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Designing and manufacturing of a drop weight impact test machine

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ABSTRACT

A state of the art instrumented Drop Weight Impact Tester Machine was developed in Iran University of Science and Technology which measures the energy absorption of composite materials under impact load. The output of the machine is used to draw load- time graph and calculate the amount of energy absorbed by the specimens. The machine was equipped with various sensor systems to measure the velocity of the impactor just before it contacts the specimen and the amount of contact force, and with a data acquisition system to record the force and time history. Capability of testing according to many different types of standards and capability of studying behaviour of the specimen after impact are two important characteristics of this machine. This designed system, after manufacturing and calibration, was installed and successfully utilized.

1. Introduction

Because of high specific strength and modulus, low specific density and corrosion resistance, fibre reinforced plastics are used in vast majority of fields such as aerospace, transportation and building structures. In order to optimize designing with these materials it is necessary to perform standard tests and find out their mechanical properties. Toughness is an important property of composite materials and shows energy absorption capacity of the specimen. This energy is measured by impact testing. Izode and Charpy are two popular methods of impact testing but with many restrictions such as: necessity of using notch in the specimen and limitation on the magnitude of applied load. There is another method which use falling weight to measure energy absorption capacity of materials, called Drop Weight Impact Testing (DWIT) with many advantages as mentioned below:

- Capability of testing based on different types of standards and shapes.

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- Results of tests are in form of load-time and absorbed energy- time format, so the history of failure can be studied more precisely.
- Recording 100 data in 0.001 s makes the result more accurate and precise.
- Capability of testing of specimens under any slope.
- Capability of investigating of behaviour of specimens after impact test.

Ghasemi-Nejhad and Parvizi-Majidi (1990) and Madjidi et al. (1996) utilized a DWIT machine which had ability to test specimen with any angle in mounting, also they studied compressive behaviour of the specimen after impact test.

Under impact loads, composite materials show different responses in comparison with metals. Metals under impact loads show a short elastic response that followed by a long plastic deformation. While, in composites, elastic response is followed by different modes of failure such as delamination, matrix cracking and fibre breakage. In fact in metals, the impact energy is absorbed by plastic deformation. However, composites absorb energy by different failure modes. Composites response under impact force was studied by many researchers based on the developed drop weight impact test machines. For instance DWIT machines have been developed by (Zoller (1983); Winkel and Adams (1985); So and Francis (1991); Ambur et al. (1995); Toropov and Grosso (1998); Barr and Baghli (1998) and Gunawan et al. (2011)). The research results show that the duration of Impact is about millisecond. This is an important factor for choosing the appropriate load cell and data acquisition instrument.
The main goal of this research is to design and manufacture of a DWIT machine which serves the abovementioned mentioned advantages over the traditional Izode and Charpy test methods.

2. Energy Absorption Calculations

The most important measurable factor by a DWIT machine is the energy absorption, although, the load-time graph has useful information. The traditional way of measuring energy absorption was calculating kinetic energy before and after impact. However, a DWIT measures the load versus time more accurately and precisely and illustrates energy absorption history. Different failure modes caused by impact can be studied from the load-time history graph obtained from the machine.
Change in kinetic energy is calculated by equations 1 and 2

$$\frac{1}{2}\cdot m\cdot {v_1}^2-\frac{1}{2}\cdot m\cdot {v_2}^2=\int F\cdot dy\,, \tag{1}$$

$$\int F\cdot dy = \text{Absorbed Energy}, \tag{2}$$

where m is the mass of impactor, F is the force, y is the displacement, v_1 and v_2 are the velocity of impactor before and after impact, respectively.
Eq. 1 is used for calibration and shows whole absorbed energy. While Eq. 2 shows absorbed energy at every moment. An installed load cell on DWIT is used to measure F(t). Displacement as a function of time y(t) is obtained by double integration of the acceleration. Eqs. 3, 4, and 5 show energy absorption calculations.

$$a(t)=\frac{F(t)}{m}, \tag{3}$$

$$y(t)=\int (v_1+\int a(t)dt)dt\,, \tag{4}$$

$$\begin{Bmatrix} y(t) \\ F(t) \end{Bmatrix} \Rightarrow F(y) \Rightarrow \int F\cdot dy\,. \tag{5}$$

A numerical method is used to calculate Eq. 4, and ν_1 is measured experimentally by a photocell. The absorbed energy at any moment is obtained by Eq. 5 if the displacement and force as functions of time are known.

3. Detail design of low velocity impact test machine

A general view of the design procedure of the machine is presented in this article. More information is available in the final report of DWIT provide by Shokrieh et al. (2002). DWIT consists of many components such as: chases, Impacting mechanism, elevation system, fixture systems, power and protection system, pneumatic system (Brake and release system) and a data acquisition system. Figure 1 shows the DWIT machine designed and manufactured in this research.

Fig. 1. DWIT machine

3.1. Plate of the machine

The calculations of the base plate of the machine are carried out by simulating it with a mass-spring system. After calculating spring constant of plate, its deflection is calculated and finally the stress is obtained. Eqs. 6 and 7 are the energy equations and simulate plate with spring–mass system to find spring constant.
By assuming m=20 kg, g=10 m/s^2, h=1.2 m:

$$e = \frac{1}{2} K y^2 = mgh \tag{6}$$

$$K = \frac{480}{y^2} \tag{7}$$

The plate rigidity is as follow:

$$D = \frac{Et^3}{12(1-\upsilon^2)} = 11738693.47 \quad Nm \tag{8}$$

where *e, E, k, y, h, D, t,* ν, are energy, elasticity modulus, spring constant, deflection, release height, plate rigidity, thickness and Poisson’s ratio, respectively.
From Hooke's law and considering the distributed force (q) per unit area we have:

$$F = ky \Rightarrow qab = ky \tag{9}$$

where a=100 mm and b=200 mm.

For a fixed rectangular plate, bending moment, deflection and stresses are as Eq. 10. For more information about driving of these equations interested readers are referred to Young (1954) and Timoshenko and Woinowsky-Kreiger (1959).

$$y = \alpha \frac{qb^4}{D}, \quad M_x = \beta q b^2, \quad M_y = \beta_1 q b^2 \tag{10}$$

where α, β and β_1 are constants and M is the moment.

For concentrated force acting on fixed plate we have:

$$\sigma_x = \frac{6M_y}{bt^2}, \quad \sigma_y = \frac{6M_x}{at^2}, M_x = \beta_1 F, \quad M_y = \beta_2 F, \tag{11}$$

$$y_{\max} = \frac{Fb^2}{2\pi^3 D}\left[\frac{a^2}{b^2}\sum_{m=1,3,\dots}\frac{1}{m^3}\left(\tanh\alpha_m - \frac{\alpha_m}{\cosh^2\alpha_m}\right) - \frac{\pi^2}{4}\sum_{m=1,3,..}^{\infty}\frac{1}{m}\times\frac{\tanh^2\alpha_m}{\sinh\alpha_m\cosh\alpha_m + \alpha_m}\right], \tag{12}$$

where F is concentrated force and $\alpha_m = \dfrac{m\pi b}{2a}$.

After simplification of Eq. 12, maximum deflection, $y_{\max}$, is simplified as follows:

$$y_{\max} = 0.436\, Fb^2 / 2\pi^3 D \tag{13}$$

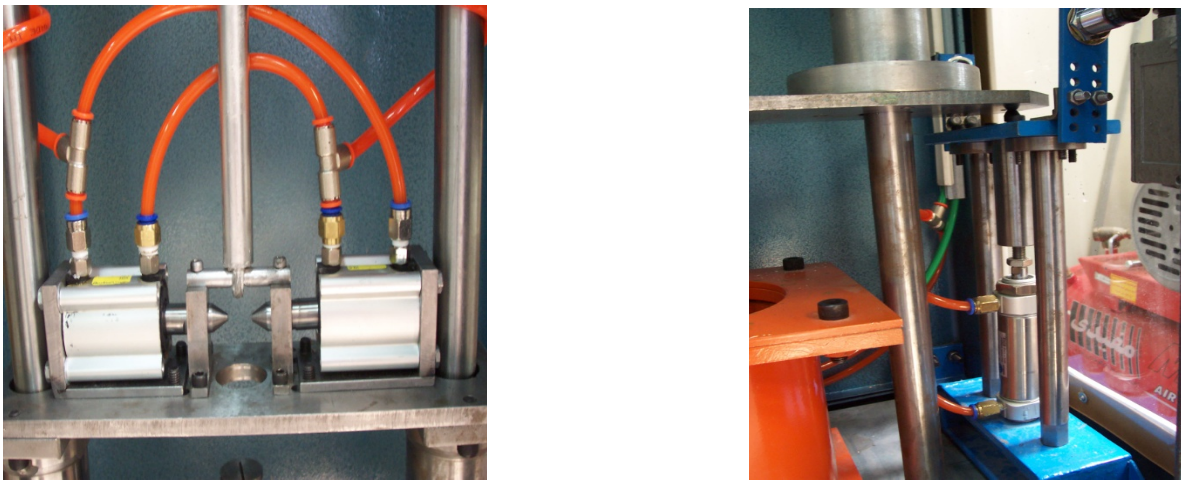
Table 1 shows the results of equation 10, 11, 13 and Ansys software

Table 1. Results of equation 10, 11, 13 and Ansys software

Method	Loading Conditions	y_{max} (mm)	σ (MPa)	M_x (Nm)	M_y (Nm)
Timoshenko and Woinowsky-Kreiger (1959)	Distributed	0.31	-	28577	127663
Timoshenko and Woinowsky-Kreiger (1959)	Concentrated	0.8	154	19544	11920
Numerical analysis performed by ANSYS	Concentrated	0.55	164	-	-

3.2. Jack choosing

Two pneumatic jacks have been selected for the release and shock damping systems. One jack is used for releasing impactor at any permissible height with outer diameter of 10 mm while the other pneumatic jack is used for protecting specimen from Second impact when the first impact was applied with the outer diameter of 40 mm. Operating pressure of jacks is 10 bar. Figures 2-a and 2-b show the selected pneumatic jack.



(a) **(b)**

Fig. 2. The selected pneumatic jack: a) release system b) damping system

4. Force measurement

During the impact the force transducer sends data to the signal conditioner. After filtering the data, an A/D card (PCL818H) converts the data to digital mode and sends them by Direct Memory Access method (DMA) to a computer. DMA is the fastest way for transmitting the data to a computer without any conflict in a simultaneously reading and writing process. More information about force signals processing could be found in Huibert and Raphael (1991).

5. Velocity and energy measurement

The absorbed energy and impactor contact speed are measured in this research by two different methods. In the first method a photocell is used for measuring initial velocity (v_1). When the bottom edge of Impactor plate passes through the photocell a signal is sent to the computer. As soon as receiving this signal, a counter begins to count elapsed time. While impactor passing through photocell, counter continues to count time until upper edge of impactor passes through the photocell. Initial velocity is computed by dividing the thickness of impactor (δ =7 mm) to the elapsed time. Also the load is measured by a load cell and finally the energy is obtained.
In the second method by using two equations $v = \sqrt{2gh}$ and $e = mgh$ the velocity and the energy are calculated. The results for m=20 kg and h=1.2 m are showed in Table (2) for the mentioned methods.

Table 2. Absorbed energy and impact velocity of DWIT machine

Parameter	First method	Second method	Error %
v (m/s)	4.88	4.03	17.41
e (J)	240	223	7.1

The differences between results of two methods are due to friction between the components of the machine. The flow chart of the automation system is shown in Fig. 3.

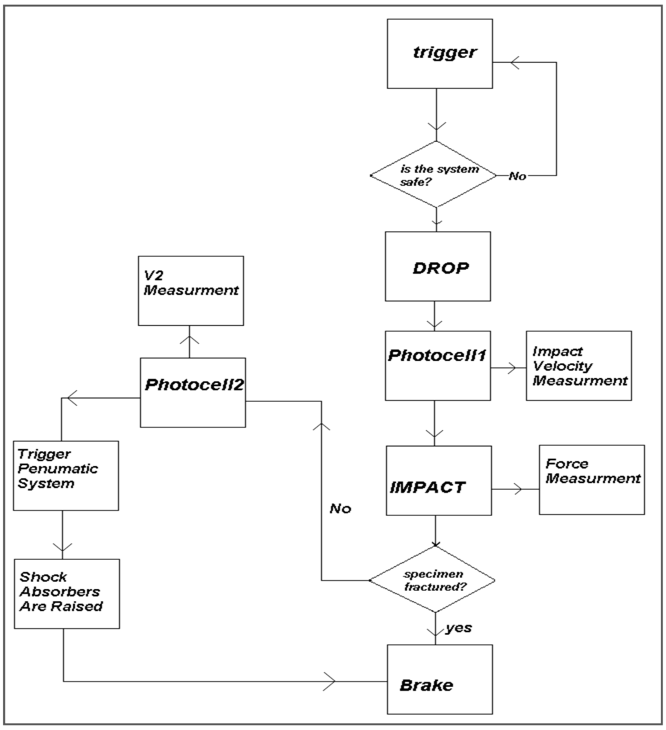


Fig. 3. The flow chart of automation system

6. Brake system

As shown in Fig. 4 there are two possibilities after impact:

- Failure of specimen occurs: shock absorber at this case shows no reaction and the impactor comes down and stops.
- If the impactor bounce backs and after sensing the return of the impactor by the second photocell, the program sends a signal to the shock absorbers. After receiving the signal, shock absorbers prevent the impactor to come down. It is noticeable that second photocell can compute return speed v_2, in same way discussed on measuring v_1, for the calibration of the machine.

7. Programming

All data such as load, falling and bouncing back velocities are logged with DMA method in PASCAL language and then are sent to MATLAB software for more processing. Users can work with created GUI and study the test results.

A sample output of DWIT in MATLAB language is shown in Fig. 4-a and Fig. 4-b.

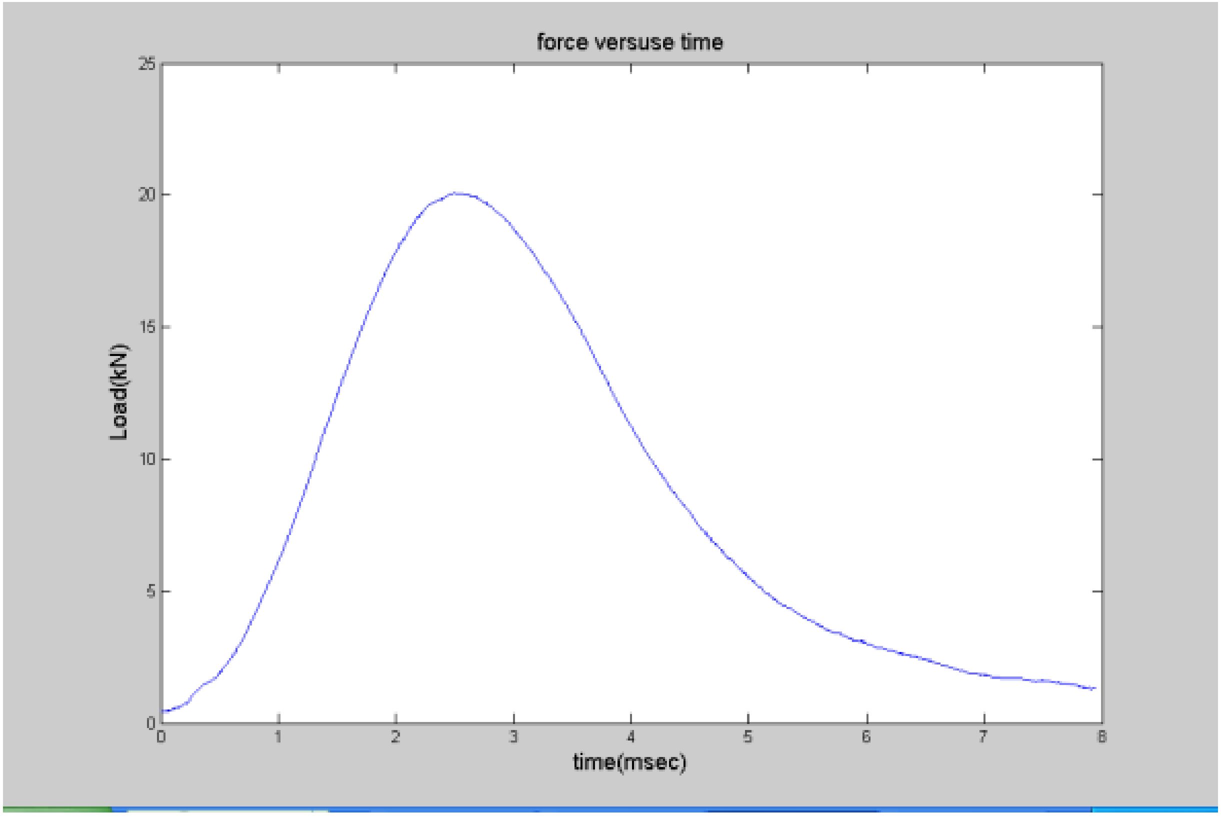


Fig. 4-a. Load-time graph

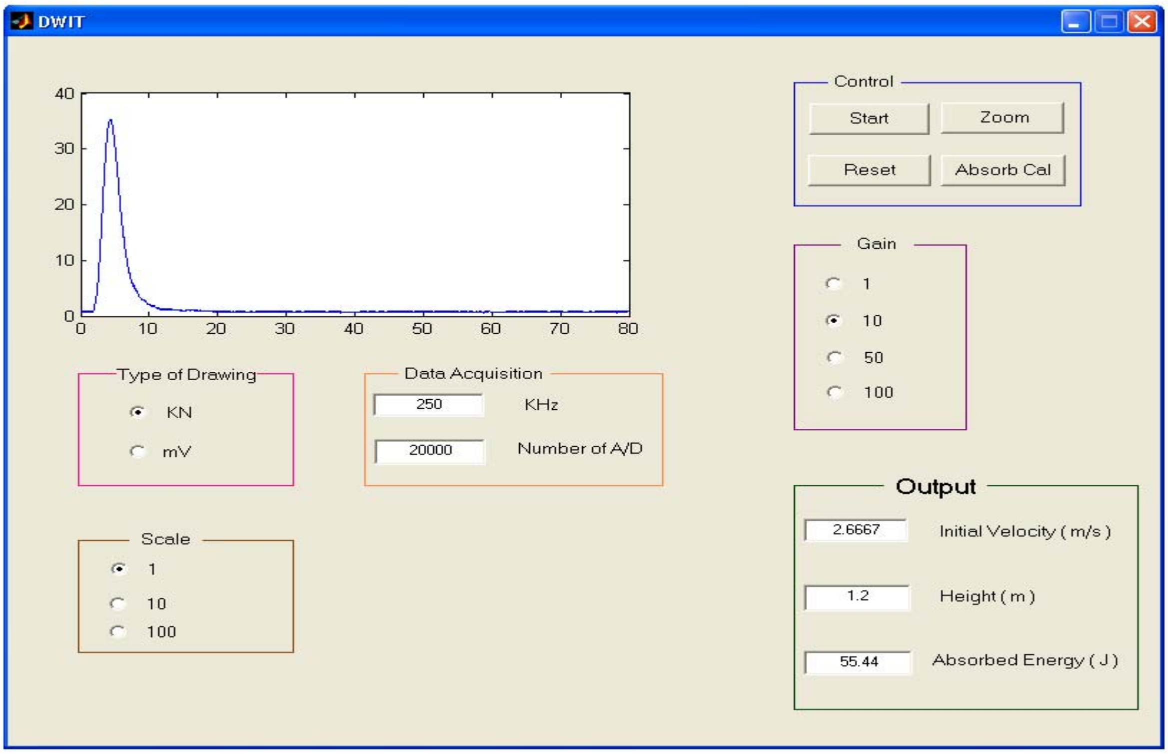


Fig. 4-b. Output of DWIT

8. Conclusions

A dropped weight impact tester machine was developed successfully which can apply impact load to a specimen with maximum speed of 4 m/s and variable mass up to maximum 20 kg. Piezoelectric force transducer used in DWIT machine provides a practical alternative method to traditional strain gauge instrumentation.

During the test, the impact speed and the time history of contact force can be measured and recorded for further analysis. The displacement of the impactor during impact would be measured by equipping the machine with displacement sensors in the future. This designed system, after manufacturing and calibration, was installed and successfully utilized.

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