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Measurement Of Energy Loss In Fixture During The Process Of Impact Test

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ABSTRACT : *Many machine or structural members are subjected to impact loading. If the material with which the component is made does not possess the necessary toughness, the component may fail catastrophically due to high impact energy. The failure may be sudden leading to loss of life and property. The impact test helps in determining the energy absorbing capacity of the specimen. In conventional impact test, the energy of the impact is determined by subtracting residual energy from the initial energy of the impact hammer. However during the process of impact loading the bar to which the impact hammer is fixed and fixture on which the specimen is supported absorb energy which are not taken into consideration while measuring the impact energy of the specimen. During this research an attempt is made to measure the energy absorbed by the fixture. The fixture design is modified to enable the mounting of strain gauges for measuring dynamic strain. The strain gauges are mounted at critical locations on fixture. A custom made electronic device is developed which consists of micro controller having capability of acquiring data at 20000 samples per second which helps in acquiring the data at the instant of impact. From this data the strain induced at the instant of impact as well as the energy absorbed by the fixture during the process of impact loading are determined. It is observed that the energy absorbed by the specimen fixture is 0.266 N-m which is 0.24% of energy of impact of the specimen. Therefore the energy absorbed by the specimen fixture can be neglected without introducing much error.*
Keywords - *Impact testing machine, Fixture, Data acquisition system, Strain gauge.*

I. INTRODUCTION

Impact testing of materials by Charpy v-notch test has been studied and applied for many years and has remained as one of the methods considered in examining the fracture toughness issue due to its low cost and reliability. It is a high strain rate test which helps in determining the amount of energy absorbed by a material during the process of impact loading. The absorbed energy obtained using dial/encoder system is considered as a measurement of the material's toughness and acts as a tool for the ductile-brittle transition studies. The use of instrumented Charpy impact apparatus with the load-time recording system aims to determine the fracture energy, and the maximum load applied on to the specimens. Dear and Macgillivray [1] carried out impact test on materials using instrumented impact testing machine to provide information about the fracture of test specimen during impact process. The force sensor is mounted near the point of contact of impact striker and the test provided information about forces acting on the specimen. Tronskar, Manahan et al. [2] studied optimum instrumented striker design. From the variety of numerical and experimental studies they showed that the indicated load from the instrumented impact striker are affected by inertial forces. Inertial forces in the impact striker can be decreased by moving the load cell closer to the contact surface. Kalthoff [3] used instrumented Charpy impact testing to investigate the strength and failure properties of glass-fiber/vinyl-ester composites. Anton et al. [4] studied experimentally by mounting accelerometer and strain gauges on the impact striker, and position sensor attached to the rotary axis of the impact testing machine for analysing the dynamic responses of Charpy impact test. The results obtained from the experiment are validated with numerical analysis. In the conventional method of impact test, energy of impact for a specimen is obtained from dial indicator or encoder system. This energy is the difference between energy of impacting hammer before and after impact. The energy of impact thus obtained is not the absolute value of impact energy consumed by the specimen as it contains part of the energy absorbed by the fixture on which the specimen is supported as well as the impacting hammer assembly. During this research an attempt is made to experimentally measure the amount of energy absorbed by the fixture supporting the impact test specimen.

II. METHODOLOGY

For determining strain energy absorbed by the fixture on which the impact testing specimen is placed, its design is modified to enable strain gauges to be mounted at highly stressed region. A CAD model of fixture is prepared using CREO software and analysis carried out using ANSYS V14 finite element analysis software. The strain data during impact test is collected using a custom made microcontroller based data acquisition system capable of acquiring 20000 samples per second. The output voltage of strain gauges is expressed in terms of strain. Using this measured strain, material property and volume of the fixture, strain energy absorbed by the fixture is calculated. Figure 1 shows the flow chart of the whole process of strain energy measurement.

Figure 1. Flow chart representing the process of strain measurement

A. THEORY

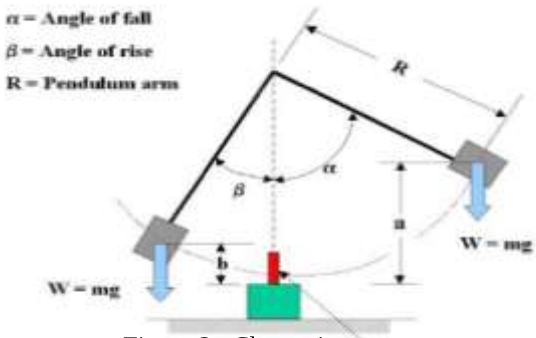


Figure 2. Charpy impact test set up

B. Charpy impact test measurements

In conventional impact testing machine, the pendulum mass (m) is latched to the desired height (a). The potential energy of pendulum during rest position is given by

$$\mathbf{E_p = m \times g \times a} \quad (1)$$

After releasing the pendulum, the potential energy decreases and kinetic energy of the pendulum increases. The kinetic energy of the pendulum at the instant of impact is given by

$$\mathbf{E_k = ½\, m \times v^2} \quad (2)$$

$$\mathbf{E_k = E_p}$$

i.e, $\mathbf{m \times g \times a = ½\, m \times v^2}$

$$\mathbf{v^2 = 2ga}$$

Therefore, impact velocity of the pendulum is given by

$$\mathbf{V = \square\ (2ga)} \quad (3)$$

From Fig. 2, $\mathbf{a = R\,(1-\cos\square\,)}$

$$\mathbf{b = R\,(1-\cos\square\,)}$$

Energy of pendulum before impact is calculated as

$$\mathbf{E_i = m \times g \times R\,(1 - \cos\square\,) = W \times R\,(1 - \cos\square\,)}$$

Energy of the pendulum after specimen fracture is obtained by

$$\mathbf{E_r = m \times g \times R\,(1 - \cos\square\,) = W \times R\,(1 - \cos\square\,)}$$

Impact energy absorbed during the process of impact

$$\mathbf{E_{abs} = W \times R\,(\cos\square - \cos\square\,)}$$

The above energy absorbed (E_{abs}) during the process of impact consists of

i. Energy for fracture of the specimen (E_{sp})
ii. Energy absorbed by the fixture supporting the specimen
iii.Energy absorbed by the hammer assembly (E_{ham})

Therefore, $E_{abs} = E_{sp} + E_{fixt} + E_{ham}$

The energy absorbed by the fixture is calculated as

$$E_{fixt} = 1/2[\sigma^2/E]$$

Where σ is the maximum stress in the fixture at the instant of impact, E is the elastic modulus of fixture material and V is the volume of the fixture. The maximum stress induced in the fixture at the instant of impact is determined from the measured strain.

III. DESIGN AND FABRICATION OF FIXTURE

To accurately measure energy absorbed by the fixture during impact process, the strain induced at the instant of impact is to be measured. Existing fixture is modified to enable mounting of strain gages at the critical location. Figure 3 shows the geometry of the fixture after modification. Table 1 shows the comparison of dimensions of fixture before and after modification. After fabrication of the fixture, four strain gages, two on front side and two on rear side, are mounted at the most stressed region. Figure 4 shows the location of two strain gages. These strain gages are connected in a Wheatstone bridge which in turn is connected to custom made data acquisition system for acquiring and further processing the data.

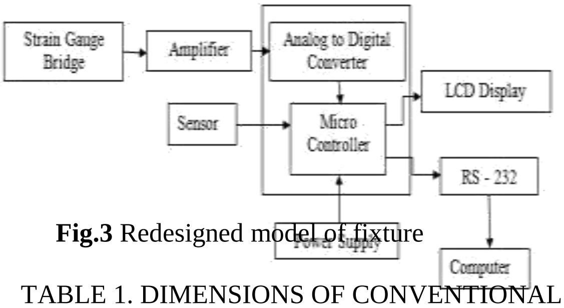
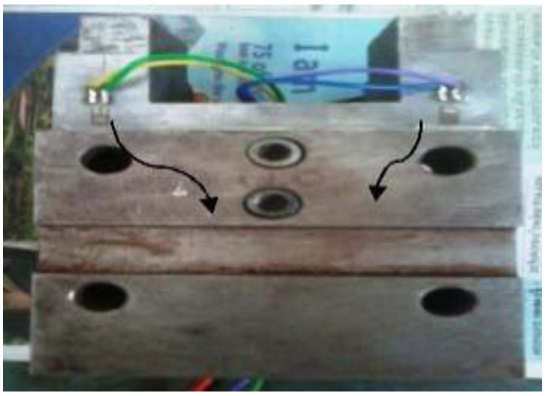


Fig.3 Redesigned model of fixture

TABLE 1. DIMENSIONS OF CONVENTIONAL AND REDESIGNED FIXTURE

Parameters	Conventional fixture	Redesigned fixture
Width(w) (mm)	85	85
Height(h) (mm)	123	123
Thickness (t) (mm)	47	47
Specimen placing width (mm)	19	10
Depth of cut (mm)	-----	10



Strain gauges mounted on front side

Fig. 4 Strain gauges mounted on redesigned model of fixture

IV. INSTRUMENTED IMPACT TEST SET UP

The experimental set-up for measuring dynamic strain at the instant of impact and thus for measuring the energy absorbed by the fixture during the process of impact loading is shown in Figure 5.

Fig. 5. Instrumented impact testing setup

It consists of modified specimen fixture with strain gages mounted on it, a photo sensor to sense the position of the impact hammer for triggering the data acquisition system to acquire data, a high speed data acquisition system for amplification digitization of acquired data and also a computer for plotting and displaying the data. The block diagram shown in Figure 6 illustrates the different components of custom made data acquisition system. The impact hammer having a mass of 25.5 kg is allowed to fall from a height of 1.44 m. The potential energy of the impacting hammer is 300 Joules and velocity of moving hammer at the instant of impact is 5.33 m/s. When the moving hammer hits the specimen, the specimen breaks and the hammer continues to move till its residual kinetic energy becomes zero. Part of energy consumed at the instant of impact is absorbed by the fixture.

Fig. 6. Block diagram of data acquisition system

Figure.7 shows different components of data acquisition system. It consists of an signal amplifier, microcontroller with built-in analog to digital converter, LCD display and power supply.

Fig. 7. Data acquisition system board

A. Amplifier **:** Amplifier is a device used to increase the amplitude of the signals received from strain gauge bride.

B. Analog to Digital Converter (ADC)**:** It converts analog signals coming from the amplifier into digital signals. The ADC used in this data acquisition system is high speed ADC with 10 bit resolution. The conversion speed is 100 Kilo samples per second. These digital signals are amenable for further processing.

C. Microcontroller**:** Microcontroller is the heart of processing unit. PIC4520 Microcontroller is used in this research as it has built in ADC, memory and IOs. The microcontroller reads the ADC data and stores in the memory. Once the acquisition is over the collected data was sent to computer for further processing. It also displays all the required information and ADC reading on LCD display.

D. LCD display: In this data acquisition system the 2x16 LCD module display is used for displaying the digital readings of ADC.

E. Sensor: A photo sensor is used in the instrumented setup to detect acquisition point based on pendulum movement. This sensor is placed 50mm before the sample under test. When the hammer passes through the sensor an output signal is generated from this sensor. This signal triggers microcontroller to start acquiring data from ADC. The number of samples acquired from the instant of triggering are 650 which will cover hammer movement through the sample and thereby capturing the impact load.

F. RS-232: This is a serial interface to PC. Microcontroller transfers the collected samples to PC using this interface.

G. Power supply: The power required for data acquisition is sourced from here.

V. EXPERIMENTAL DETERMINATION OF IMPACT ENERGY OF FIXTURE

Experiments are conducted to determine impact energy absorbed by the fixture during the process of impact in the following two cases:

2) Mild steel test specimen
3) Bright steel test specimen

A. Test on mild steel specimen

The instrumented impact test was carried out on the standard charpy specimen with 2 mm depth notch at the center. The wheatstone bridge out voltage in digital form is recorded using hyper terminal software in computer. Graph of output voltage (as number of counts) v/s Number of samples was plotted. Figure 8 is the graph of amplifier output in number of counts in digital form vs. number of samples. From this graph maximum value of amplifier output is considered for calculating the amplifier output voltage. Using this amplifier output voltage, dynamic strain, stress and energy are calculated. The results obtained from the experiment are as follows.

Maximum amplifier output = 327 counts

Amplifier Gain = 366

As 5 volts of analog voltage is represented by 1024 counts in digital form, the effective output voltage of the amplifier for the above read out is

$(5/1024)\times 327 = 1.59$ Volts

As the amplifier gain is 366, the strain gage bridge output is

$$\Delta e_0 = 4.3442 \quad 10^{-3} \text{ Volts.}$$

Using the relationship between bridge output and induced strain:

$$\Delta e_0 = [(N \times f \times \varepsilon)/4]ei$$

Therefore,

$$\varepsilon = 217.2\ \mu s$$

Where, Δe_i is the input voltage, Δe_o is the output voltage, N is number of active gauges, f is gage factor and ε is the strain in terms of microstrains.

Also, Stress

$$\sigma = E \times \varepsilon = 210 \times 10^3 \times 217.2 \times 10^{-6}$$

$$\sigma = 45.612 MPa$$

Fig. 8. Amplifier output v/s number of samples Recorded for mild steel specimen.

Strain energy

Volume of the fixture= 53891 mm^3

Strain energy = 0.266 Joule

B. Test on bright steel specimen:

Similar test was carried out for bright steel specimen and energy absorbed by the fixture was determined. Figure.9 is the graph of amplifier output in digital form vs. number of samples for this case. Bright steel material is softer than mild steel and therefore the energy absorbed by the fixture is considerably less compared to that for mild steel specimen.

Maximum amplifier output = 263

Gain = 366

Amplifier output voltage

Δe_o = 3.5086 $*10^{-3}$ Volts

Strain ε =175.43μs

Also, Stress (σ)= E $\times\varepsilon$ = 36.84MPa

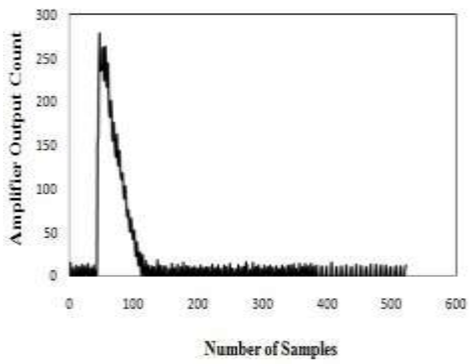


Fig. 9. Amplifier output v/s number of samples recorded for bright steel specimen.

Strain energy

Volume of the fixture= 53891 mm^3

Strain energy = 0.1741 Joule.

V. RESULTS AND DISCUSSION

Experiments have been conducted for determining energy absorbed by the fixture during charpy impact test. Four strain gages are mounted at the critical location based on result of finite element analysis. The strain gage data is processed to obtain maximum strain induced in the fixture at the instant of impact. This strain data is used to determine stresses and strain energy absorbed by the fixture. Experiments are carried out on specimens made of a) Mild steel specimen and b) Bright steel specimen. Table 2 gives the magnitudes of strains and stresses at critical location obtained from experiments and also from finite element analysis. The table also gives magnitudes of strain energies absorbed by the fixture for the above cases. It is observed that the strain energy absorbed by the fixture for the case of mild steel specimen is 0.266 Joule and is only a very small fraction (0.24 %) of the total energy absorbed during the impact process. Similar is the situation for the bright steel material.

TABLE 2: RESULTS OF EXPERIMENTS AND NUMERICAL ANALYSIS FOR FIXTURE

Particulars	**Experimental values**		**FE Analysis values**	
Material	**MS**	**BS**	**MS**	**BS**
Strain (μm)	217.2	175.43	240.5	191.6
Stress (MPa)	45.612	36.840	46.38	36.96
Energy absorbed (J)	0.266	0.276	0.174	0.175

MS- Mild Steel, BS – Bright Steel

VI. CONCLUSION

The Charpy impact tests were carried out using conventional impact testing machine. The dial indicator gives the energy absorbed during impact process. This energy is not just the energy absorbed by the specimen. This energy also includes energy absorbed by the fixture on which specimen is supported as well as the impacting hammer assembly. The energy absorbed by the fixture is determined by redesigning the fixture to enable strain gauges to be mounted at critical locations. Maximum strain induced in the fixture at the instant of impact is measured using a custom made microcontroller based data acquisition system capable of acquiring 20000 samples per second. Using maximum strain induced, energy absorbed by the fixture is calculated. It is observed that during Charpy impact testing of a mild steel specimen, energy of impact displayed by the dial indicator is 110 Joules and from the strain measured, energy absorbed by the fixture is 0.266 Joule which is about 0.24% of the total energy absorbed during impact. Therefore from this study it is concluded that the energy absorbed by the specimen during instrumented impact test will give more accurate results as compared to the conventional impact testing machine. It is also observed from this experiment to find out minor energy losses during the process of impact test.

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