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Energy absorption characteristics of Carbon /Epoxy nano filler dispersed composites subjected to localized impact loading.

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Abstract

Energy absorbing capacity of carbon/epoxy nanocomposite laminates subjected to impact loading is studied in this paper. Nano fillers of 1% to 5% are dispersed in the epoxy matrix. The laminates with and without nano filler are prepared by hand lay-up and compression moulding process. Nanocomposite laminates and carbon/epoxy laminates are subjected to impact testing by using a gas gun with spherical nose cylindrical projectile. The velocity of impact is above the ballistic limit of the laminates. Energy absorbed by the laminates is calculated from initial and residual velocity of the projectile. The energy absorbed by the laminates in various failure modes and influence of nano filler dispersion are analyzed. It is observed that dispersion of nano filler in the matrix enhances the energy absorbing capacity of carbon/epoxy laminates during impact loading.

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Keywords: Nanocomposites; Carbon/Epoxy; Impact loading; Energy absorption

1. Introduction

For the past few decades, extensive studies were carried out for synthesizing new variety of materials and improving the mechanical properties to replace traditional metals in many applications such as aerospace, military, container and high pressure applications. In that connection, composite materials and nanocomposites are finding attractive solution due to their superior mechanical properties and light weight. [1]. Moreover, unlike other polymer

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composites, carbon fiber reinforced composites exhibit excellent damping properties, enhanced electrical, high resistance, thermal conductivity, rigidity and lower density and also uses of CFRP(Carbon Fiber Reinforced Plastics) are inexorable in protective structures and high pressure applications. However, these phenomena aren't sufficient enough to conclude the promising design criteria for material to replace the traditional materials, since polymer composites are brittle in nature. Also, on account of poor performance in dynamic loading conditions and absorb mechanical energy through only elastic behavior [2], investigating impact resistance and ability of absorbing energy would be one of the important manifestations to achieve the desire improvements [3].

Impact damages are vulnerable threats to polymer composites material's structural integrity that even causes invisible interlaminar damages to visible penetration of the targets, depending on target speed and type [4]. Unlike, low speed impact events, as reported in [5], in the ballistic impact events, contact time between target and structure is comparatively very less and induces localized damage in the laminate. At the impact of velocity below the ballistic limit, vibration of target laminate absorbs more energy than the failure of laminate in delamination and matrix crack [6]. The energy absorbed by the laminates above the ballistic velocity is due to failure of fibers, deformation of secondary fibers, delamination and matrix crack in delaminated area [7].

The mechanical properties of CFRP can be enriched by hybridization of active matrix system with micro or nano fillers reinforcements such as nano clay, Al2O3, CNT and etc., [8]. Addition of nano fillers in composite materials increases interlaminar strength with lower percentage of filler dispersion in the matrix [9]. On other hand, increasing these phenomena serves in increasing mechanical properties as well as impact resistance and energy absorption capacity. Very first study on nano fillers reinforced composites materials performed by Toyota Central Research Laboratories and proved that intercalating polymer into silica layers provided strong interface between organic and inorganic phases that leads to considerable improvements on mechanical properties [10]. Yuvan et al. studied nano fillers dispersed CFRP and reported that montmorillonite nano clay modified TGDDM epoxy system increase the interlaminar fracture toughness by 85 % when 4% nano clay dispersed in matrix. Also small amount of nano clay presence increase the flexural strength by 38% [11]. Velmurugan et al., demonstrated a comparison study between modified and unmodified nano Garamite as filler elements in epoxy that revealed homogenously dispersed orgono clay and unmodified clay improved hardness, mechanical properties, thermal properties and stiffness. Moreover, Considerable improved properties are estimated in modified orgonoclay dispersed epoxy system compares with unmodified clay. They also reported that treated montmorillonite dispersed epoxy resin system and composites possess superior tensile strength over unmodified clay dispersed epoxy resin system [12]. Balaganesan et al. investigated energy absorbing mechanism of nanoclay loaded glass fiber reinforced composites (GFRP) elaborately and they confirmed that addition of nanoclay act as a secondary fibers and improves energy absorption capacity and ballistic limits in dynamic loading [13] and also optimum loading of 5% nano clay in GFRP is absorbed more energy and deformation of laminates absorb 70% of projectile energy irrespective of projectile velocity and nano clay loading [14]. Kosar Iqbal at al. verified the influence of nano fillers in CFRP under low speed impact events and they reported that nano clay presence brought significant improvement in damage tolerance and impact resistance [15]. There are limited studies on ballistic impact of carbon fiber reinforced nano composites.

The purpose of this article is to investigating the influence of nano particles in ballistic performance and energy absorption behavior of carbon fiber reinforced composite materials. Nano fillers of 1% to 5% are dispersed in the epoxy matrix. The laminates with and without nano filler are prepared by hand lay-up and compression moulding process. Nanocomposite laminates and carbon/epoxy laminates are subjected to impact testing by using a gas gun with spherical nose cylindrical projectile. The velocity of impact is above the ballistic limit of the laminates. Energy absorbed by the laminates is calculated from initial and residual velocity of the projectile. The energy absorbed by the laminates in various failure modes and influence of nano filler dispersion are analyzed.

Nomenclature

E_{frac}	Energy absorbed by tensile failure
E_{defv}	Energy absorbed due to deformation

E_{delam}	Energy absorbed due to delamination
G_{II_c}	Critical strain energy release rate in mode II
$\sigma_s(\varepsilon_s)$	Equation of stress-stain function curve

2. Experiments

Epoxy resin Araldite LY 556 and hardener HY 551 were used as an active matrix system for fabrication of specimens in which woven roving mat carbon fiber of 610gsm was used as a reinforced materials. Epoxy system was dispersed with 0%, 1%, 3% and 5% of Garamite 1958 nano clay purchased from Southern Clay Products, USA. Mechanical shear mixer was used for dispersing nano clay in the epoxy system and was maintained at 750 RPM for two hours for better dispersion. The size and the properties of clay were discussed in our earlier study [13].Six layered laminates were prepared and 3mm thickness was obtained. Specimens were cut into 150 X 150 mm plates by using band saw.

Single stage gas gun was used to conduct projectile impact on the laminates at impact velocity 110m/s and 125m/s. Spherical nose cylindrical projectile of diameter 9.5mm and mass of 8.4g was used for the study. Specimens were rigidly clamped in all four sides along in the fixture. High speed camera was used to capture projectile trajectories and also used to capture initial and residual velocities of the projectiles**.**

3. Energy Absorbed by the laminates

The energy absorbed by the laminates during impact is mathematically analysed. The analysis is based on energy absorption principle. Incident energy of the projectile is absorbed by the target during impact in several energy absorbing and damage mechanisms.

Energy lost by the projectile during impact is

$$E_l = KE_i - KE_f \tag{1}$$

Where, KE_f is kinetic energy of the projectile after impact and KE_i is kinetic energy of the projectile before impact. The energy lost by the projectile is absorbed by the laminates due to tensile failure of primary fibres, deformation of secondary fibres and delamination.

The total energy absorbed due to tensile failure is given by,

$$E_{frac} = v \int_0^{\varepsilon_0} \sigma(\varepsilon) d\varepsilon \tag{2}$$

where, $\sigma(\varepsilon)$ is equation of stress-stain function curve, v is the volume of primary fibres subjected to tensile failure and ε_0 is failure strain of the primary fibers at the point of impact.

The fibres in deformed zone are subjected to variation in strain according to their position from the point of impact. The fibres close to impact point experience a strain equal to tensile failure strain. The fibres which are far away from the impact point are strained to the least. The energy absorbed by the deformation of the laminate per unit volume (E_{defv}) is the area under the stress-strain curve up to elastic limit.

$$E_{defv} = \int_0^{\varepsilon_s} \sigma_s(\varepsilon_s) d\,\varepsilon_s \tag{3}$$

Where, $\sigma_s(\varepsilon_s)$ is equation of stress-stain function curve within elastic limit, ε_s is strain in elastic limit.

The energy absorbed in delamination is given by,

$$E_{delam} = A_d G_{II_c} \tag{4}$$

Where,G_{II_c} is critical strain energy release rate in mode II and $A_d$is area of delamination.

3. Results and Discussion

3.1. Energy absorption behavior

Experiments were conducted to find the ballistic performance of laminates. Impact testing were done at projectile velocities 110m/s and 125 m/s on carbon reinforced nanocomposite laminates. Corresponding kinetic energy of the projectiles are 48.4J and 65.6J. The initial and residual velocities of projectile were predicted from the images of high speed camera. Energy lost of projectile was calculated from initial and residual velocity of projectile. It is made an assumption that energy lost by the projectile is equal to energy absorption of the laminate.

Fig. 1 shows the energy absorption of laminates with and without clay when subjected to impact velocities 110m/s and 125m/s. For the laminates without clay, the energy absorbed at 110 m/s is higher than the laminate subjected to impact at 125 m/s. The dispersion of clay in the epoxy matrix enhances the energy absorption of the laminates during impact. Laminate with 3% clay absorbs 75% higher than the laminate without clay when subjected to impact at 110 m/s. For the laminate with 5% clay, the energy absorption is less than the laminate with 3% clay, at the same time it is 65% higher than the laminate without clay. This is due to presence of clay in the epoxy matrix which acts as secondary reinforcement with the matrix system. The same trend is observed when the laminates subjected to impact at 125 m/s. But the energy absorption at 125 m/s is marginally les when compare to impact velocity at 110 m/s. This is due to less contact duration and saturation of energy absorption in the laminate.

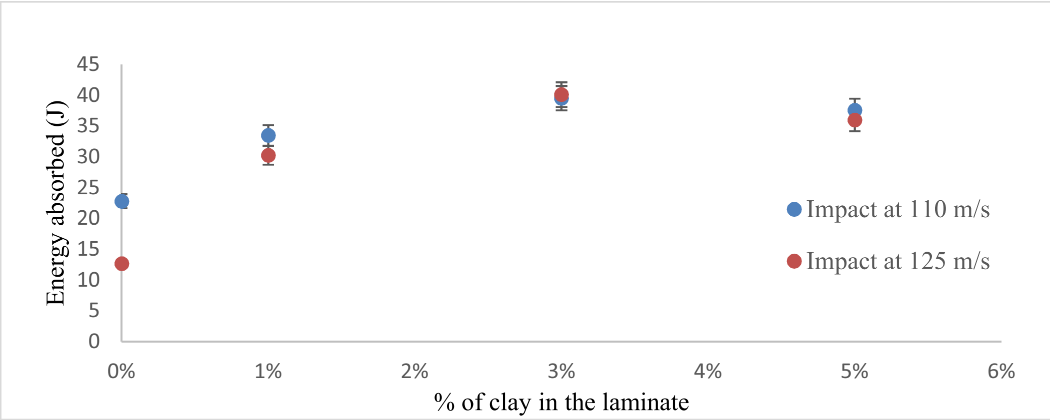

Fig. 1. Energy absorption behavior of 3mm virgin CFRP and nanoclay loaded CFRP.

XRD results interpreted for the dispersion of clay in our earlier study [13]. It is observed in XRD tests that the laminate up to 3% clay does not show any reflection peak which is due to exfoliated nano formation. In exfoliated structure, the area of contact between the polymer and nano filler is more which enhances the energy transfer between the polymer and filler. The improvement in energy absorption is observed up to 3% clay, but there is decrease in energy absorption for the laminate with 5% clay. This is due to agglomerated structure in the matrix with 5% clay.

3.2. Energy absorbed by delamination of the laminates

Figs. 2-4 show for the laminates with and without clay subjected impact at 125 m/s. It is observed that the damage of the laminates is due to tensile failure of the fibers and delamination. The failure of fibers is observed in the warp and weft direction of WRM and at the point of impact. These fibers are subjected to failure strain. The fibers in the other region are subjected strain values within elastic limit. The fibers close to boundary is subjected least value when compare to fibers close to impact point. Fig. 2 shows for the laminate without clay when subjected impact at 125 m/s. The delamination area is about 500 mm^2. Fig. 3 shows for the laminate with 1% clay when subjected to impact at 125m/s. It is observed that the delamination area increases for the increase in dispersion of clay in the matrix system. The delamination area of the laminate with 3% clay is about 1750 mm^2. This is seen in Fig. 4. This is about three times higher than the laminate without clay. This increase in delamination area increases the energy absorption of the laminate during perforation.

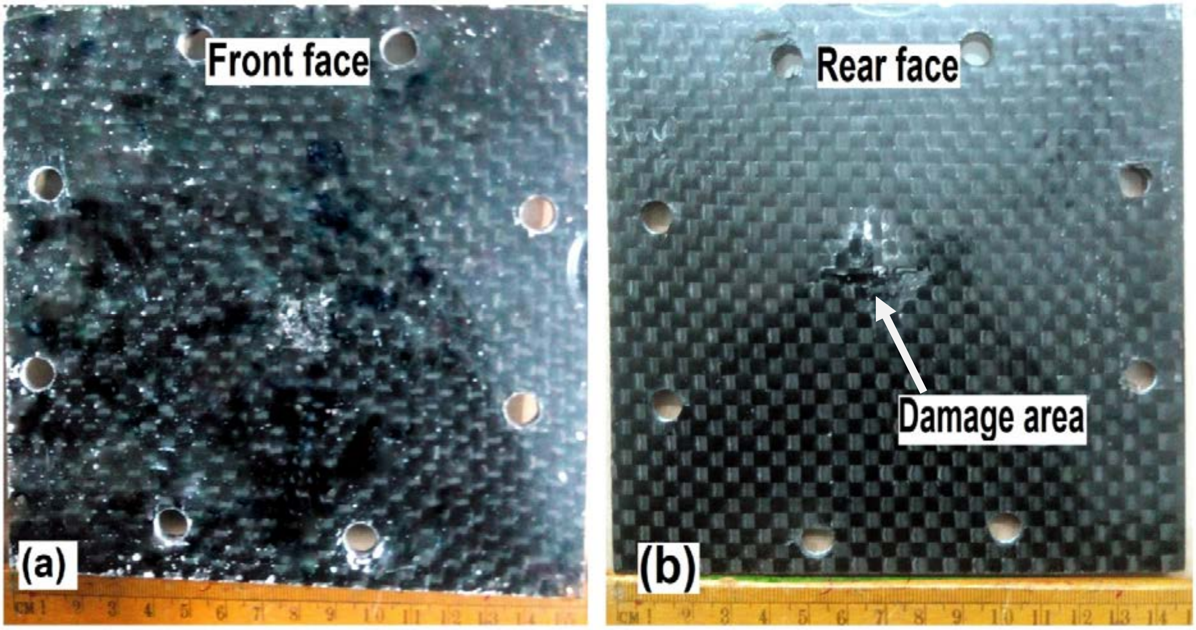

Fig 2. (a) Front and (b) Rear view of 3mm laminates without clay after the experiment of 125 m/s impact event.

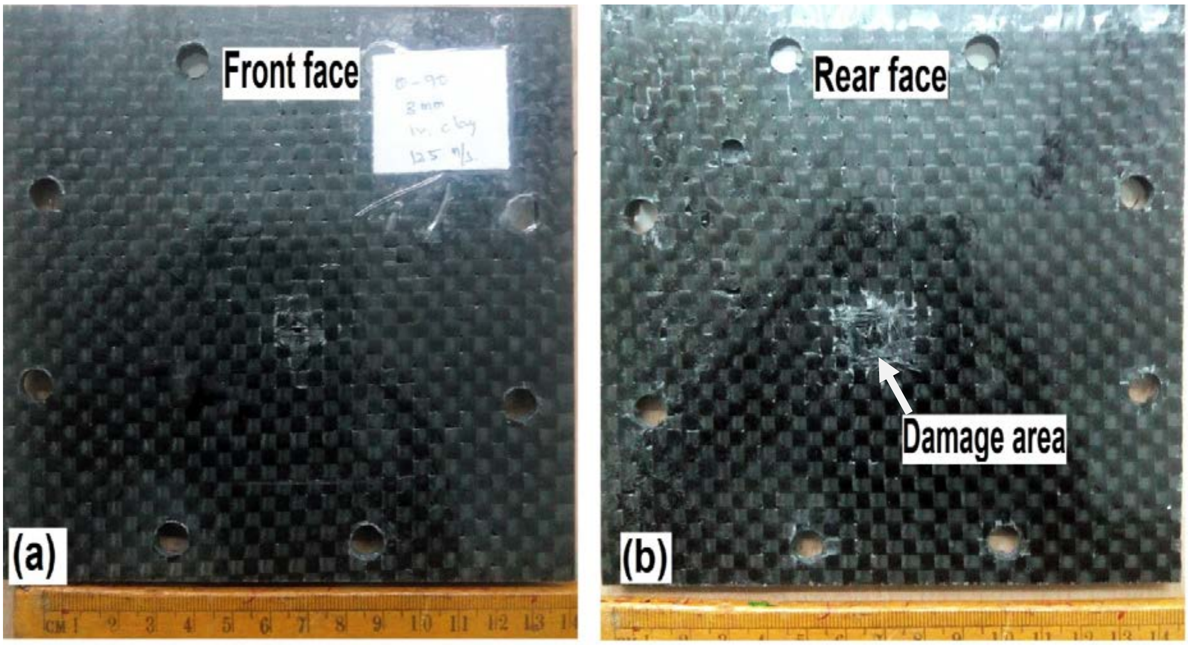

Fig 3. (a) Front and (b) Rear view of 3mm laminates with 1% clay after the experiment of 125 m/s impact event.

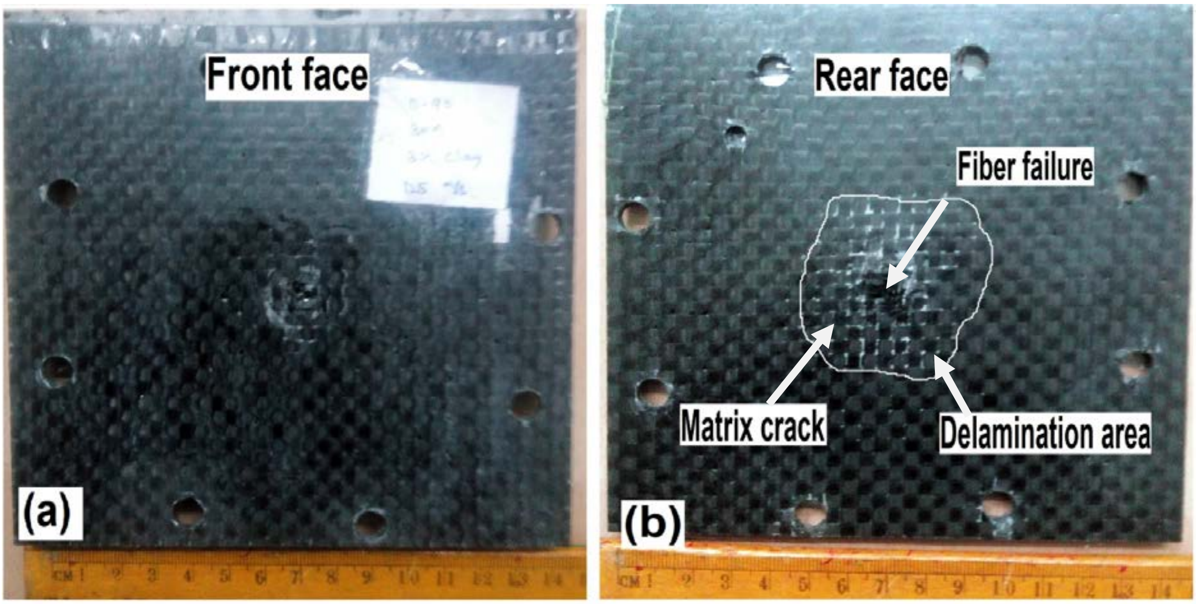

Fig 4. (a) Front and (b) Rear view of 3mm laminates with 3% clay after the experiment of 125 m/s impact event.

The energy absorbed by the laminates during impact is due to tensile failure, deformation and delamination. The values are calculated based Eqns. (2) – (4). The variation between laminates with and without clay in tensile failure and deformation is due to variation in stiffness and strength of the laminate. Fig. 5 shows for the energy absorption of the laminates with and without clay when subjected to impact at 110 m/s and 125 m/s. The laminate with 3% absorb 4 times higher than the laminate without clay when subjected to impact at 110 m/s. For impact at 125 m/s, the energy absorbed due to delamination is 3.5 times higher than the laminate without clay. The clay dispersion enhances stiffness and strength of the laminate and as well as support for better energy absorption in dynamic loading conditions. This is due to secondary reinforcement of nano scale fibres in the matrix. The increase area between nano filler and the matrix absorbs energy in various failure mechanisms within the matrix. The mechanisms are stretching, torsion and bending nano filler within matrix.

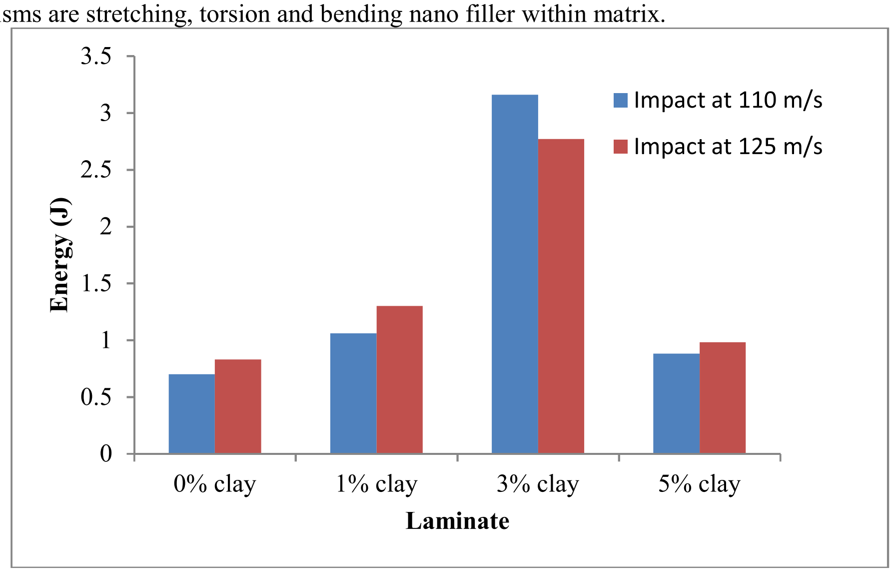

Fig. 5. Energy absorbed by the laminates with and without clay in delamination

4. Conclusion

Energy absorbing capacity of carbon/epoxy nanocomposite laminates subjected to impact loading is studied**.** The energy absorbed by the laminates in various failure modes and influence of nano filler dispersion are analyzed. The following conclusions are made based on this study.

- It is observed that dispersion of nano filler in the matrix enhances the energy absorbing capacity of carbon/epoxy laminates during impact loading.
- The delamination area of nano filler dispersed laminates is less than that of laminate without clay when subjected to impact loading at same velocity.
- The increase in energy absorbed by nanocomposite laminates is due to secondary reinforcement of nano filler in the composite laminates.

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