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# On the ballistic impact response of microbraid reinforced polymer composites

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ABSTRACT

This paper presents the behaviour of microbraid reinforced polymer composites (mBRPC) subjected to impact loading conditions. Ballistic impact tests were performed by firing 7.94 mm steel balls onto composites reinforced with microbraids having different architectures, braid angles and of different materials (Kevlar® and Dyneema®). Two high speed cameras were employed to record the impact events. Experimental results revealed an improvement in the ballistic limit, of up to 19.5% for certain types of mBPRC, with respect to composites made with unidirectional fibres. Visual inspection of the impacted laminates revealed similar deformation mechanisms for composites reinforced with microbraids having different architectures and of different material. The slippage of the impactor through the layers of the laminates could have had detrimentally affected the ballistic properties of the manufactured composites. Modifications in the arrangement of the reinforcing phase are needed to fully exploit the potential of the microbraids in polymeric structures.



## 1. Introduction

High performance polymeric fibres, such as ultra high molecular weight polyethylene (Dyneema®, Spectra®), aramids (Kevlar®, Twaron®), LCP (Vectran®) and PBO (Zylon®) are widely exploited in applications in which high levels of energy absorption and protection are required. Dry fibres are mainly used in the construction of ropes, lines and nets, fabrics composed of such fibres are used in high performance textiles and vests, whilst impregnated fibre or fabric systems in hard components for ballistic applications and containment, for example. It has been demonstrated that tailored yarns can be developed by braiding fibres (for example [1–7]). It has also been demonstrated in [7] that the tensile properties of certain types of fibres can be enhanced by braiding; typically the tensile strength, strain to failure and energy absorption can be modified by braiding. There is sparse documentation in the open literature on the behaviour, under ballistic impact conditions, of braid reinforced polymer composites. Haijun et al. [8] investigated the ballistic properties of triaxial braided composites by firing titanium alloy cylindrical projectiles and blade-shape projectiles with the same mass of 17.5 g. Composites were manufactured using flattened $0 \pm 60^\circ$ triaxial carbon braid tubes and epoxy resin via an RTM process. The manufactured laminates were 10 mm thick, from which 100 mm × 100 mm impact test coupons were cut. The ballistic limit of the braided composites were above 195 m/s and 207 m/s when impacted with flat cylinders and blade-like projectiles, respectively. Triaxial braided composites showed a higher ballistic limit and smaller damaged area with respect to satin woven composites having approximately the same areal density and fibre volume fraction, when tested under the same impact conditions. Roberts et al. [9] performed ballistic impact tests to investigate the response of 2D triaxial braided composites. An extensive series of impact tests were conducted on braided composite plates, of dimension 610 mm x 610 mm and with a nominal thickness of 3.2 mm, and braided reinforced half-rings specimens, which replicate the shape of fan cases for jet engines. Composites were manufactured using 6 layers of carbon triaxial braids having a bias angle of $0 \pm 60^\circ$ and epoxy resin via RTM and impacted at different speeds using soft gelatine projectiles. Fracture propagated along the bias fibre direction. However, the damage area was very localised around the impact point and no delaminations were observed. The penetration threshold was determined to be $155 \pm 5$ m/s and $135 \pm 3$ m/s for the flat plates and the half-ring specimens, respectively. The authors highlighted the importance of performing impact tests on specimens reflecting their actual shape design. This is to highlight characteristic features which otherwise could be missed using different geometries. Bienienda

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and Cheng [10] performed impact tests on triaxial braided reinforced composites with different bias angles. The materials and manufacturing method were the same as [9]. They noted that the damage pattern and velocity penetration threshold depended on the braid architecture. Composites having 0 ± 45° bias fibres have been shown to have the best ballistic performances with respect to those having fibre orientation 0 ± 60°. However, the axial fibre content of the former specimens had twice the fibre content in axial direction with respect to the latter.

To the authors best knowledge, no information is available in the open literature on the ballistic impact response of polymer composites reinforced with high performance microbraids. It has been shown in our previous study [7] that the mechanical performance of polymer composites reinforced with microbraids can be superior with respect to those made of unidirectional fibres in terms of energy absorption, tensile strength and strain to failure. In this paper, the ballistic performance of sixteen different types of microbraid reinforced polymer composites (mBRPC) are experimentally investigated through a series of impact tests. Results are compared with those obtained from testing conventional cross-ply laminates made of unidirectional fibres (having similar areal density and fibre volume fraction, and manufactured via the same technique), deemed as the baselines.

## 2. Materials, manufacture and testing method

### 2.1. Materials

Three high performance polymeric fibres were used in this investigation, namely Dyneema®SK75, Dyneema®SK76 and Kevlar®49. Physical properties of these materials, provided by the manufacturers [11–13], are listed in Table 1. Fibre diameters were determined by analysis of images from scanning electron microscope (SEM).

**Table 1**
Physical properties of the investigated materials [11–13].

| Yarns | Density (g/cm$^3$) | Linear density (dtex) | Single fibre diameter (μm) | No. filaments/yarn |
|---|---|---|---|---|
| Dyneema®SK75 | 0.97 | 220 | 17.28 ± 0.58 (112) | 100 |
| Dyneema®SK76 | 0.97 | 1760 | 17.44 ± 0.36 (98) | 780 |
| Kevlar®49 | 1.44 | 215 | 12.14 ± 0.41 (108) | 130 |
| Kevlar®49 | 1.44 | 1580 | 12.06 ± 0.44 (97) | 955 |
| Matrix | Density (g/cm$^3$) | | Areal Density (g/m$^2$) | Thickness (μm) |
| Rayofix TP | 0.932 | | 71.63 | 75 |

### 2.2. Manufacture

The manufacture and mechanical characterisation of dry microbraids and mBRPC used in this work were described in detail in [7], and it can briefly summarised as follow.

Different types of microbraids were manufactured using the yarns having the smaller linear density by a Herzog RU2-16/80 vertical braiding machine. Microbraids having different bias angles $\alpha$ and architectures were created by varying the cogwheel ratio and the number of working carriers, respectively. Core-filled microbraids were produced by overbraiding a unidirectional (UD) yarn with eight bias yarns of the same material in a diamond fashion. The diameter of the microbraids and their bias angles were determined by analysis of SEM images. The microbraid linear densities were determined according to the ASTM D1577-07 [14] Standard Test Methods for Linear Density of Textile Fibers. The investigated braid patterns are sketched in Fig. 1. Physical properties of the manufactured microbraids are listed in Table 2.

The tensile properties of dry microbraids were assessed through a series of tensile tests performed on specimens with a gauge length of 250 mm and tested at a strain rate of 0.01 s$^{-1}$.

The dry microbraids were aligned in a unidirectional fashion over a spinning plate via a robotised filament winding system and subsequently consolidated into prepregs using a thermoplastic resin film (Rayofix TP) via a hot-pressing technique. Then, the prepregs were manual assembled in a cross-ply laminate and hot-pressed into the final laminate form.

In order to directly compare the properties of the mBRPC with cross-ply laminates made with UD fibres and manufactured via the same route, composites having similar areal density and fibre volume fraction were manufactured using the coarser yarns. Physical properties of the mBRPC tested under ballistic impact conditions are presented in Table 3.

Given below is the nomenclature or classification used for the microbraids and mBRPC. A generic dry microbraid and mBRPC will belong to the class "w X Y Z", where:

- w will be the physical form of the material, in particular "b" stands for dry microbraids and "c" for microbraid reinforced composites;
- X will be the material of the microbraid, in particular D for Dyneema®SK75 and K for Kevlar®49;
- Y will denote the braid angle, where A < B < C ...;
- Z will represent the braiding architecture, in particular "1" for diamond 1/1, "2" for regular 2/2 and "H" for core-filled microbraids;
- Composites cXUD were manufactured using UD yarns;

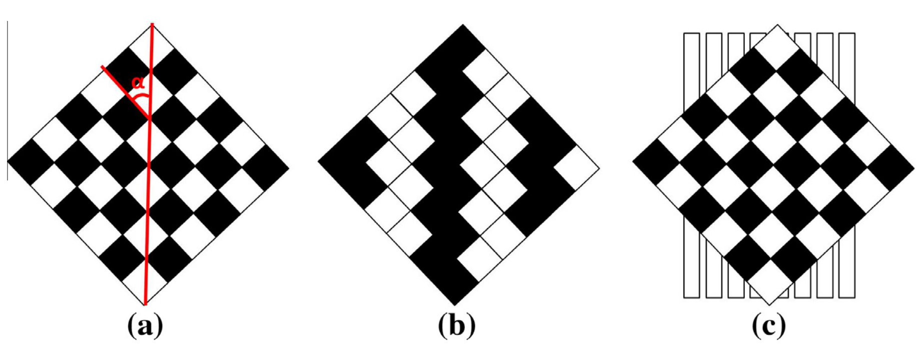


**Fig. 1.** Investigated braid patterns: (a) diamond (1/1); (b) regular (2/2); (c) diamond with UD core (1/1 + core).