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Experimental Investigation on Low Velocity Impact Resistance Characteristics of Polycarbonate Sheets

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Abstract

Polycarbonates are intrinsically soft, aesthetically transparent and extremely malleable and are widely used in structural applications. In this work, low velocity impact tests at different impact energies are done using custom-built Falling Weight Impact tester. From the Force – time plots obtained from the tests, different impact resistance characteristics of polycarbonate sheets like absorbed energy and peak absorbed load are evaluated. These parameters are analyzed as a function of impact energy using different numerical methods. Visible damage on polycarbonate sheet after each test is assessed and the maximum absorbed energy at which complete perforation occurs is determined. The impact resistance characteristics of polycarbonate sheets are also comparatively assessed with different composite laminates reported by various researchers. It is generally observed that in the case of polymeric materials, the absorbed energy is around 50 – 60% of the impact energy up to complete perforation irrespective of the type and grade of the material. However, it is found that the absorbed peak load as a function of impact energy is strongly dependent on the thickness, modulus and strength of the polymeric material.

Key words: ***Polycarbonate, Low Velocity Impact resistance characteristics, Absorbed energy, Peak load, Impact energy, Impact damage.***

1.0 Introduction

Polycarbonate sheets have many attractive characteristics like low density, high transparency, fairly high glass transition temperature, ability to undergo large plastic deformations before fracture and high impact resistance. The maximum usage for Polycarbonate sheets are used in construction industry, e.g. dome-lights, curved glazing and corrugated sound walls. In automotive sector, they are used as decorative bezels, head lamp lenses and optical reflectors. They are laminated and used as bullet resistance windows. It is also used as cockpit canopy in aircrafts. Large sheets of Polycarbonate are used as structural materials in Green-houses [1]. Because of its better characteristics as a good energy absorber as far as low velocity impact is concern, the polycarbonate is mainly used as energy absorbent in safety equipment and product packaging [2]. Polycarbonate being a soft structural material, its low velocity impact behavior has not been studied in detail. This study will give a clear insight for a comparative assessment of impact resistance characteristics of polymeric materials with a wide range of tensile strengths.

Low velocity impact is generally in the range up to 10 m/s which is frequently encountered in any transport vehicles. Analysis of impact damage in composite materials is of major concern in many of the engineering sectors like aerospace, automotive, Packaging in Food and electronic devices etc. The types of damage that can be inflicted include bird strikes, hail and runaway debris during service and dropping of tools or tool boxes during maintenance and fabrication [3]. It is well known that polymer materials and polymer matrix composite laminates are very sensitive to impact loading and can lead to several types of failure modes like partial or full indentation, matrix cracking, fiber cracking, de-lamination and complete perforation. The impact resistance of materials can be assessed by maximum absorbed energy and peak absorbed load for a given impact energy [4]. After conducting impact tests at incrementally higher impact energies, maximum saturation absorbed energy and peak absorbed load before complete perforation has to be determined in order to arrive at the true impact resistance characteristics of any polymeric material. Against this background, in this paper, an attempt is made to analyze the low velocity impact resistance characteristics of polycarbonate sheets and compare the findings with other polymeric based composite laminates investigated by different researchers.

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2.0 Materials and experimental methods

For the experimental investigation, 2 mm polycarbonate sheet has been used. The mechanical properties of polycarbonate sheets [1] are given in Table 1.

Table 1: Specified mechanical properties of Polycarbonate sheet

Density, Kg/m^3	1.20 – 1.22 x10^3
Young's Modulus, GPa	2.0 – 2.4
Tensile strength, MPa	55 – 70
Elongation at Break, %	80 - 150
Poisson's ratio	0.37
Glass Transition Temperature, °C	147

Tensile tests are done to verify the grade of the present material and the results are given in Table 2. It is seen that the properties are well within the specified range.

Table 2: Tensile properties of Polycarbonate sheet

Specimen	Yield strength, MPa		Tensile strength MPa		Elongation at Fracture %	
A-TEN-01	47		67		87	
A-TEN-02	46	45	66	64	92	90
A-TEN-03	43		59		90	

For the Low Velocity Impact test 150 x 150 mm specimens are used and firmly gripped on all the sides and the tests are done using custom – built Falling weight tester. The impact mass can be varied from 3.6 Kg to 15.0 Kg and the maximum height of fall is 1.5 m. A hemispherical indenter of diameter 12.5 mm is mounted to a 25 KN piezoelectric force sensor which in turn is firmly fixed to the impact mass and the Schematic of the low velocity drop-weight impact tester is shown in Figure 1. The output of the transducer is fed to the signal conditioner and 14 bit Data Acquisition System at a frequency of 10 kHz and further the readings are synthesized in Lab-view interface in a user friendly format. The parameters of impact tests on Polycarbonate sheet are given in Table 3.

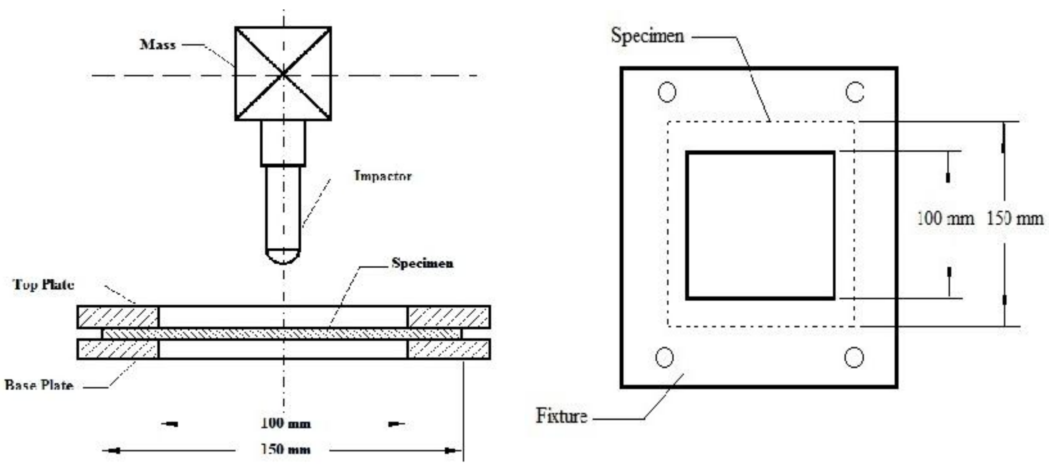

Figure 1 : Schematic of the low velocity drop-weight impact test

The parameters of impact tests on Polycarbonate sheet are given in Table 3.

Table 3: Low velocity impact test parameters

Specimen No.	**Mass** Kg	**Height** m	V_i m/s	**Impact energy** E_i (J)
A-LVI-01	3.6	0.2	1.98	7.06
A-LVI-02	3.6	0.4	2.80	14.13
A-LVI-03	3.6	0.6	3.43	21.19
A-LVI-04	3.6	0.8	3.96	28.25
A-LVI-05	3.6	1.0	4.43	35.32
A-LVI-06	3.6	1.2	4.85	42.38
A-LVI-07	3.6	1.4	5.24	49.44
A-LVI-08	3.6	1.5	5.43	52.97

3.0 Results and discussion

Force – time plots and the material damage after impact are indicated in Figures (2) through (9). The damage occurred on top side and bottom sides are depicted to understand the extent of penetration/perforation as the case may be. From Figures (2) to (6), it is observed that the absorbed load increases with time and after reaching a maximum and then the load drops gradually till zero, in cases where the material is not perforated. However, in the tests (Figure 7 to 9) where complete perforation has occurred, the load after reaching peak suddenly falls to zero.

From the Force – time plots, velocity, displacement and absorbed energy are computed using numerical integration as proposed by Joshua et al [3], Warnet et al [4] and Torre et al [5]. The relevant formulae suggested for computing the above parameters are given below:

Computational method by Joshua et al [3]

$$V(t) = V_i + \int_0^t \left(g - \frac{F(t')}{M} \right) dt' \qquad ..\text{Equation (1)}$$

$$X(t) = 0 + \int_0^t V(t')\, dt' \qquad ..\text{Equation (2)}$$

$$E(t) = \int_0^t F(t')\, V(t')\, dt' \qquad ..\text{Equation (3)}$$

Computational method by Warnet and Reed [4]

$$V(t) = V_i + g.t - \frac{1}{M} \int_0^t F\, dt \qquad ..\text{Equation (4)}$$

$$X(t) = V_i t + \frac{gt^2}{2} - \frac{1}{M} \int_0^t \left(\int_0^t F\, dt \right) dt \qquad ..\text{Equation (5)}$$

$$E(t) = V_i \int_0^t F\, dt + g \int_0^t tF\, dt - \frac{1}{2M} \left(\int_0^t F\, dt \right)^2 \qquad ..\text{Equation (6)}$$

Computational method by Torre et al [5]

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$$E(t) = \frac{M}{2} V_i^2 - \frac{M}{2} V_t^2 \quad \text{..Equation (7)}$$

Where

$F(t)$ = Absorbed force at a time, t

$X(t)$ = Displacement at a time, t

$V(t)$ = Velocity at a time, t

$E(t)$ = Absorbed energy at a time, t

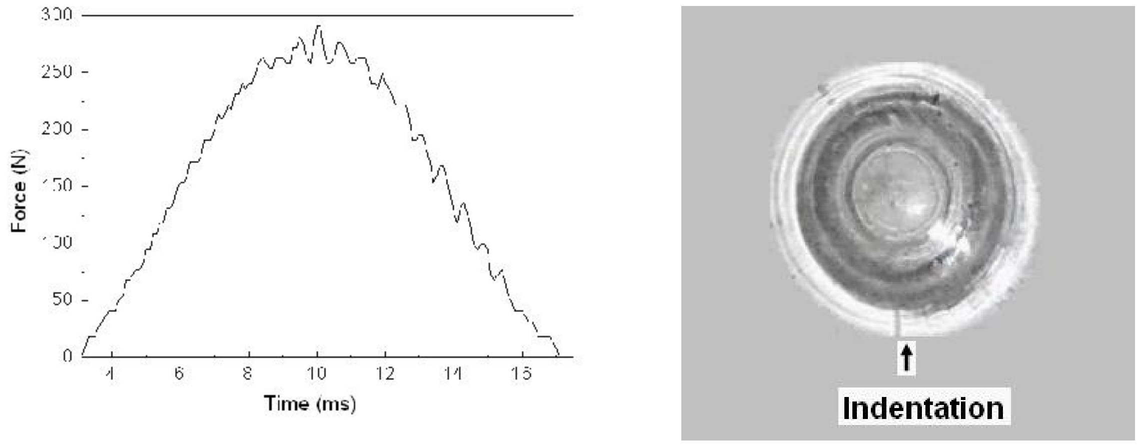

Figure 2: Force – time plot and indentation damage (Specimen: A-LVI-01).

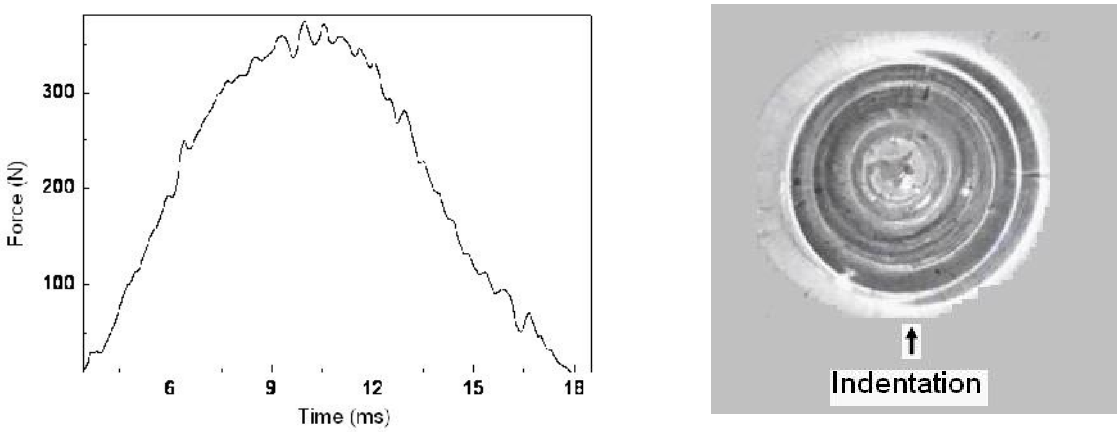

Figure 3: Force – time plot and indentation damage (Specimen: A-LVI-02).

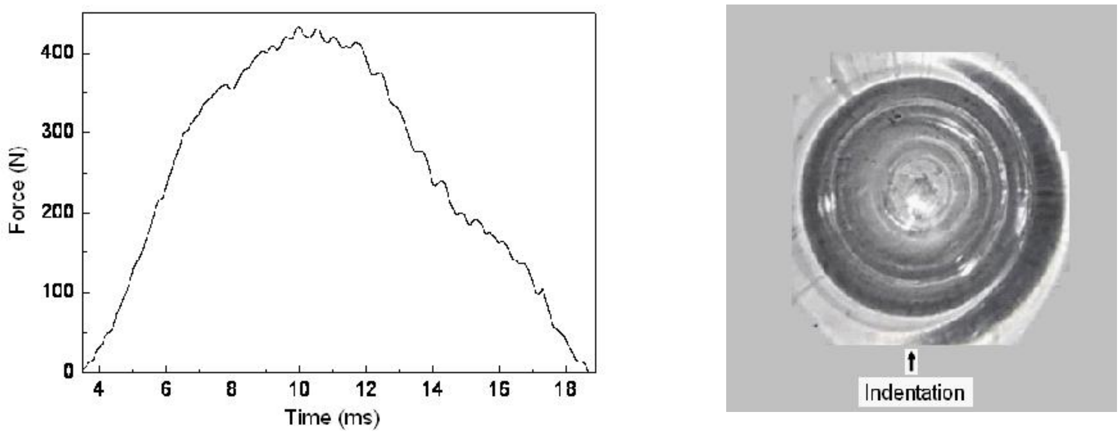

Figure 4: Force – time plot and indentation damage (Specimen: A-LVI-03).

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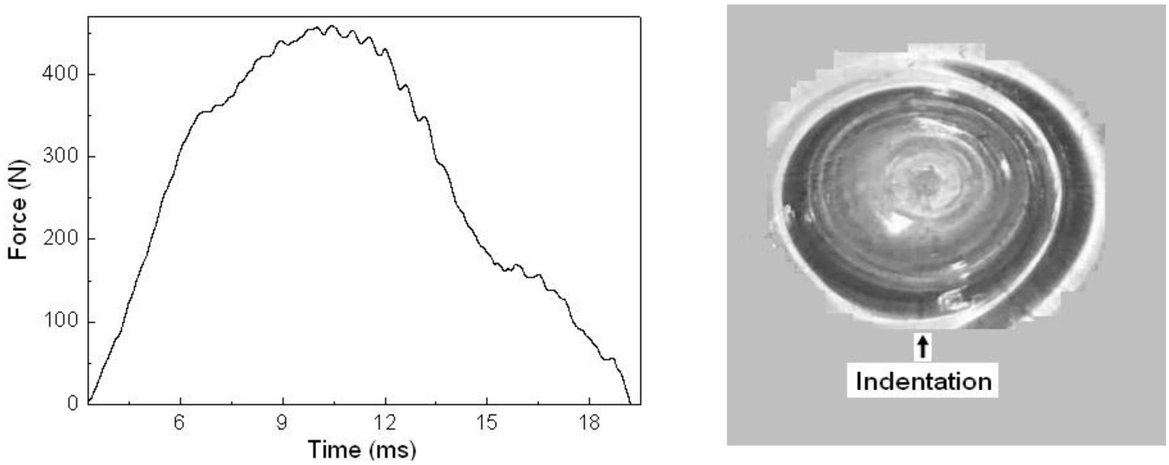


Figure 5: Force – time plot and indentation damage (Specimen: A-LVI-04).

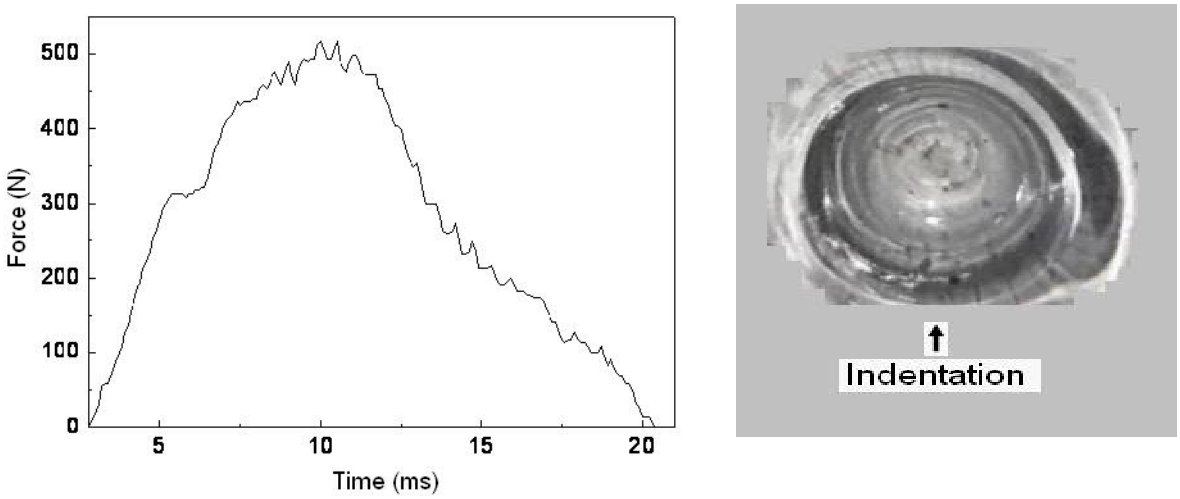


Figure 6: Force – time plot and indentation damage (Specimen: A-LVI-05).

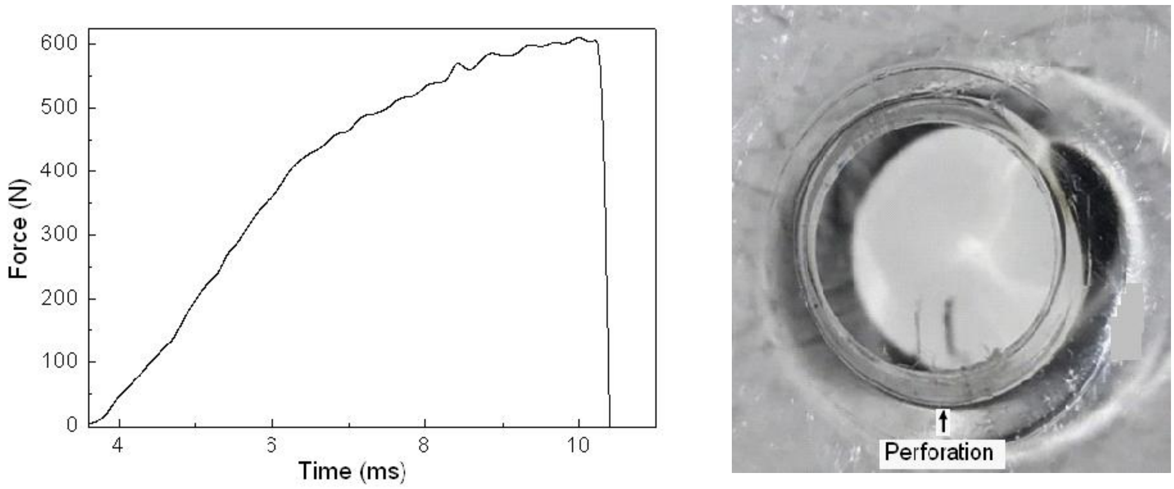
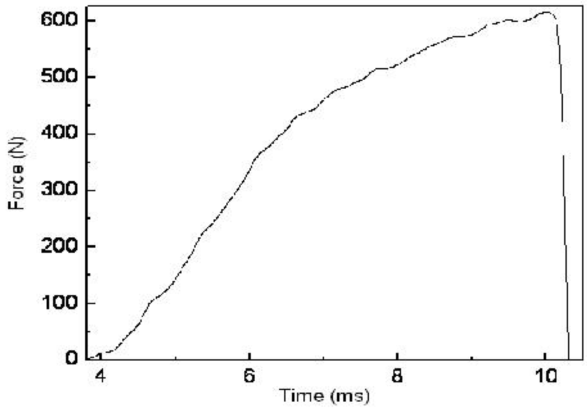


Figure 7: Force – time plot and indentation damage (Specimen: A-LVI-06).



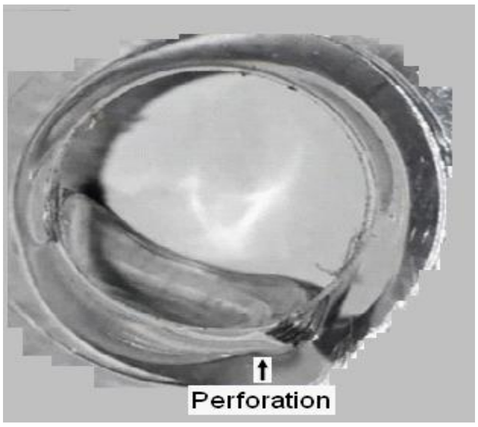
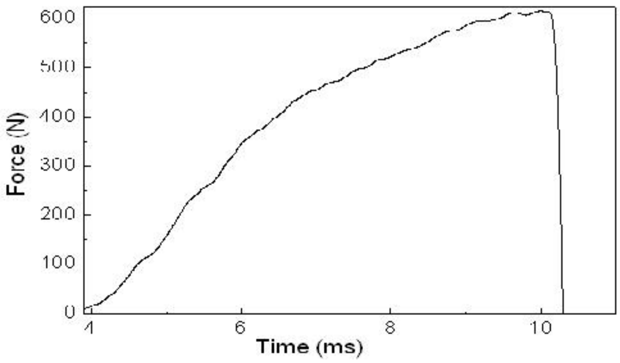


Figure 8: Force – time plot and indentation damage (Specimen: A-LVI-07).



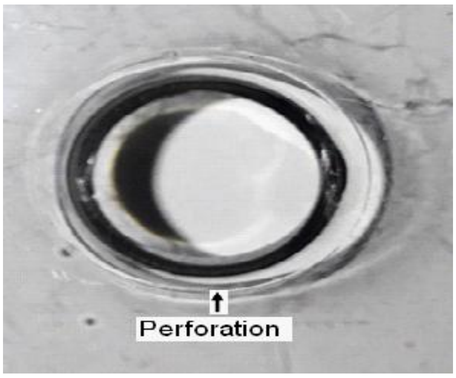


Figure 9: Force – time plot and indentation damage (Specimen: A-LVI-08).

It can be seen from equations (3), (6) and (7), the absorbed energy computation is slightly different and hence we can expect some variations in the absorbed energy values obtained by numerical integration. Figure (10) shows the absorbed energy as a function of impact energy up to the point of complete perforation. While the absorbed energy obtained from the method by Warnet et al [4] is around 60% of impact energy, the absorbed energy obtained by Joshua et al [3] is around 52% and that computed by using Torre et al [5] is around 46%. The average absorbed energy is around 53% of impact energy up to the point of complete perforation. For polycarbonate sheet, complete perforation occurs at impact energy beyond 35.8 J. At impact energies beyond this value, absorbed energy drops to 12 to 13 J which is around 35% which is significantly lower.

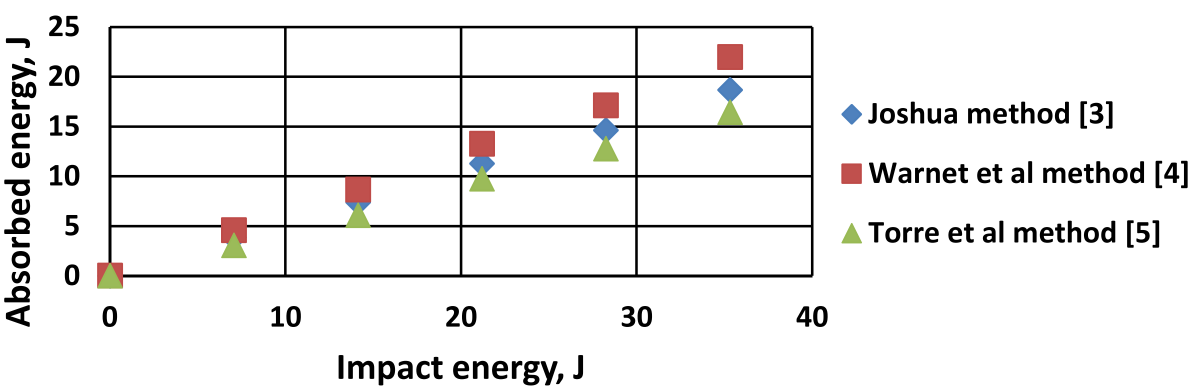


Figure 10 : Impact energy versus absorbed energy of Polycarbonate sheet

An attempt has been made to compare the absorbed energy obtained for polycarbonate sheets with other polymeric laminates investigated by different researchers and these are indicated in Figure 11. From the figure, it is evident that the absorbed energy as a function of impact energy, until complete perforation, is almost same irrespective of the type of polymeric material. It is also seen that a linear trend exists between impact energy and absorbed energy and the absorbed energy is around 53% of impact energy. Further, it is found that at impact energies beyond 35.3 J, the indenter completely perforates the sheet and the absorbed energy drops significantly to around 11 to 13 J. This reduction in absorbed energy may be due to lower time duration of impact loading. Peak absorbed load for different impact energies for polycarbonate sheet is plotted in Figure 12. In the same plot, peak load for different laminates obtained by different researchers are also included. It is seen that the peak load is strongly dependent on the thickness, elastic modulus and strength of the material. Higher the strength and modulus, higher is the peak load for the same impact energy. Maximum absorbed energy at the point of complete perforation for soft materials is much higher and the absorbed load is much smaller.

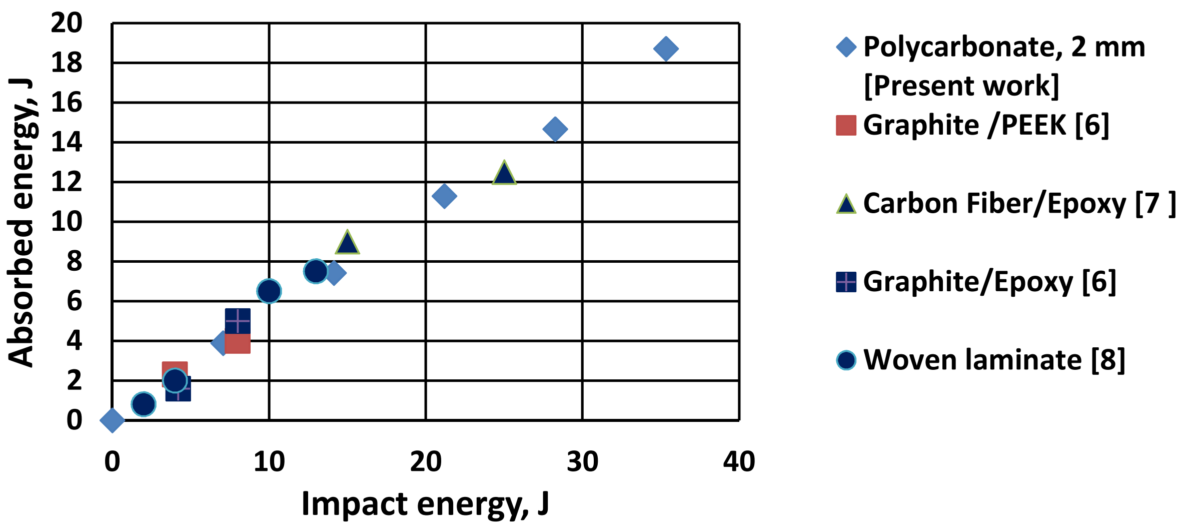


Figure 11 : Absorbed energy vs Impact energy for Polymeric materials

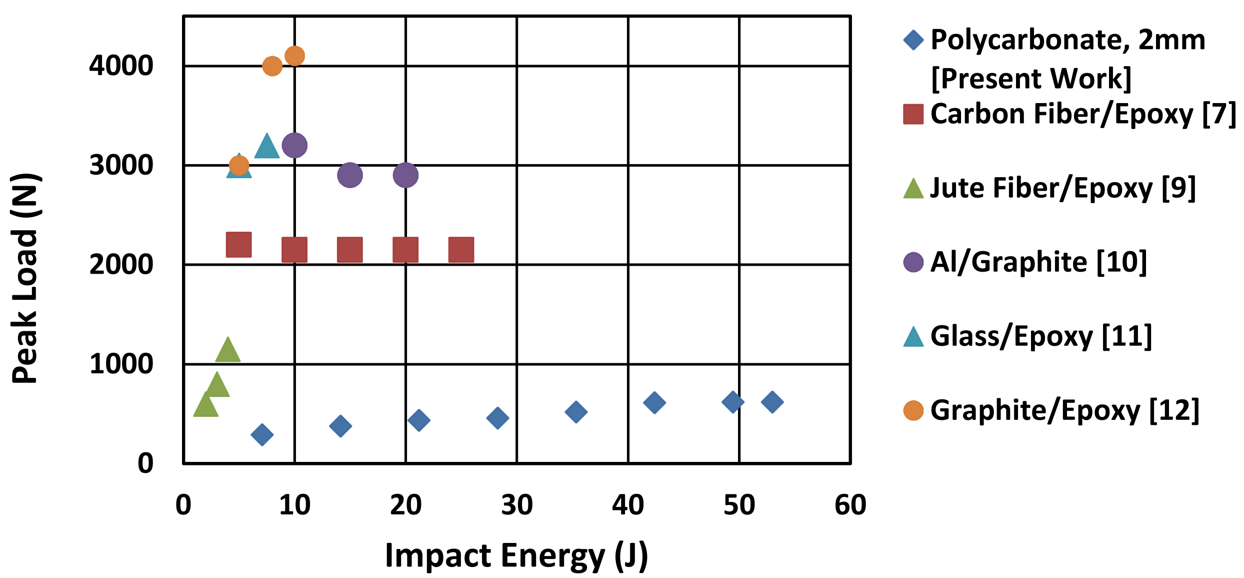


Figure 12 : Peak load versus Impact energy for different polymeric materials

4.0 Conclusions

Impact behavior of Polycarbonate sheet under low velocity impact at different impact energies have been studied in detail. The absorbed energy as a function of impact energy is evaluated using different numerical methods and it is observed that the ratio of absorbed energy to impact energy is around 53% of the impact energy until the impact energy completely perforates the specimen. The absorbed energy characteristics have also been compared with other polymeric laminates and it is observed that the ratio of absorbed energy to impact energy is independent of the material. The absorbed load as a function of impact energy is found to be strongly dependent on the thickness and mechanical properties of the material. Softer materials like polycarbonate sheets tend to absorb more energy until perforation and the peak load absorbed is significantly lower.

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