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Material behaviour

Stress wave attenuation in composites during ballistic impact

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ABSTRACT

Experimental studies are presented on stress wave attenuation during ballistic impact for four types of polymer matrix composites. The materials considered are plain weave E-glass/epoxy, 8H satin weave T300 carbon/epoxy and two types of hybrid composite made using plain weave E-glass fabric and 8H satin weave T300 carbon fabric with epoxy resin. Strain profiles were obtained during ballistic impact event at certain distances from the point of impact. There is stress wave attenuation leading to reduction in peak strains obtained as the stress wave propagates away from the point of impact. Further, it is observed that ballistic limit velocity, V_{50}, can be increased compared to carbon only composites by adding E-glass layers to T300 carbon layers.

1. Introduction

Polymer matrix composites are used in high performance structural applications as well as in day-to-day applications because of their excellent mechanical properties such as high specific stiffness, high specific strength, high resistance to corrosion and increased fatigue life. Structural components undergo different loading conditions during their service life and impact loading is one of the critical conditions. Hence, resistance to penetration/perforation is one of the critical requirements of structural components. Polymer matrix composites are generally susceptible to impact loading and, for their effective use in high performance applications, their behaviour under such loading conditions should be fully understood.

During an impact event, different types of waves propagate in the impacted bodies depending on how the motion of the particles of the body is related to the direction of propagation of the waves and the boundary conditions. The most common types of waves are given in [1].

Many factors affect the response of composites to impact loading, including type of fiber and matrix, laminate thickness, lay-up sequence, geometry and boundary conditions. Size, shape and kinetic energy of the projectile also influence the ballistic impact response. Experimental studies are available in literature on the ballistic impact behaviour of polymer matrix composites covering various aspects, such as effect of target thickness [2,3], form of reinforcement of target [4–9], damage due to impact loading [10–15], post-impact mechanical behaviour [16,17] and penetration/perforation [18–26]. Since the test conditions and the target materials are different in those studies, the results cannot be compared.

The studies available are generally on penetration/perforation, effect of target material and geometry, damage due to impact loading, post-impact mechanical behaviour and determination of ballistic limit velocity. It would be interesting to note stress wave attenuation during ballistic impact which can be represented in terms of strain profiles. Hence, in the current work, experimental investigations were carried out to obtain strain profiles as a function of time and distance from the point of impact. The materials used for the studies were plain weave E-glass/epoxy, 8H satin weave T300 carbon/epoxy and two types of hybrid composite made using plain weave E-glass fabric, 8H satin weave T-300 carbon fabric and epoxy resin. Strain profiles are provided at certain distances from the point of impact.

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2. Experimental studies

2.1. Experimental facility

Experimental studies were carried out on a single stage gas gun operated ballistic impact test apparatus. A photograph of the ballistic impact test apparatus used is shown in Fig. 1. The apparatus consists of a projectile propelling mechanism, chronograph for velocity measurement, support stand for holding the specimens, containment chamber, safety devices and strain measuring facility.

A single stage compressed gas gun was used with air as the propelling gas. Compressed gas cylinder, barrel for propelling and guiding the projectile, quick release valve and a nitrogen gas based solenoid valve to operate the quick release valve are the components of the propelling mechanism. The barrel was 1.5 m long with its inner diameter governed by the diameter of the projectile used. Projectile speed was varied up to 200 m/s by changing the air pressure in the cylinder.

A hollow shield was used from the tip of the barrel up to the impact chamber in order to enclose the projectile after propulsion. This was used for protecting the user of the ballistic impact test apparatus from accidental stray firings. The center lines of the barrel, hollow shield, chronograph and the center of the specimen after clamping in the holder were aligned.

Experimental studies were carried out on flat specimens of 125 mm × 125 mm with thickness of 3 mm. The specimen dimensions are governed by the specimen holding device which is part of the ballistic impact test apparatus. The mass of the hardened steel projectile was 6.42 g and its diameter was 6.36 mm. Experimental studies were carried out on at least 3 specimens for each impact condition.

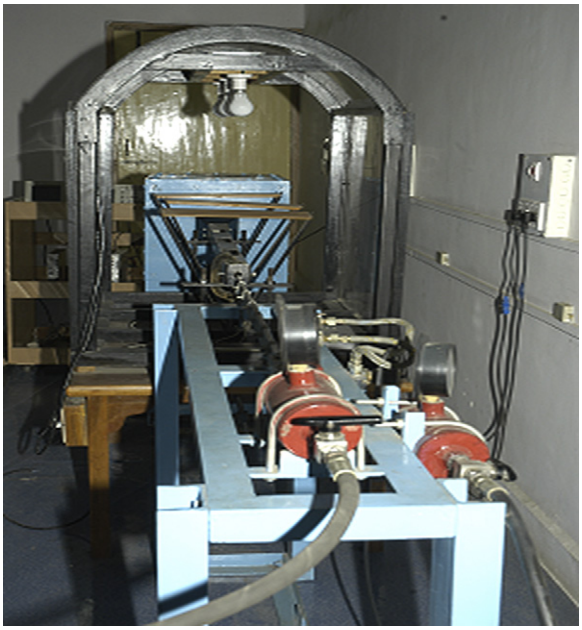

Fig. 1. Photograph of a typical ballistic impact test apparatus.

2.2. Planning for experiments

The study of stress wave attenuation during ballistic impact of polymer matrix composites is a relatively unexplored field of research as evident from the available literature. Hence, experiments were planned in order to study the stress wave attenuation of polymer matrix composites in terms of strain profiles as a function of time and distance from the point of impact.

2.3. Specimen details

Two types of hybrid composites, H4 and H5 were made using 8H satin weave T300 carbon fabric and plain weave E-glass fabric with epoxy resin. Specifications of tows/strands, fabrics, resin and composites for plain weave E-glass/epoxy and 8H satin weave T300 carbon/epoxy are presented in the Appendix.

The lay-up sequences used were: For hybrid H4, $[C_2G_2]_S$
For hybrid H5, $[G_2C_2]_S$

Here, G represents plain weave E-glass fabric whereas C represents 8H satin weave T300 carbon fabric.

For comparison, 8H satin weave T300 carbon/epoxy and plain weave E-glass/epoxy composites were also studied.

- Fiber volume fractions: For hybrids H4 and H5, $V_f = 0.53$

For plain weave E-glass/epoxy, $V_f = 0.51$.
For 8H satin weave T300 carbon/epoxy, $V_f = 0.56$

- Composite volume fraction

Composite volume fraction is defined as the ratio of volume of one of the constituents of the hybrid composite to the volume of the hybrid composite.

For hybrids H4 and H5: T300 carbon composite volume fraction, $V_c = 0.55$.
E-glass composite volume fraction, $V_g = 0.45$

- Volume fraction of a particular type of reinforcement as a part of volume of total reinforcement

This is defined as the ratio of volume of one type of reinforcement to the volume of total reinforcement of the hybrid composite.

For hybrids H4 and H5: T300 carbon fiber volume fraction, $V_f^c = 0.57$.
E-glass fiber volume fraction, $V_f^g = 0.43$.

Fig. 2 presents the schematic arrangement of a test specimen and locations of centres of strain gauges. Fig. 3 presents a photograph of a test specimen with strain gauges mounted on it.

2.4. Test procedure, data acquisition and analysis

Strain gauges of type FLA-6-11-3LT with gauge factor of 2.11, resistance 120 Ω and gauge length of 6 mm were used together with a Wheatstone circuit in quarter bridge configuration. Data from the strain gauges was routed through DC-96A dynamic strain meters and a TDS 1002