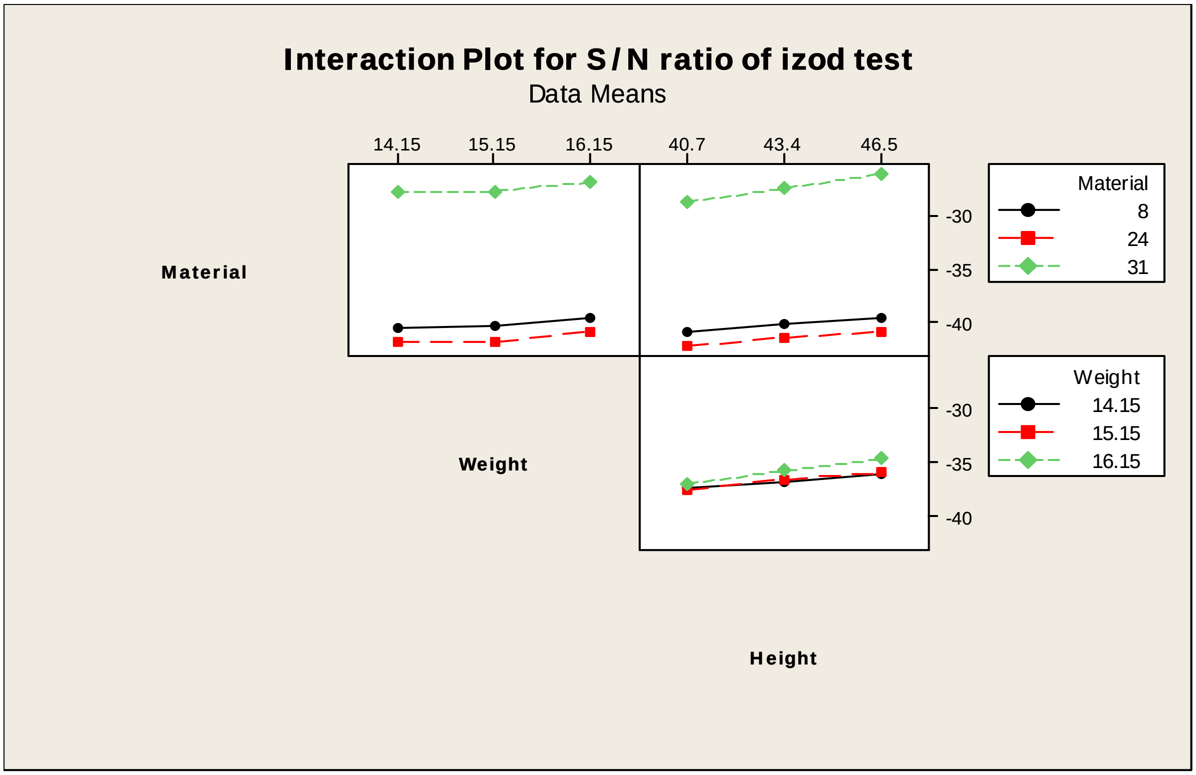


Figure 5.2: Main effect and Interaction plot of Izod Test for Signal to Noise ratio

5.3 ANOVA OF CHARPY IMPACT TEST

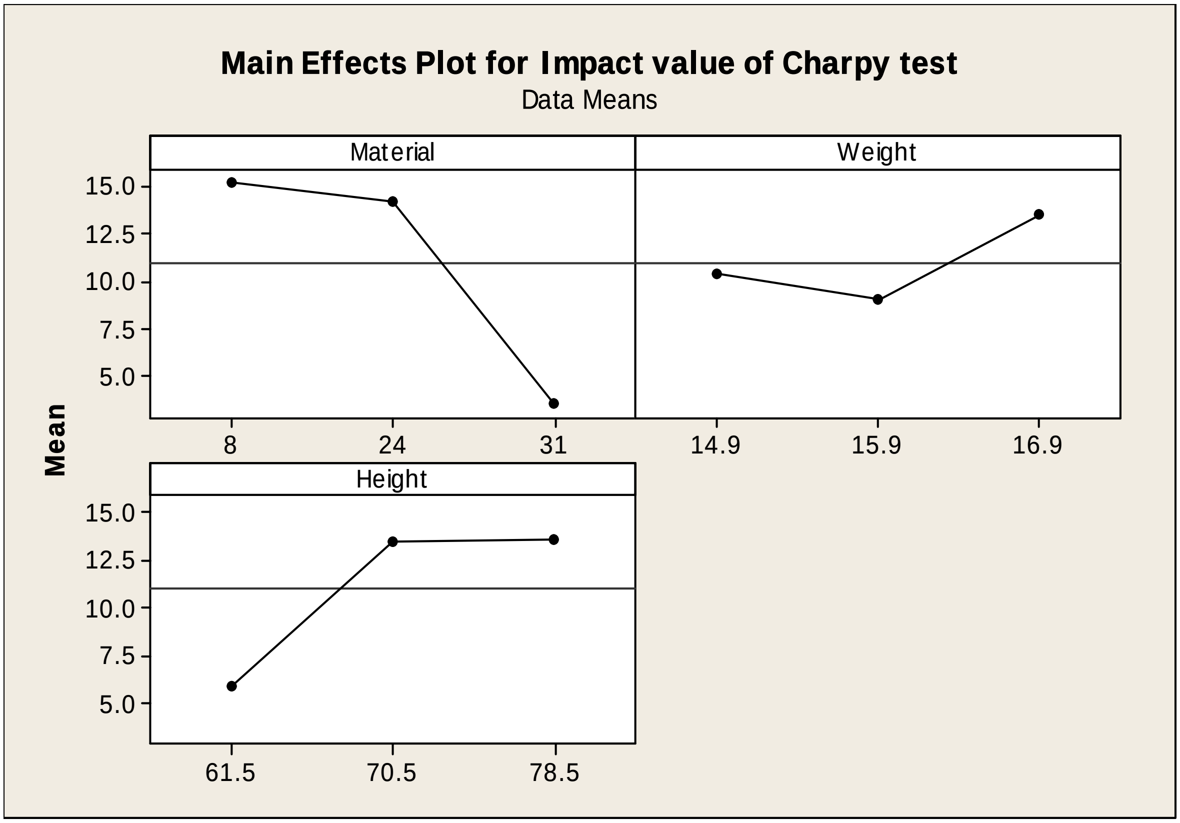
Table No.5.5 shows the results of 27 experimental trail runs for Charpy Impact Test. Table No.5.6 shows ANOVA Table of Charpy Impact Test. Figure No. 5.3 shows Main effect and Interaction plots for Charpy Impact Test. F value for all the factors and their interaction was obtained. ANOVA Table No. 5.6 shows Material (F= 22.12) and Height (F= 10.49) are significant. Weight (F= 2.80) was found to be insignificant. None of the interaction was found to be significant. Main effect plot for Charpy impact test shows maximum impact value for EN-8 and minimum impact value for EN-31.Also lower impact values were observed at height 61.5(level 1) and rapid increase in impact value was observed at higher levels.

Table 5.5: Results of Experimental Trail Runs for Charpy Impact Test

Experiment No.	Specimen material (mm)	Weight (kg)	Height (inch.)	Impact value of Charpy test (kg-m)
1.	EN 8	14.9	61.5	3.5
2.	EN 8	14.9	70.5	15.5
3.	EN 8	14.9	78.5	19.5
4.	EN 8	15.9	61.5	1.75
5.	EN 8	15.9	70.5	22.5
6.	EN 8	15.9	78.5	16.5
7.	EN 8	16.9	61.5	16
8.	EN 8	16.9	70.5	20
9.	EN 8	16.9	78.5	21.5
10.	EN 24	14.9	61.5	12.5
11.	EN 24	14.9	70.5	20.5
12.	EN 24	14.9	78.5	15
13.	EN 24	15.9	61.5	4
14.	EN 24	15.9	70.5	12
15.	EN 24	15.9	78.5	15.2
16.	EN 24	16.9	61.5	5.5
17.	EN 24	16.9	70.5	20.7
18.	EN 24	16.9	78.5	22.3
19.	EN 31	14.9	61.5	2
20.	EN 31	14.9	70.5	1.75
21.	EN 31	14.9	78.5	3.2
22.	EN 31	15.9	61.5	2.5
23.	EN 31	15.9	70.5	3.3
24.	EN 31	15.9	78.5	3.5
25	EN 31	16.9	61.5	4.8
26	EN 31	16.9	70.5	5.3
27	EN 31	16.9	78.5	5.5

Table 5.6: ANOVA Table of Charpy Impact Test

Parameters	DOF	Sum of Square	Mean Square	F
Material	2	750.86	375.43	22.12
Weight	2	95.16	47.58	2.80
Height	2	356.02	178.01	10.49
Material*Weight	4	54.66	13.67	0.81
Material*Height	4	153.09	38.27	2.26
Weight*Height	4	12.02	3.01	0.18
Error	8	135.77	16.97	
Total	26	1557.59		



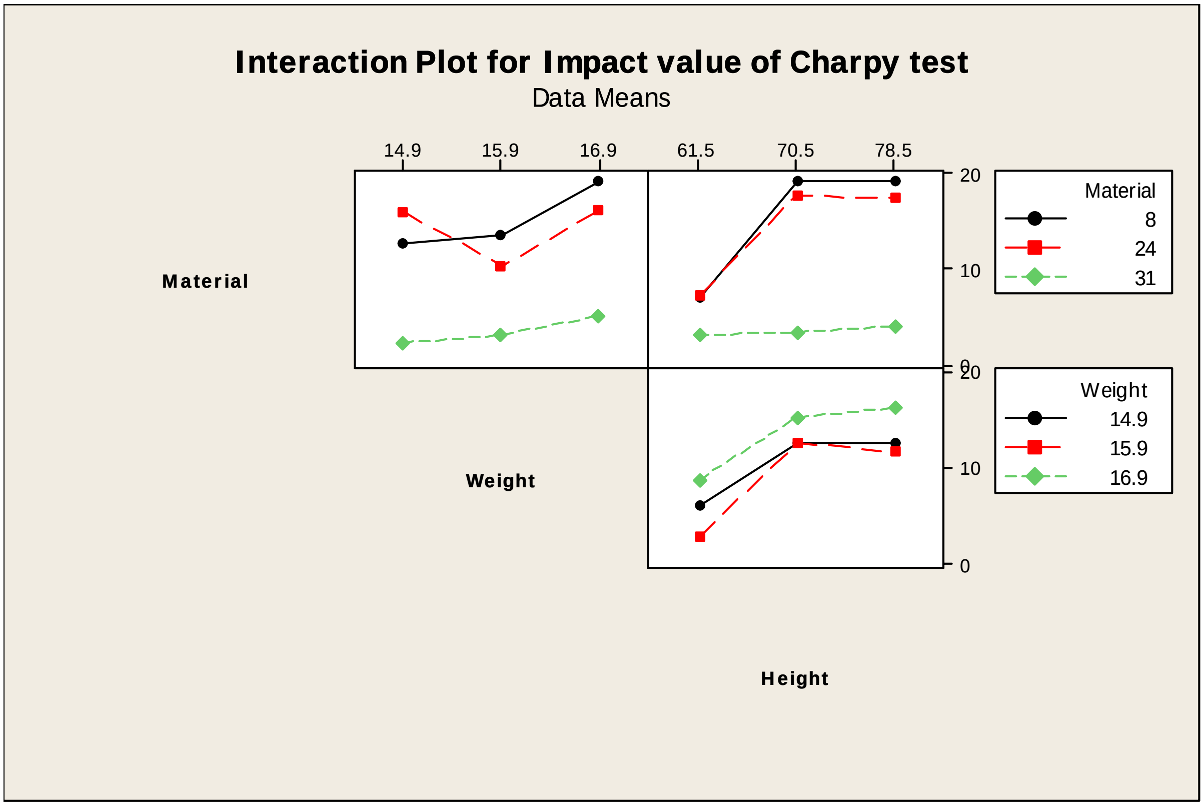


Figure 5.3: Main Effects and Interaction Plots for Charpy Impact Test

5.4 SIGNAL-TO-NOISE RATIO OF CHARPY TEST

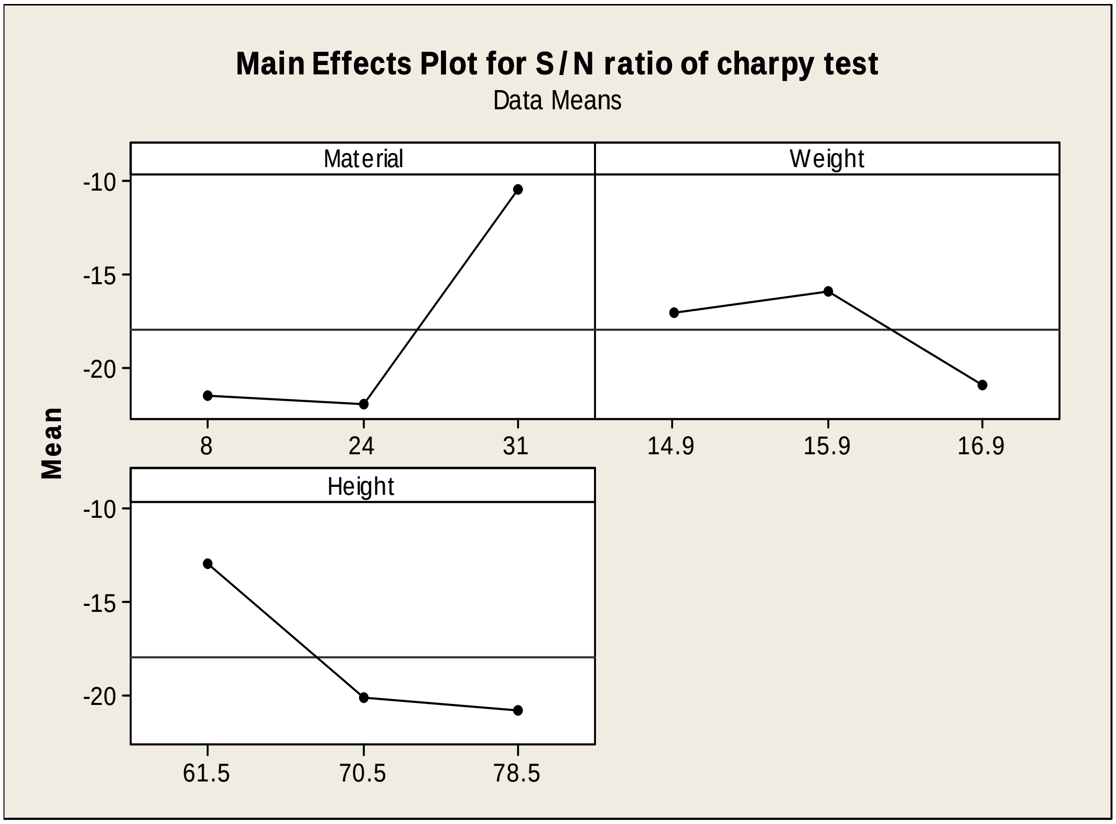
Table No.5.7 shows the results of Signal-to-Noise ratio for Charpy Impact Test. Table No. 5.8 shows ANOVA Table for Signal-to-Noise ratios. Main Effect Plots and Interaction plot for signal-to-noise ratio are shown in figure 5.4. F value for all the factors and their interaction was obtained. ANOVA Table for Signal-to-Noise ratio shows Material (F= 25.47) and Height (F= 11.20) are significant. Weight (F= 4.00) was found insignificant. None of the interaction was found to be significant

Table 5.7: Signal-to-Noise Ratio of Charpy Impact Test

Experiment No.	Specimen material (mm)	Weight (kg)	Height (inch.)	Impact value of Charpy test (kg-m)	S/N ratio of Charpy test
1.	EN 8	14.9	61.5	3.5	-10.88
2.	EN 8	14.9	70.5	15.5	-23.80
3.	EN 8	14.9	78.5	19.5	-25.80
4.	EN 8	15.9	61.5	1.75	-4.86
5.	EN 8	15.9	70.5	22.5	-27.04
6.	EN 8	15.9	78.5	16.5	-24.34
7.	EN 8	16.9	61.5	16	-24.08
8.	EN 8	16.9	70.5	20	-26.02
9.	EN 8	16.9	78.5	21.5	-26.64
10.	EN 24	14.9	61.5	12.5	-21.93
11.	EN 24	14.9	70.5	20.5	-26.23
12.	EN 24	14.9	78.5	15	-23.52
13.	EN 24	15.9	61.5	4	-12.04
14.	EN 24	15.9	70.5	12	-21.58
15.	EN 24	15.9	78.5	15.2	-23.63
16.	EN 24	16.9	61.5	5.5	-14.80
17.	EN 24	16.9	70.5	20.7	-26.31
18.	EN 24	16.9	78.5	22.3	-26.96
19.	EN 31	14.9	61.5	2	-6.02
20.	EN 31	14.9	70.5	1.75	-4.86
21.	EN 31	14.9	78.5	3.2	-10.10
22.	EN 31	15.9	61.5	2.5	-7.95
23.	EN 31	15.9	70.5	3.3	-10.37
24.	EN 31	15.9	78.5	3.5	-10.88
25	EN 31	16.9	61.5	4.8	-13.62
26	EN 31	16.9	70.5	5.3	-14.48
27	EN 31	16.9	78.5	5.5	-14.80

Table 5.8: ANOVA Table for Signal to Noise Ratio of Charpy Test (Larger is better)

Parameters	**DOF**	**Sum of Square**	**Mean Square**	**F**
Material	2	776.27	388.13	25.47
Weight	2	122.03	61.01	4.00
Height	2	341.36	170.68	11.20
Material*Weight	4	73.56	18.39	1.21
Material*Height	4	119.54	29.88	1.96
Weight*Height	4	48.26	12.07	0.79
Error	8	121.91	15.24	
Total	26	1602.92		



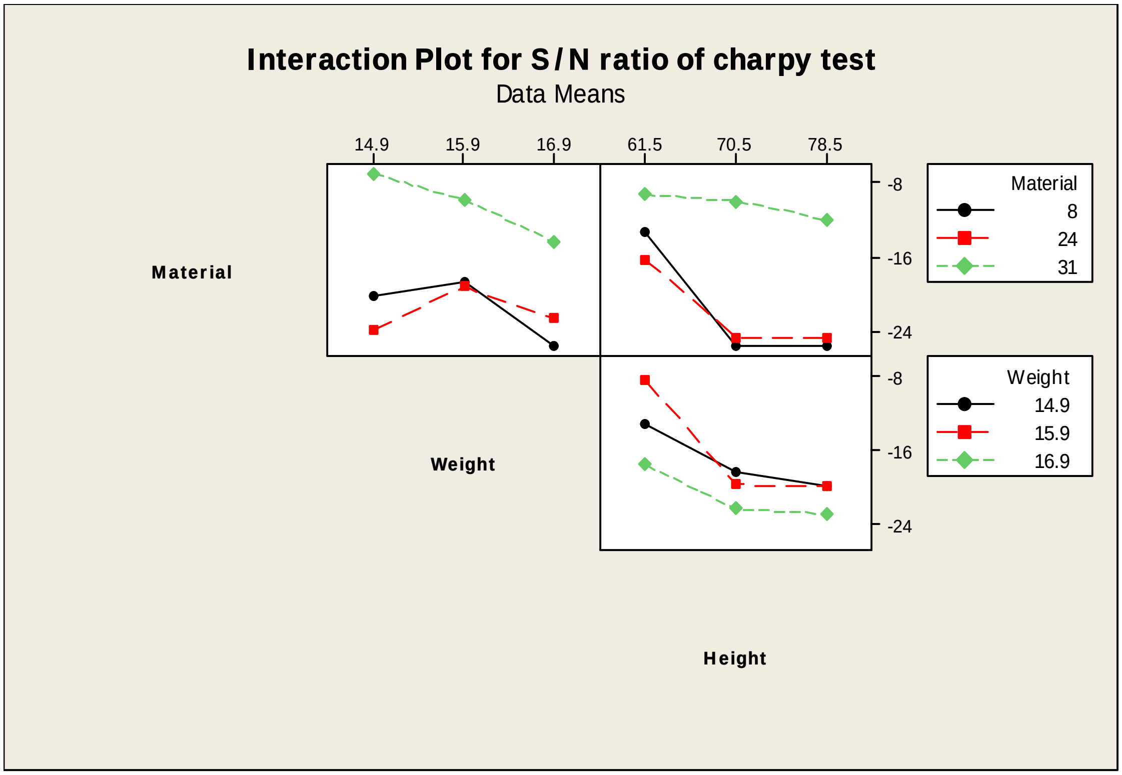


Figure 5.4: Main effect and Interaction plot of Charpy test For Signal to noise ratio

5.5 CONFIRMATION TEST

After evaluating the optimal parameter settings, the next step of the Taguchi approach is to predict and verify the enhancement of quality characteristics using the optimal parametric combination. The estimated S/N ratio using the optimal level of the design parameters can be calculated:

$$\eta_{opt} = \eta_m + \sum_{i=1}^{o}(\overline{\eta_i} - \eta_m)$$

Where η_m is the total mean S/N ratio , $\overline{\eta_i}$ is the mean S/N ratio at optimum level and '**o**' is the number of main design parameter that effect quality characteristic. Based on the above equation the estimated multi response signal to noise ratio can be obtained. Below shows the confirmation experiment for Izod and Charpy Impact test.

Table 5.9: Response table for Signal to Noise ratio of Izod impact test

LEVEL	A	B	C
1	-40.15	-36.68	**-35.47**
2	-41.47	-36.64	-36.35
3	**-27.45**	**-35.75**	-37.25

From figure 5.2, optimal parameters for Izod impact test were A_3, B_3 and $C_{1.}$

Table 5.10: Response table for Signal to noise ratio of Charpy impact test

LEVEL	A	B	C
1	-21.49	-17.01	**-12.90**
2	-21.88	**-15.85**	-20.07
3	**-10.34**	-20.85	-20.74

From figure 5.4, optimal parameters for Charpy impact test were A_3, B_2 and $C_{1.}$

η_{opt} (Izod impact test) = -36.36 + (-27.45+36.36) + (-35.75+36.36) + (-35.47+36.36)

= -25.95

Similarly, optimal value of Charpy impact test can be obtained by:

η_{opt} (Charpy impact test)

= -17.70 + (-10.34+17.90) + (-15.85+17.90) + (-12.90+17.90)

= -3.29

The optimal value of Izod impact test was **-25.95** and Charpy impact test was **-3.29.**

CHAPTER 6

RESULT AND CONCLUSION

6.1 SUMMARY

The objective of this research work was to study the effect of varying three input variables (work material, weight of hammer and height of hammer) and their interactions were evaluated using ANOVA and factorial design on impact energy absorbed by specimens. For the purpose of experimentation was carried out on Izod and Charpy impact testing machine in the solid mechanics lab of the Thapar University. To obtain the desired results with minimum possible number of experiments, Taguchi method has been employed. Using Taguchi, L27 orthogonal array has been selected and the experiments have been designed. After performing the experiments, results of the experimentation have been analyzed and graphs for effect of various input variables upon output parameters and for Signal to noise ratio have been studied and discussed using ANOVA (Analysis of variance) was done using the MINITAB15 software. Also the optimum combination of input variables has been determined which will give the best results for output parameters using signal to noise ratios.

6.2 RESULT AND CONCLUSION

Material (F= 2756.26) was found to be significant in ANOVA for Izod Impact Test. Weight (F= 25.56) and Height (F= 49.94) were factors found insignificant for Izod impact test. Material (F= 2756.26) was found to the most significant factor and weight (F= 25.56) was found least significant factor of Izod impact test. None of the interaction was found to be significant. Main effect plot for Izod impact value shows maximum impact value for EN-24 and minimum impact value for EN-31.Maximum impact value was observed at lower height levels. Since lower the S/N ratio, better is the response for reducing the variation in impact value. Material (A), Weight (B) and Height (C) i.e. A_3, B_3 and C_1 .The results from the significant factor and their interaction indicate that material is the most significant factor of Izod impact value. Change in weight and height has no significant effect on the impact value of Izod impact test.

Material (F= 22.12) and Height (F=10.49) are significant in ANOVA for Charpy Impact Test. Weight (F= 2.80) factor is found insignificant for Charpy impact test. Material (F= 22.12) and Height (F=10.49) were found to the most significant factor and weight (F= 2.80) was found least significant factor of Charpy impact test. None of the interaction was found to be significant. Main effect plot for Charpy impact test shows maximum impact value for EN-8 and minimum impact value for EN-31.Also lower impact values were observed at height 61.5 (level 1) and rapid increase in impact value was observed at higher levels. Since lower the S/N ratio, better is the response for reducing the variation in impact value. Material (A), Weight (B) and Height (C) i.e. A_3, B_2 and C_1. The results from the significant factor and their interaction indicate that material and height are the most significant factor of Charpy impact value. Change in weight has no significant effect on the impact value of Charpy impact test

6.3 SCOPE OF FUTURE WORK

- In this research work, the material used is EN8, EN24 and EN31 (Alloy steel).The experimentation can also be done for other materials (plastics, polymers, ceramics and composites) to see the effect of parameters on impact value.
- The notch angle of standard Charpy impact test specimen can be varied 45^0, 60^0, 75^0 and 90^0 to conduct the test and the other effects can be studied.
- Izod and Charpy impact test can be conducted at different temperature of specimen and effects can be studied.
- The composition of varies alloying elements can be varied and effects of alloying elements can be studied and microstructure can checked.
- The dimensions of the specimen can be varied and can be studied like thickness of the specimen.

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