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Effect of viscoelastic behaviour of glass laminates on their energy absorption subjected to high velocity impact

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ABSTRACT

In the present work, a comparative study is carried out on the energy absorption ability of phenolic and epoxy matrices reinforced with glass fibres. E-glass/phenolic and E-glass/epoxy laminates having different thickness (5 mm, 10 mm, 15 mm, 20 mm & 25 mm) were fabricated and subjected to ballistic impact against 7.62 × 39 mm mild steel core projectile. Dynamic Mechanical Analysis (DMA) of E-glass/phenolic and E-glass/epoxy laminates was also carried out. It was observed that, E-glass/phenolic laminates which have shown higher storage and loss modulus were found to show higher energy absorption than E-glass/epoxy laminates which have shown lower storage and loss modulus. This is observed to be because of ease of delamination and transverse stretching of fibres in E-glass/phenolic laminates as the matrix at the interface is allowing easy sliding. However this effect is found to be significant only when the laminate thickness to projectile diameter ratio (t/d) is more than two. Mechanisms influencing the observed trend in results are analyzed in the present paper with the help of DMA and high speed video imaging during impact. Failure analysis of laminates was studied by using microscopy techniques.

1. Introduction

The role of armour is to provide protection to fighting vehicles against kinetic and chemical energy threats. Fighting vehicles comprising light weight armour made up of ceramic and polymer composite possess better mobility, fighting ability and fire power as compared to the vehicle with traditional steel armour. Penetration of projectile into armour made up of fibre reinforced polymer composite is influenced by various parameters like type of fibre, weave pattern, matrix, fibre/matrix interaction, projectile velocity and its geometry [1,2,3,4]. Fabric with plain weave pattern shows better ballistic performance than satin and twill weave patterns [5]. During the last two decades, various researchers explored polymer composites for armour applications due to their high specific strength and high energy absorption under ballistic impact. Effect of type of fibre reinforcements such as glass, aramid, carbon and ultra-high molecular weight polyethylene (UHMWPE) on ballistic performance were reported [6,7,8,9]. Energy absorption mechanisms of different fibre reinforced composites have been addressed by various researchers through analytical, numerical and experimental studies. For example Naik and Shrirao have studied ballistic impact behaviour of E-glass/epoxy and carbon/epoxy laminates. They reported that glass laminates can show higher ballistic limit than carbon fibre reinforced laminates [10]. Kedar et al. measured stress wave attenuation on rear side of four different fibre reinforced polymer matrix composites during ballistic impact and reported reduced peak strains away from point of impact as the stress wave propagates through thickness due to the attenuation of stress wave [11]. Rahul et al. carried out experimental and analytical studies on effect of fibre orientation on ballistic performance of glass/epoxy laminates. They found that 0/90 layup sequence gives optimum impact performance. They also reported that above the ballistic limit the damage area decreases with increase of projectile velocity. It is also reported that ballistic limit and energy absorption capacity of the laminate increases with increase of dynamic young's modulus and failure strain of fibres [12]. Elias et al. studied the ballistic performance of hybrid composites using carbon/glass/Kevlar fibres and measured energy absorption for different combination of hybrid laminates [13]. All these studies pointed out that fibres having higher tensile strength, high modulus and high failure strain give better ballistic performance.

Though the fibre is the primary energy absorbing material in a composite, the role of matrix is also important. Few researchers have studied the effect of matrix on the ballistic performance of composites. It is reported that, even when the matrix is present at lower volumes in armour grade composites, it restricts the lateral motion of the fibres by holding different yarns together which leads to participation of large volume of material in the dissipation of impact energy to successive layers [14]. Thermoset resins like epoxy, phenolic, polyester and

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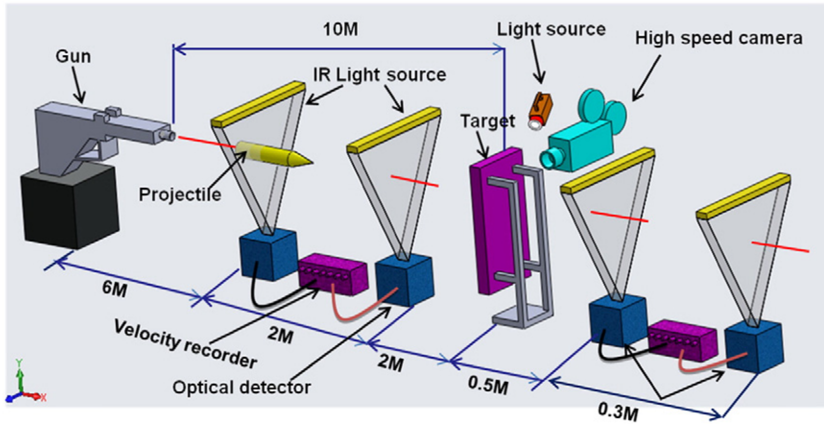

Fig. 1. Schematic drawing of ballistic impact experimental setup.

polyurea and thermoplastic resins like polypropylene (PP) and polyethylene (PE) resins are generally employed as matrix for making armour grade composites [15]. Among these resins, phenolic and epoxy resins are used widely for making armour grade composites due to their availability, ease of fabrication and lower cost. Studies have been carried out on effect of thermoplastic and thermoset resins on impact resistance of composites. For example, Nayak et al. and Carrillo et al. studied the effect of PP and epoxy matrix on ballistic performance of aramid composite laminates against armour piercing (AP) and steel projectiles. They found that PP matrix based aramid laminate has higher ballistic limit as it undergoes global mode of deformation [16,17]. Ralph et al. reported that matrix cracking is the most important energy absorption mechanism during impact in ductile composites and delamination is the dominated energy dissipation mechanism in brittle composites [18]. Karthikeyan et al. studied the effect of shear strength on ballistic response of dyneema and carbon/epoxy composites against steel projectile and found that the ballistic performance of the laminate increases with decrease in laminate shear strength [19]. James and Gary studied the effect of laminate properties on ballistic performance of ceramic-polymer composite armour against lead and AP projectile. They observed that, lower resin content and lower interlaminar shear strength (ILSS) of composite leads to progressive delamination and fibre tensile stretching during impact and thus supports higher energy absorption in composite armour [20]. Study by Michal Barcikowski et al. on the effect of resin modification on mechanical and ballistic impact properties of glass/polyester composite laminates indicated that, the addition of

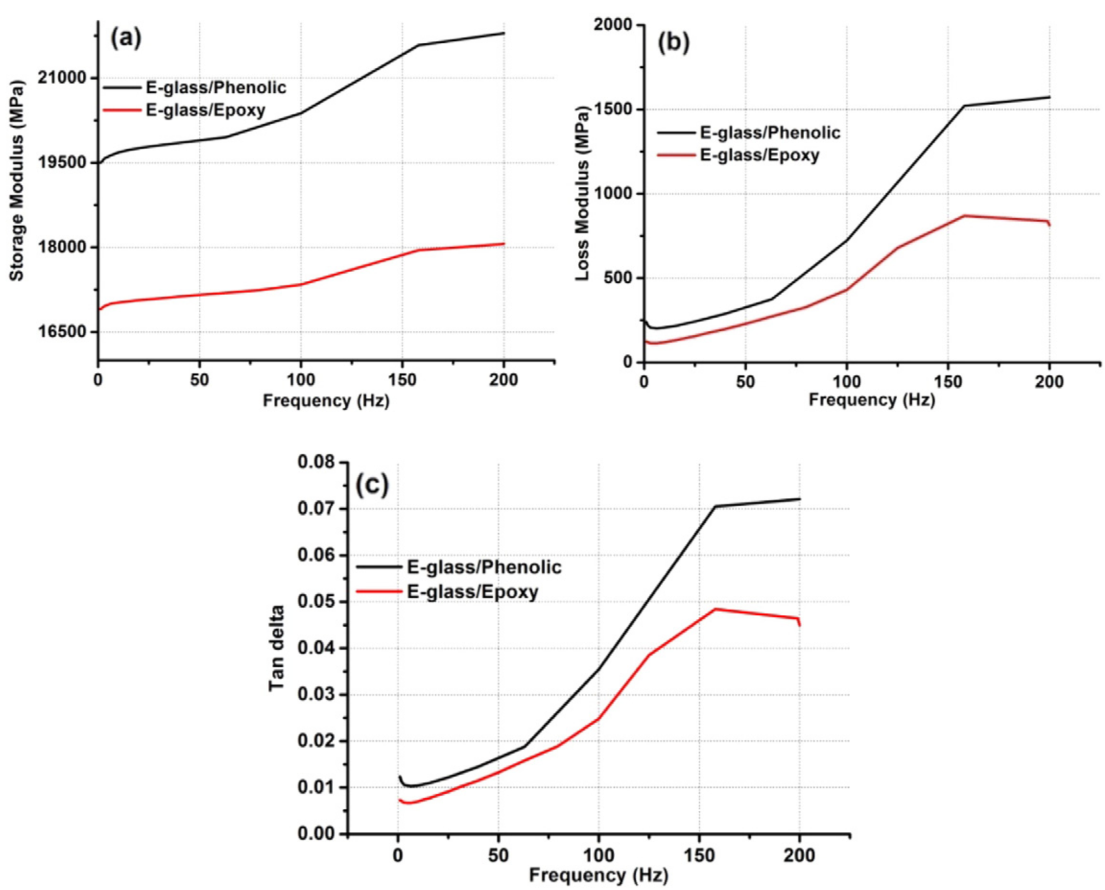

Fig. 2. DMA results of E-glass/epoxy and E-glass/phenolic laminates. (a) Storage modulus, (b) loss modulus, (c) tan delta.