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The response of natural fibre composites to ballistic impact by fragment simulating projectiles

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Abstract

While plenty of work has been published on ballistic properties of high performance fibres such as ultra high molecular weight polyethylene (UHMWPE) and aramid, and their composites, literature on the ballistic impact potential of natural fibre composites is almost non-existent. In this paper, the ballistic properties of flax, hemp and jute fabric reinforced polypropylene composites processed by hot compression moulding are investigated. The composites' ballistic limit (V_{50}) was determined by subjecting the material to ballistic impact loading by fragment simulating projectiles (FSPs) using a block manometric cannon interchangeable (BMCI) gun. The composites' ballistic effect was further examined by investigating the ballistic limit of composite-steel hybrid systems prepared by gluing thin mild steel plates on the face and rear of the natural fibre composites. Flax composites exhibited better energy absorption than hemp and jute composites. The composites failed by shear cut-out, delamination and fibre fracture. It was found that the ballistic properties of the hemp composites increased significantly when a mild steel plate was used as facing and backing.

Keywords: Ballistic impact; V_{50}; Natural fibre composites; Fragment simulating projectiles

1. Introduction

Over the last few decades, the search for lighter armour materials with better performance armour materials has continued unabated due to increasing sophistication in the weapons industry. Aramid and ultra high molecular weight polyethylene (UHMWPE) fibres appear to have replaced ballistic nylon and glass fibres as the most dominant materials for structural lightweight armour. However, the scientific based research output in the open literature includes most of the high performance fibres and their composites.

The response of composite materials to ballistic impact has been investigated by many researchers. Recently, D'Almeida et al. [1] investigated ballistic impact damage of glass fibre reinforced epoxy composites while Hasur et al. [2] report on the response of carbon/epoxy composites under high velocity impact. Lee et al. [3] studied ballistic impact on armour grade spectra and aramid reinforced composites while Chou et al. [4] report work on damage of S2 glass reinforced plastic structural armour. Hine et al. [5] researched on the energy absorption of woven nylon and aramid composites and UHMWPE (dyneema UD66). Cantwell and Villanueva [6] investigated the failure of fibre–metal laminate (FML) reinforced aluminium foam sandwich structures at high velocity impact and found the failure modes included longitudinal splitting and fibre fracture in the FML skins.

Due to weight considerations, use of ceramics for body armour has continued to increase over the years. Ceramics are, however, brittle and normally have to be backed by a laminate of high strength and high modulus. The hard ceramic front face erodes the projectile while the laminate backing absorbs the residual kinetic

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energy of the projectiles to prevent a penetration [7]. The major disadvantage of ceramic armour is their high cost compared to metallic armour.

It is clear from the open literature that research on ballistic impact has been focused on the high performance fibres, metals and ceramics. No attempts seem to have been made to study the behaviour of natural fibre composites under ballistic impact. The present research work bridges the gap and investigates the response of flax, hemp and jute fabric reinforced polypropylene composites subjected to high velocity impacts by standard fragment simulating projectiles (FSPs) [8].

2. Materials

The polypropylene sheet roll of areal density about 525.6 g m^{-2} was supplied by Japan GMT Co. Ltd. The sheet was 33 cm wide and 0.5 mm thick and was used as matrix in the processing of the fabric composites.

The linen fabric was purchased from Libeco.Lagae, Meulebeke, Belgium while the hemp fabric was obtained from HNF Handels GMBH, Germany. Jute fabric was sourced from Champdany Industries Limited, Calcutta, India.

The parameters of the fabrics used are as shown in Table 1. All the fabrics were plain woven and in loom-state (i.e. not dyed and not finished).

3. Experimental procedure

3.1. Composite plates

The flax, hemp and jute plain woven natural fibre reinforced polypropylene composite panels were processed at 46% fibre volume fraction by compressing layers of fabric and polypropylene sheet stacking between the hot platens of a compression moulding press. The platens were electrically heated to a temperature of 190 °C at a pressure of 6.4 bar (0.64 MPa) applied on the material. Cooling of the sample was carried out under pressure between the cold platens of the hydraulic press. The composite specimens were cut to 30×30 cm^2 dimensions.

Table 1
Parameters of the woven fabrics

	Flax woven fabric	Hemp woven fabric	Jute woven fabric
Areal density (g m^{-2})	280	366	336
Ends (cm)	10	7	8
Picks (cm)	10	7	8

3.2. Composite/steel hybrids

Composite/mild steel hybrids were prepared in order to investigate the effect of incorporating thin mild steel plates on the V_{50} and failure of the composite materials under ballistic impact. The composite test specimens are as shown in Table 1. The tensile properties of the mild steel plates are presented in Table 2.

The steel used as facing and backing to the composites was a commercial grade of mild steel plate 0.8 and 1.5 mm thick having a tensile yield stress of 167.7 MPa and a high ductility of 35.3% (see Table 3). Their areal densities were about 6.3 and 11.8 kg m^{-2} respectively.

The surfaces of the steel plates and the composites were sanded with a variable speed orbital sander to increase their surface roughness (this enhances the surface contacts leading to improved adhesion) and cleaned (degreased) with acetone. Though modified polypropylene could have resulted in a better bond between the composite and steel, it was not used in the processing of the plain composites and the composite/mild steel hybrids for ballistic tests since a strong fibre–matrix bond may cause reduction of the impact properties.

The steel plates were bonded to the composites with Araldite® 2011 glue manufactured by Ciba Speciality Chemicals Holding Inc. The glue was prepared in the laboratory by mixing 10 parts of Epoxy resin adhesive

Table 2
Composite and hybrid samples for ballistic testing

Sample	Sample code	Thickness (mm)	Areal density (kg m^{-2})
Flax composite	F26	12.9	14.5
Flax steel faced hybrid	F26S	14.4	26.3
Flax steel faced and backed hybrid	SF26S	14.5	26.7
Hemp composite	H12	6.9	7.8
Hemp composite	H18	10.1	11.4
Hemp composite	H22	12.5	13.5
Hemp composite	H24	13.0	13.9
Hemp steel faced hybrid	H24S	14.3	26.4
Hemp steel faced and backed hybrid	SH24S	14.9	27.4
Jute composite	J26	12.9	13.7
Jute steel faced hybrid	J26S	14.6	25.6
Jute steel faced and backed hybrid	SJ26S	14.8	26.3

Table 3
Tensile properties of the mild steel plates

	Tensile modulus (GPa)	Yield stress (MPa)	Maximum stress (MPa)	Maximum technical strain (%)
Mean	210.5	167.71	283.7	35.31
Std. dev.	11.3	3.12	6.4	1.71