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Experimental investigation of the mechanical properties of dry microbraids and microbraid reinforced polymer composites

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ABSTRACT

This paper presents a comprehensive series of mechanical tests performed on two high performance polymeric fibres, microbraids and microbraid reinforced polymer composites (mBRPC). Quasi-static tests were performed on the raw materials and the effect of different gauge lengths and strain rates investigated. Then, microbraids having sub-millimetre diameters were manufactured from the raw yarns using a Maypole-type braiding machine. The effects of different braid architectures, number of braided yarns and bias angles were assessed through a series of tensile tests on dry microbraids. A novel and unique manufacturing method of aligning microbraids in a unidirectional fashion via robotised filament winding was developed to manufacture microbraid reinforced polymer composites (mBRPC). Quasi-static tensile tests performed on mBRPC showed improved mechanical properties, for certain architectures, with respect to those noted for unidirectional composites manufactured using same technique.

1. Introduction

High performance polymeric fibres are extensively used to make personal protective textiles and as reinforcing phase in polymer composite materials. Thanks to their high tenacity and toughness, low elongation at break as well as the ability to dissipate shock waves over large areas in a short amount of time, they are very suitable for applications where impact resistance and energy absorption capabilities are of vital importance.

Braiding is the process of interlacing three or more threads in such a way that they cross one other and are laid together at a bias angle. In theory, any material, in the form of strips or filaments, can be braided to produce linear, flat, tubular or solid forms. Braids can be produced as 2D, in flat or tubular form, and as 3D structures. The former contains only two sets of strands through the thickness, and axial yarns in case of triaxial braids, whereas the latter have several strands through the thickness. Over the past decades, braided reinforced polymer composites (BRPC) have been increasingly used in high performance structures due to their outstanding properties such as damage and impact resistance, high delamination resistance, greater through-the-thickness reinforcement and lesser notch sensitivity with respect to unidirectional (UD) and woven reinforced composites. Moreover, the investment and labour costs can be minimised due to the inexpensive machinery, high production rate and level of automation which the braiding technique offers [1–3].

Brunnschweiler [4,5] and subsequently Ko and Pastore [1] discussed in details the principles of braid manufacture and the use of braided fabrics as reinforcing phase within engineering structures. Recently, Carey and Ayranci [6] reviewed the published studies on 2D braided composites outlining advantages and disadvantages of this technique, different characterisation methods currently employed and applications of BRPC in the composite industry. Omeroglu [7] investigated the properties of dry 2D polypropylene (PP) braided ropes by varying the braid architecture, fibre linear density and take-up speed. Regular braids showed higher tenacity, modulus and yield strength with respect to diamond braids. The higher the take-up speed, the higher the aforementioned properties. Moreover, the Young's modulus and tenacity were noted to be higher for braids made of finer PP strands. Harte and Fleck [8] studied the tensile behaviour of glass–epoxy braided tubes having different braid angles. Although they noted a lower Young's modulus and tensile strength with increasing fibre bias angle, the strain to failure and the energy absorption increased for the same angles. Moreover, the failure mechanism of the tubular composites changed from brittle to ductile with increasing the fibre bias angle from 23° to 55°.

Usually, braided reinforced composites are produced by stacking many braided slit sleeves or flattened tubes in order to create

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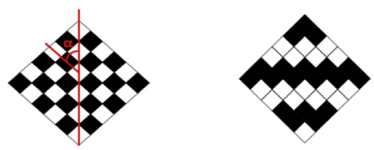
Table 1
Physical properties of the investigated materials.

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
Kevlar®49	1.44	215	12.14 ± 0.41 (108)	130
Matrix	Density (g/cm^3)	Areal density (g/m^2)	Thickness (μm)	
Rayofix TP	0.932	71.63	75	



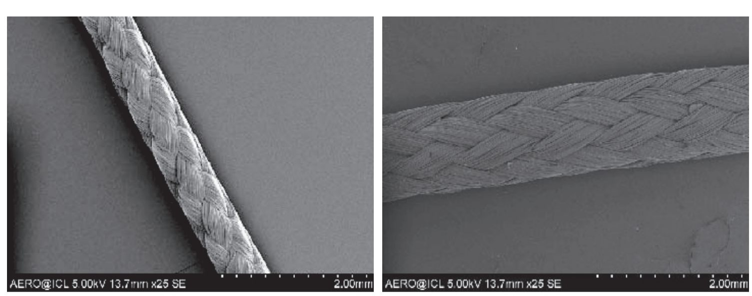
(a) (b)

Fig. 1. Braid patterns: (a) Diamond 1/1; (b) Regular 2/2.

layers of desired orientation and thickness. For instance, Kelkar et al. [9] investigated the tensile and fatigue properties of epoxy-reinforced laminates made from 2/2 carbon braid slit sleeves and flattened braided tubes. As the fibre bias angle increased, the ultimate tensile strength and Young's modulus of the composites decreased whilst the endurance increased with respect to increasing braid angle. Fouinneteau and Pickett [10] studied the properties of carbon and glass braided composites made from flattened braided tubes and thermoset epoxy resin. For the same braid angle, they noted a higher tensile strength and strain to failure for the carbon braided composites. However, premature failure occurred locally in the region close to the specimen tabbed area, regardless of the material. The tensile strength and strain to failure of the carbon braided composites were detrimentally affected by as much as 27.5% and 39.1%, respectively, when the specimens had cut edges. Falzon and Herszberg [11] found a reduction of 20% in the tensile strength of braided composite laminates with respect to UD ones. They attributed this reduction to fibre damage while braiding.

To the authors' best knowledge, there are very few studies in the open literature in which the mechanical behaviour of braids and microbraids made of high performance polymeric fibres has been experimentally assessed (for example, in [7,12–14]). Moreover, there are no existing studies of microbraids directly used as reinforcing phase in composite materials. Sakaguchi et al. [15] and Fujihara et al. [16] claim the manufacture of microbraid reinforced composites. They braided matrix filaments over high performance fibres. The manufactured braids were filament wound over a steel plate and then cured. However, after melting the braided filaments, a composite material reinforced by unidirectional fibres would appear. Moreover, a linear density of the used microbraids above 10,000 dtex (the microbraid's diameter and linear density was not stated in either paper) would not be truly applicable to a "micro" range of dimensions.

The main aim of this work is to investigate the potential use of 2D microbraids as the primary constituent in high performance textiles and as the reinforcing phase within polymer composite systems. In this contest, the present investigation is concerned with the mechanical characterisation of high performance polymeric yarns and 2D microbraids. A comprehensive series of



(a) (b)

Fig. 2. SEM images of two different microbraids: (a) bDA1, (b) bKA2.

Table 2
Physical properties of the manufactured microbraids.

bID	Material	Number of braided yarns	Braid pattern	Braid diameter (mm)	Braid angle (°)	Linear density (dtex)
bDA1	Dyneema®SK75	8	1/1	0.86 ± 0.02	15.0 ± 0.8	1816 ± 54
bDB1	Dyneema®SK75	8	1/1	0.85 ± 0.02	19.3 ± 1.3	1996 ± 48
bDC1	Dyneema®SK75	8	1/1	0.67 ± 0.01	28.7 ± 1.1	2238 ± 61
bDA2	Dyneema®SK75	16	2/2	1.34 ± 0.01	22.0 ± 0.6	3878 ± 59
bDB2	Dyneema®SK75	16	2/2	1.2 ± 0.01	31.9 ± 1.5	4419 ± 66
bDC2	Dyneema®SK75	16	2/2	0.97 ± 0.01	43.9 ± 0.7	5066 ± 48
bKA1	Kevlar®49	8	1/1	0.84 ± 0.02	13.1 ± 0.7	1890 ± 57
bKB1	Kevlar®49	8	1/1	0.84 ± 0.01	23.9 ± 0.5	1934 ± 64
bKC1	Kevlar®49	8	1/1	0.69 ± 0.02	39.1 ± 0.9	2026 ± 53
bKA2	Kevlar®49	16	2/2	1.25 ± 0.01	21.7 ± 1.6	3920 ± 62
bKB2	Kevlar®49	16	2/2	1.12 ± 0.01	28.6 ± 1.4	4117 ± 49
bKC2	Kevlar®49	16	2/2	0.98 ± 0.01	40.1 ± 1.1	4478 ± 69