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Experimental, analytical and numerical analysis to investigate the tensile behaviour of hemp fibre yarns

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ABSTRACT

Natural fibre reinforced composites are emerging as the alternative of synthetic composite materials in several applications due to their limited recyclability and biodegradability. In this study, the tensile behaviour of hemp yarns detached from taffeta and serge fabrics were investigated. Experimental analysis was performed to characterize the crimped yarn properties. Analytical analysis was carried out in order to model and predict the mechanical behaviour of hemp fibre yarns under tensile loading. An inverse optimization approach was also adapted to optimize the mechanical properties of the yarns numerically.

1. Introduction

Synthetic composite materials like glass and carbon fibre based composites are widely used in many industries like automotive, aerospace, sports, construction, etc. Demand of synthetic raw materials is rapidly increasing and thereby the price is increasing rapidly. Moreover, they have some significant drawbacks such as limited recyclability, renewability, biodegradability, etc., which are some of the highest priorities in the modern world industries [1–3]. One of the best solution to solve these issues is widening of natural fibre composites utilization in different engineering application which are cheap, light weight, low energy consumption, recyclable, renewable and biodegradable compared to synthetic fibre composites. They also have good impact strength which produces good energy absorption and thereby they can obtain a good accident behaviour. The less sharp edges and low risk in the tooling of the material compared to synthetic fibre composite also increase the demand of natural fibre composites in automotive and aerospace industries [4,5].

Hemp is an annual plant and the production of hemp plant is increasing steadily every year. The price of highly utilized natural fibre flax is increased highly in past years due to the high demand of the natural fibres in the composite materials industry. Hemp fibre is comparatively cheap and hemp fibre straw is produced in a so-called 'total fibre line' where the production of random non-aligned technical fibres together. On the other hand, short and long fibre was separated in the production process of flax fibre which make hemp fibre ahead in the availability of raw material and attracts hemp fibres in automotive or aerospace industry where the production speed is very essential [6,7]. There are plenty of studies related to hemp fibre [8–11] and few studies on hemp fibre yarns [12–14]. But all theses studies were not concentrated on the virgin yarns and the crimped yarns were not considered. It is interesting to study the mechanical properties of hemp yarns with crimps which are directly detached from the woven fabrics.

The aim of this study is to investigate the tensile behaviour of hemp yarns by experimental, analytical and numerical analysis. Initially, the specimens will be prepared with yarns which are directly detached from taffeta and serge (warp and weft) fabrics and tensile tests will be performed to characterize the crimped yarn mechanical properties. Analytical analysis will be carried out in order to predict the mechanical behaviour of hemp fibre yarns under tensile loading. An inverse optimization approach will be adapted to optimize the mechanical properties of the yarns numerically. The proposed model will be also validated in tensile loading of yarns in different orientations.

2. Experimental analysis

2.1. Material and method

Hemp fibre woven fabrics used in this study were provided by 'Naturallement-chanvre enterprise' which is 100% hemp that is cultivated in Europe. Pure hemp yarns were produced by grinding, mechanical carding and spinning of textile hemp stem (length of 4/5 m) and weaved into fabrics [15]. Hemp yarns detached from the warp and weft directions of taffeta (plain) and serge (2 × 1) (twill) hemp woven

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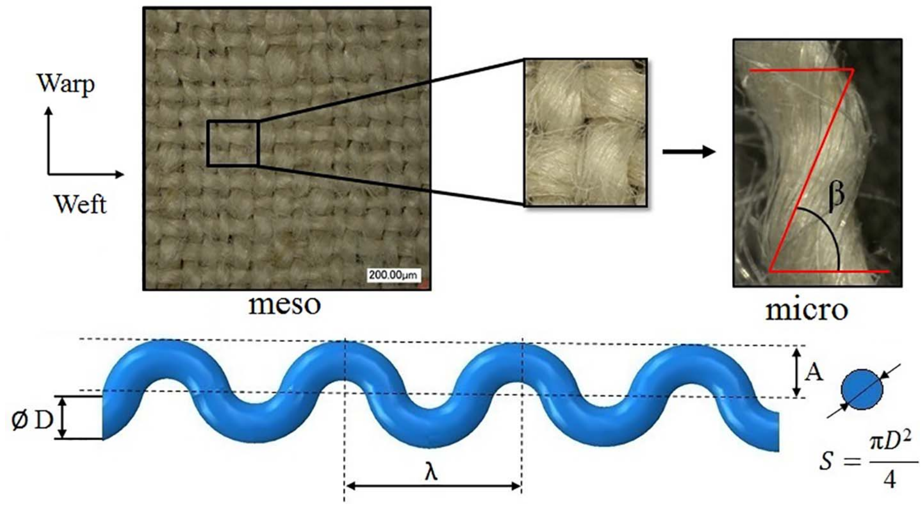

Fig. 1. Hemp fabrics and yarns geometry.

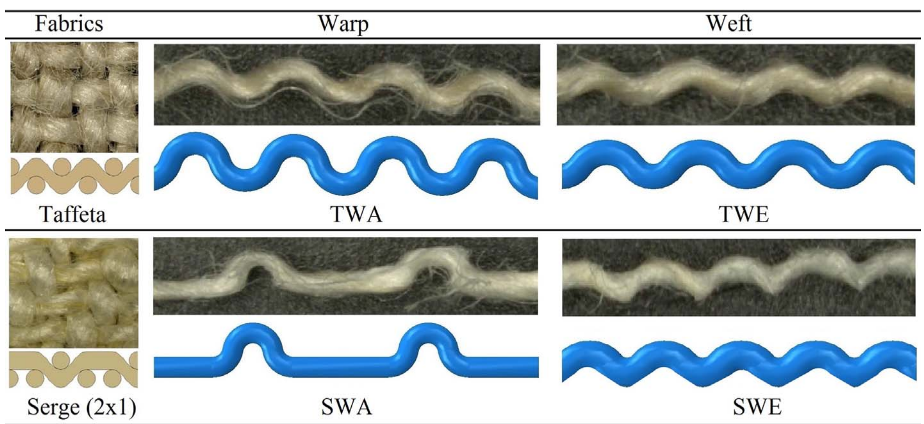

Fig. 2. Experimental yarn,shapes and CAD of yarns of taffeta and serge (2 × 1).

Table 1
Characterization of hemp yarns.

Fabrics	Yarn	Diameter (D) μm	Amplitude (A) mm	Wavelength (λ) mm	Z-twist (β) deg	Crimp %
Taffeta	TWA	356.35 ± 35.96	0.468 ± 0.010	1.55 ± 0.24	16.64 ± 1.43	20.5 ± 0.55
	TWE	356.35 ± 35.96	0.320 ± 0.009	1.32 ± 0.42	16.64 ± 1.43	8.35 ± 0.25
Serge (2x1)	SWA	361.12 ± 28.85	0.4775 ± 0.059	3.05 ± 0.36	22.27 ± 2.56	10.25 ± 0.30
	SWE	361.12 ± 28.85	0.4125 ± 0.081	1.66 ± 0.21	22.27 ± 2.56	5.75 ± 0.20

fabrics with an areal density of 290 g/m^2 and 380 g/m^2 respectively (Fig. 1) were investigated to study their mechanical behaviour. Some geometrical parameters such as diameters (D), amplitude (A), wavelength (λ), Z-twist angle (β), crimp percentage (%) of yarns from taffeta and serge fabrics (warp and weft) (Fig. 2) were measured using Keyence VH-Z20R digital microscope and calculated (Table 1). Due to the non–homogeneous section of yarn along the length, the parameters were measured in different sections and average values were calculated [16].

Hemp fibre yarn specimens for tensile tests were prepared using a paper frame technique using thick paper and yarn specimens were attached using glue. Several specimens were prepared for each yarn with a gauge length L_0 = 30 mm (Fig. 3). Tensile tests were performed with a static load under a cross-head speed V = 1 mm/min at ambient temperature using INSTRON 4411 machine.

2.2. Tensile behaviour of hemp yarns

The force versus displacement curves for the initial orientation of yarn α = 0° from taffeta (T) and serge (S) yarns were obtained (Fig. 4). In this curves, taffeta yarns were able to withstand a maximum load of 6–8 N and serge yarns withstand a maximum load of 16–19 N. This difference is due to the variation in the initial diameter of the yarns, quality of fibres, crimp percentage, twist angle and also due to difference in retting, season, culture of plant etc. which are some of the drawbacks of natural fibres in small scale [17].