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Low velocity impact behavior of carbon nanotube filled glass fiber/vinyl ester composites

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ABSTRACT

In this study, the impact behaviors of glass-fiber/vinyl ester (GG) and carbon nanotube filled glass-fiber/vinyl ester (CG) subjected to increasing impact energies have been experimentally investigated at room temperature. Using a drop weight test rig, specimens were impacted using steel 12 mm in diameter hemispherical impactor. The impact tests performed at impactor mass (15.5 kg). The penetration and perforation thresholds of composites were determined by using energy profiling method (EPM). It is designated that adding carbon nanotube to the glass-fiber/vinyl ester composite contributes to the increasing of perforation threshold. Furthermore, overall damage areas caused by the impactor were evaluated and it is found that addition of carbon nanotube to the composite decreases the damages.

Keywords *- Glass/ vinyl ester, impact response; damage modes, carbon nanotube*

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I. INTRODUCTION

Composite laminates are used in many engineering applications, which expose them impact by foreign objects. While metallic components such as steel, aluminum, etc. absorb impact energy by plastic deformation, composite materials dissipated it by damage mechanisms such as fiber debonding, fiber fracture, and matrix cracking. Laminated composite structures are also more susceptible to impact damage than a similar metallic structure. In composite structures, impacts create internal damage that often cannot be detected by visual inspection. This internal damage can cause severe reductions in strength and can grow under load. These damages can influence seriously the residual properties and structural integrity of composite materials [1], [2], [3], [4] and [5]. Therefore, the effects of foreign object impact on composite structures must be understood, and proper measures should be taken in the design process to account for these expected events. Ataş ve Liu [6] investigated the impact response of woven composites with various weaving angles between interlacing yarns experimentally. They concluded that the energy absorption capability and perforation threshold of woven composites can be significantly improved by using a small weaving angle between interlacing yarns. Sayer *et al*. [7] studied the impact response of hybrid composite laminates. They used energy profiling method (EPM) was used to identify the perforation thresholds of composites. Aktaş *et al*. [8] have investigated the impact response of unidirectional glass/epoxy laminates by considering energy profile diagrams and associated load versus deflection curves. They concluded that the primary damage mode was found to be fiber fracture for higher impact energies. Toyota Research Group introduced the use of nano-clays as enforcement of polymer systems in the early 90s, as stated by Liu *et al*. [9]. Morphological changes were conducted on that time by nano-clays and nano-clays influenced the crystallization process as well. Storage elastic modulus of 100% increased when clay content was up to 8wt% in comparison with net nylon 11 as tendered Liu *et al*. [9]. The glass transition temperature was higher than the virgin polystyrene for polystyrene-montmorillonite (MMT) as shown in Yie *et al*. [10]. However, the effect of nanoparticles in epoxy systems due to their residual use by the composite structures industry has been decided to be studied by different researchers. Isik *et al*. [11] has studied on usage of nanoparticles into epoxy system. They tied up both stiffness and toughness was enhanced by nanoparticles. However, the maximum impact strength was achieved at 1% in weight of MMT content for their binary system, resin-diglycidly ether of bisphenol A and cure agent-triethylenetetramine. Yasmin *et al*. [12] worked on the influence of nanoparticles into epoxy systems. An increase in the elastic moduli to a maximum 80% has been traced by varying the amount of Cloisite 30B, in weight from 1% to 10%. Avila *et al*. [13] were investigated that the effect of montmorillonite (MMT) silicate layers on glass-fiber-epoxy laminated composites mechanical properties low-velocity impact tests. They identified that the presence of intercalated nano-clays into laminates caused an enhancements stiffness, increasing impact resistance/fracture toughness and changing failure mechanisms. Velmurugan and Balaganesan [14] and [15], focused on experiments and analytical model on energy absorption of nanocomposites laminates subjected to impact loading above ballistic limits. It is observed that the presence of clay enhances the energy absorbing capacity of the laminates during perforation.

II. METHODOLOGY

For making composite plates, unidirectional E-glass fabric having weight of 500 g/m^2 was used as reinforcing material. Polives^{TM} 701 Bisphenol-A vinyl ester matrix resin was used. Timestub^{TM} purified multi-walled carbon nanotubes were used as filler. The carbon nanotubes compositions of 0.1 by percentage weight of CNT in vinyl ester were chosen as the specimen preparation. A hot lamination press was used for fabrication of composite plates. For curing process, laminated plates were retained at a constant pressure (20 MPa) and 118 $^{\circ}$C during 2 h.

The tests were performed using a specially developed instrumented drop weight testing system (Figure 1). It is a test rig suitable for a wide variety of applications requiring low to high impact energies. A tup insert, which was assumed to be perfectly rigid, with a hemispherical nose of 12 mm in diameter was used. The total mass of the impactor used was 15.5 kg. The composite specimen with dimensions of 150 mm by 150 mm was clamped on a fixture along a square circumference having a 100 mm side. The force values were measured by using a 22.6 kN quartz force ring (PCB, Piezotronics, Inc., New York, USA).

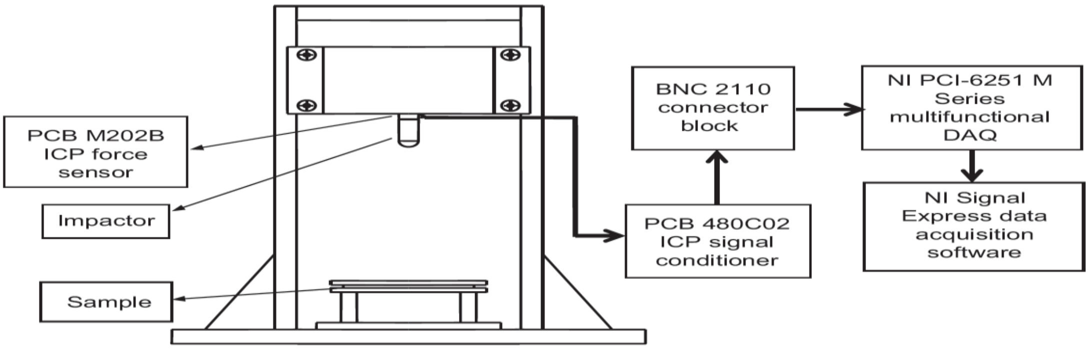

Figure 1. The Test rig [16]

Impact energy (E_i) and absorbed energy (E_a) are two important parameters to assess impact response and resistance of composite structures. The impact energy is defined as the total amount of energy introduced to a composite specimen. The absorbed energy is the energy absorbed by the composite specimen through the impact event by formation of damage inside specimen [7].

III. RESULT AND DISCUSSIONS

Low velocity impact tests

Low velocity impact tests were applied different impact energy levels. The tests were performed under various impact energies ranging from 20 J to 115 J in order to determine the penetration and perforation thresholds of composites. Force-time histories were evaluated from the impact tests was given in Figure 2. Figure 2 shows the largest contact force on the specimens increase with increasing impact energy. The oscillations of the curves in graph are increasing with rising impact energy owing to the occurrence of a damage mechanism.

Absorbed energy in an impact event can be calculated from load-deflection curves. Characteristic of load deflection curves also includes some useful tips in assessing damage process of composite structures. Therefore, several load-deflection curves of samples, in this study, for varied impact energies are given in Figure 3. Since they had similar characteristics, only load-deflection curves of carbon nanotube filled glass-fiber/vinyl ester are given in the figure. The bending rigidity is increasing part of the load–deflection curve and it is taking place owing to the resistance shown by the specimen against impact load. No significant changes were observed on the specimens' bending rigidity as the impact energy increased.

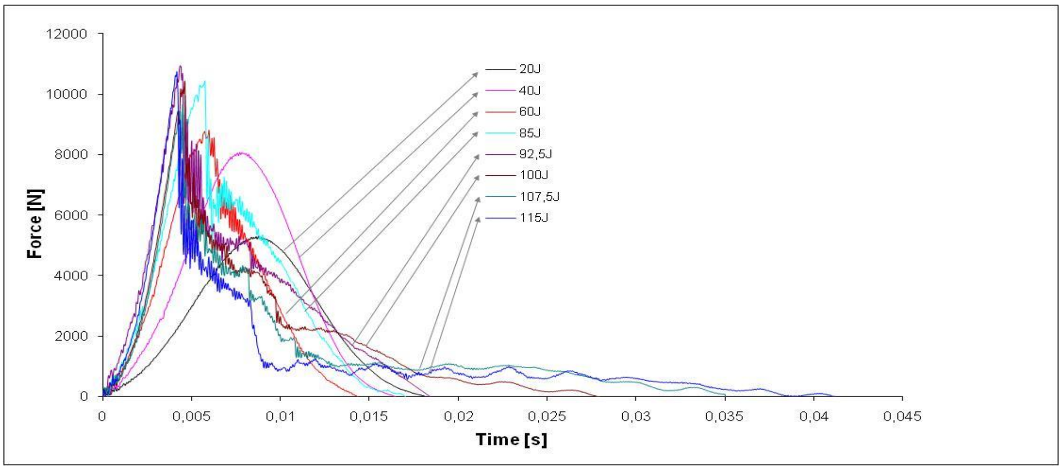

Figure 2. Force-time histories.

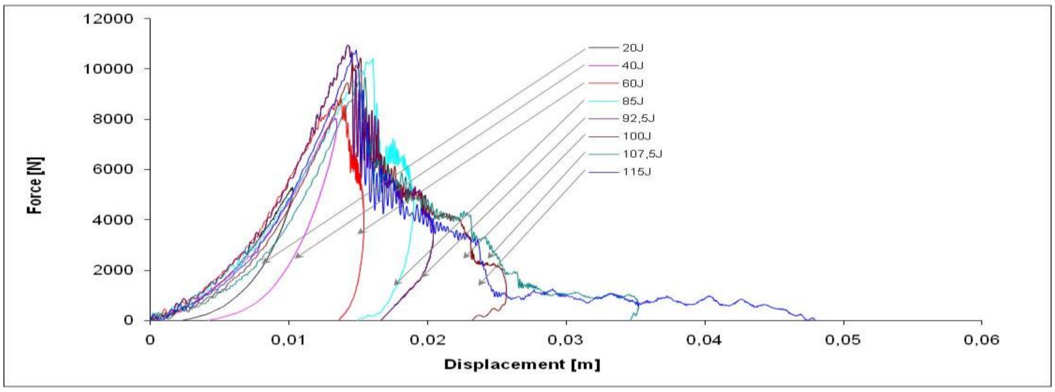

Figure 3. Force versus deflection curves.

According to test results, energy profile diagram of carbon nanotube filled composite is depicted in Figure 4. The energy profile diagram shows the correlation between the impact energy and corresponding absorbed energy. A diagonal line, called equal-energy line, is added to diagrams representing the equality between impact and absorbed energies. It is seen from the figure that for a given impact energy value, up to energy level of 100 J, the absorbed energy is smaller than the E_i. The excessive impact energy (the difference between impact energy and corresponding absorbed energy) is retained in the impactor and used to rebound the impactor from the sample at the end of an impact event. Therefore, the energy absorption capability of composite seems to be good.

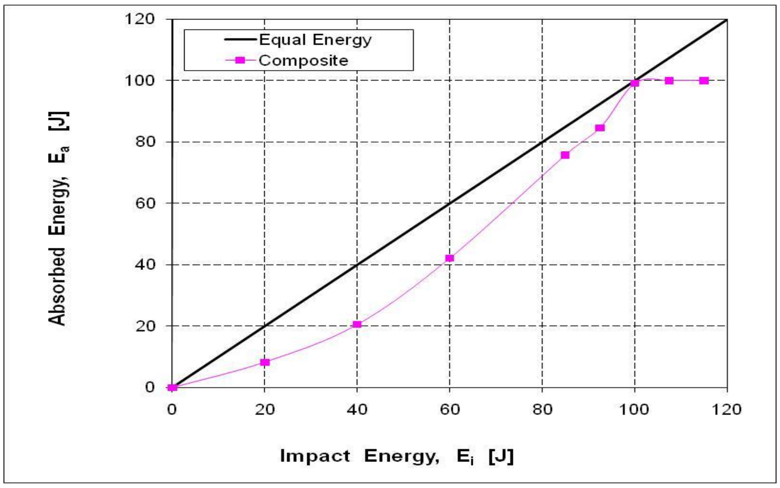

Figure 4. Energy profile diagram of the composites

Damage Mechanisms

Front and back views of the impacted specimens are given in Fig. 5. In all specimens, back surface damages were greater than that occurring on the front.

It is shown from the images that damaged zone expands as impact energy increases. Matrix cracks occurred on the front face of laminates for 20 J and 40 J impact energy levels. Delaminations took place on the back face of specimens. In addition to this, fiber debonding was also observed. Permanent indentations were appeared in addition to matrix cracks for the samples subjected to 60 and 85 J impact energies. For these samples, delaminations at the back face were enlarged, fiber debonding increased but no fiber breakage was observed. The indenter got stuck into the samples partially for 95 J and it was realized completely for 100 J. For these energy levels fiber breakage was observed. For the 107.5 J and 115 J, the samples perforated. The impactor rebounded up to 100 J impact energy. At this energy level, the indentation was occurred. Beyond this point, the composite was perforated.

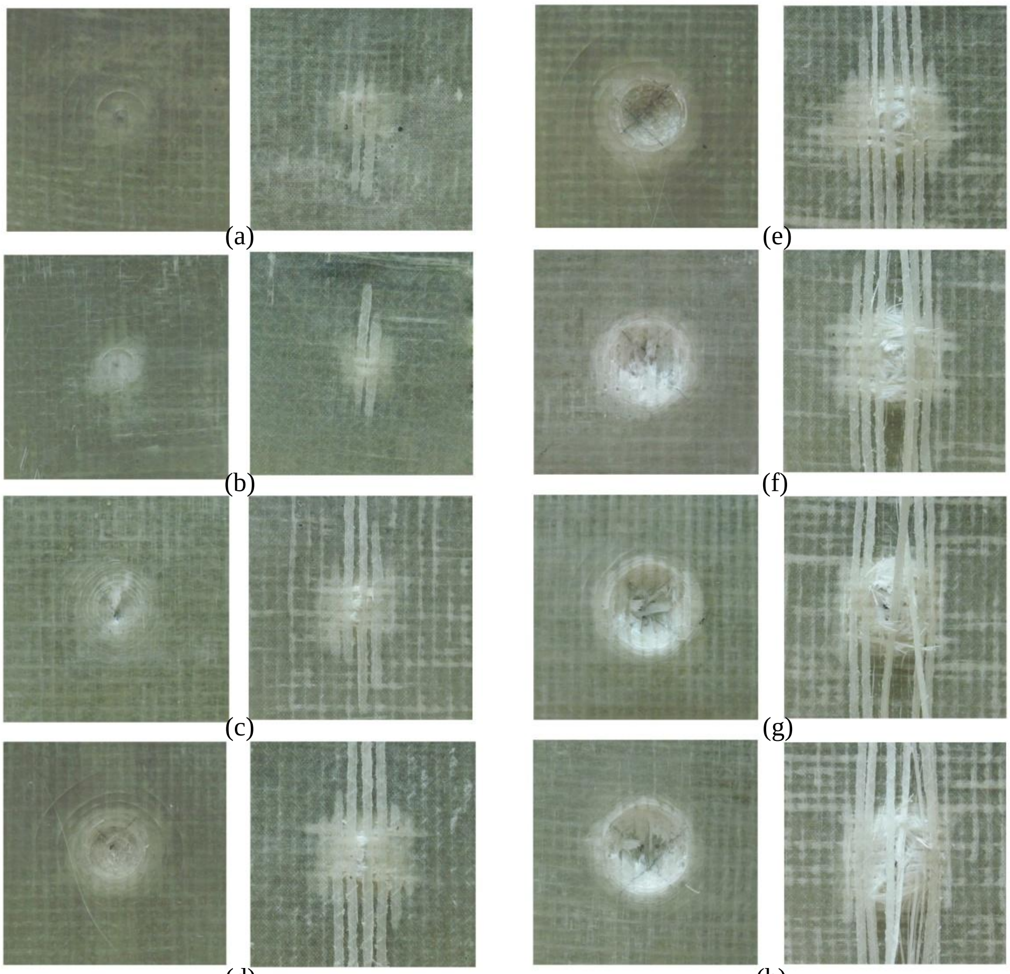
(a) (e)
(b) (f)
(c) (g)
(d) (h)

Figure 5. Views of damaged zone caused by (a) 20 J (b) 40 J (c) 60 J (d) 85 J (e) 92.5 J (f) 100 J (g) 107.5 J and (h) 115 J impact energy.

IV. CONCLUSION

The impact behaviors of glass-fiber/vinyl ester (GG) and carbon nanotube filled glass-fiber/vinyl ester (CG) subjected to increasing impact energies have been experimentally investigated in this study. Practical results obtained from this study;

- Maximum contact force and duration time go up as the impact energy increases for all specimens.
- Amount of indentation increases as the impact energy increases, but this did not cause any reduction on the bending stiffness.

- Main failure types are matrix cracks, delaminations and fiber debonding. In addition to them fiber breakage and splitting occurred at higher strike energies.
- It is concluded from this study that nano-structured composite seems very good to absorb energy.

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Biographies

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