INFLUENCE OF THE NUMBER OF LAYER ON MECHANICAL PROPERTIES OF 3D WARP INTERLOCK FABRIC MADE WITH FLAX ROVING

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ABSTRACT

From 1000 Tex flax rovings, five 3D warp interlock structures, based on a plain weave diagram, were woven on a prototype weaving machine developed at GEMTEX laboratory. The aim of this study is to compare these 3D warp interlock fabrics with different number of layers (3, 5, 7, 11 and 23). Results show that thicknesses, areal densities, weft densities, binding warp crimp and maximum tensile load in weft direction are related to the number of layers.

Key Words: NATURAL FIBRE, 3D WARP INTERLOCK FABRIC, MECHANICAL PROPERTIES

1. INTRODUCTION

Preform architectures and fibre ratio have a preponderant role on the composite material's mechanical properties and failure mode [1] [2]. Natural fibres, as reinforcement of composites materials, show better results in densities and vibration damping than man-made fibres [3]. Flax fibre is the strongest natural fibre [4]. Mostly composed of cellulose, the Young's modulus of flax fibre borders on 70 GPa. Consequently, the use of flax fibre as reinforcement structure is nowadays common in automotive, sporting equipment and biomedical applications [3] [5] [6]. If natural fibres are mostly used to produce non-woven fabric, 2D woven, braid or non-crimp fabric [4] [7], few studies develop 3D structures. Layers can be linked by yarns, stitching, tufting or Z-pinning [8] [9]. A 3D warp interlock fabric is a multi-layer fabric in which layers are linked together by binding warp yarns. Boussu et al. [2] defined 3D warp interlock fabric with many parameters as:

$$X_1 - X_2\ N\ Y_1 - Y_2\ \{Binding\}$$

with

X_1	Type of angle of binding, O (Orthogonal) or A (Angle)
X_1	Type of depth of the binding warp yarn, L (layer to layer) or T (through the thickness)
N	Number of layer of weft yarn
X_1	Step of the binding warp yarn
X_1	Depth of the binding warp yarn
$Binding$	Weave diagram shaped by binding warp yarn

This kind of structure, which allows disposing yarn on the z-direction, is behind through thickness strength composite. Delamination resistance and impact damage tolerance are also increased [10]. 3D warp interlock fabrics can be woven both on dobby or Jacquard loom. To ensure the quality of the fabric, processes must be slowed down, caused by its complexity [11].

2. METHODS

Flax rovings, from Depestele Group, are lightly twisted on a Twistec TW 4/300. 40 tpm was applied to the roving. This low level of twist gives to the roving the cohesion for the weaving step and lightly affect the permeability to the future matrix. Tensile test, at the scale of the roving, is performed according to NF ISO 2062. Linear density and twist level are checked according to NF G07-316 and NF ISO 2061.
A dobby loom, dedicated to prototyping [12], has been used to produce five 3D warp interlock fabrics with different numbers of layer. Warp yarns are produced onto 24 beams, and for each evolution of warp yarn, one warp beam is associated. This combination beam-frame allows flexibility and to ensure to weave all the five structures one after the others. The pattern formed by binding warp yarn is based on a plain weave diagram. The final warp density, after warping and drawing in, is 6 yarns/cm. Both warp and weft yarns are 1000 Tex flax roving. 3D schematic representations are given in Figure 1. On this figure, binding warp yarn are represented in light blue, stuffer warp yarn in dark blue and weft yarn in red. In the case of these structures linked through the thickness ($X_2 = T$), the number of layer and the depth of binding is the same ($N = Y_2$).

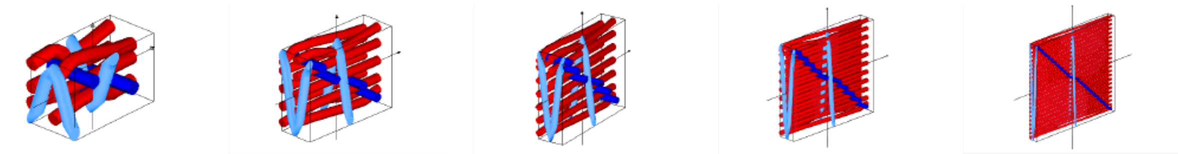

Figure 1: 3D schematic representation of the five 3D warp interlock fabric

After weaving, the thicknesses, and the areal densities of the manufacturing fabrics are determined according to the NF ISO 4603 and NF ISO 12127 standards, respectively. Densities in both directions of the fabrics are checked according to the NF ISO 4602. Crimps are determined according to the ISO 7211-3 standard and separately for each depth of stuffer warp yarns and weft yarns. Tensile tests, performed on the dry state, have been realized according to the ISO 13934 standard on a Instron machine. A coefficient of determination, marked R^2, is a statistic test which measures of the quality of the prediction of a linear regression. A coefficient of determination close to 1, expresses a linear relation between the parameters.

3. RESULTS

For a twisting value of 40 tpm, the linear density of the roving increases and reaches 1057.0 ± 41.3 Tex. Table 1 displays weft densities (yarn/cm), and the crimps (%) of binding warp yarns and weft yarns. Warp densities are all close to the density defined during the drawing in, as 6 yarns/cm. Weft densities are controlled during the weaving. Results show that the density is different for all the fabric but is about 2 columns/cm for all the fabric. The number of yarns by columns is given in the description of the 3D warp interlock fabric. The weft density depends on the number of yarns per layer, which is the number of layers (R^2 =0.996). About the crimp, binding warp yarns show the highest crimp than other yarns in the fabric. This kind of yarn, which links the layer together, goes through the thickness. The required length of yarn depends on the thickness of the fabrics. Consequently, binding warp crimp is proportional to the number of layers (R^2 =0.962). Stuffer warp yarns, which are under tension between the beams and the comb, present the lowest crimp. The weft yarn crimp is slowly higher than the stuffer warp yarn crimp because the weft is inserted during the weaving without tensile.

Table 1: Mesured densities and crimps of the five fabrics

Structure	Weft density (yarns/cm)	Binding yarn crimp (%)	Weft crimp (%)
O-T 3 1-3 {Plain}	5.2 ± 0.2	22.3 ± 4.1	2.7 ± 0.7
O-T 5 1-5 {Plain}	8.1 ± 0.2	31.7 ± 6.9	1.0 ± 1.2
O-T 7 1-7 {Plain}	12.2 ± 0.2	48.3 ± 10.1	1.3 ± 1.1
O-T 11 1-11 {Plain}	25.0 ± 0.0	138.8 ± 25.9	3.3 ± 0.8
O-T 23 1-23 {Plain}	54.6 ± 0.0	237.2 ± 12.5	2.3 ± 1.2

Table 2 displays the thicknesses and areal densities of the five structures. The thickness depends on the number of yarns in a column. The more wefts in a column are added in a column, thicker the fabric is. The thickness is also proportional to number of layers (R^2=0.994). As the warp density is fixed for the all fabrics, the areal density only depends on the number of weft yarns inserted by columns. Consequently, areal density is also proportional to the number of layer (R^2 =0.994). This highlighting process allows weaving fabrics thicker than 15 mm and heavier than 5 kg/m².

Table 2: Thicknesses and areal densities of the five fabrics

Structure	Thickness (mm)	Areal density (kg/m²)
O-T 3 1-3 {Plain}	5.1 ± 0.3	1.25 ± 0.03
O-T 5 1-5 {Plain}	5.4 ± 0.3	1.58 ± 0.01
O-T 7 1-7 {Plain}	6.8 ± 0.4	2.04 ± 0.02
O-T 11 1-11 {Plain}	10.0 ± 0.4	3.49 ± 0.04
O-T 23 1-23 {Plain}	18.0 ± 1.0	6.35 ± 0.12

Figure 2 displays representative curve of tensile test for the five structures, in weft direction. The five curves can be divided in three sections. The first section corresponds with a non-linear part. During this section, weft yarn crimp is absorbed. This section is identical to the five curves, because the weft crimp is the same for all the structures (cf. Table 1). During the second section (linear part until the maximum load), weft yarns deforms themselves until reaching the breaking value of the woven structure. Maximum load is reached during this section. Maximum load depends on the number of yarn in the sample. This number of yarn is related to the weft density. Consequently, maximum load is proportional to the number of layer (R^2 =0.969). During the third section, load decreases, without fluctuations, which express the rupture of all weft yarns at the same time.

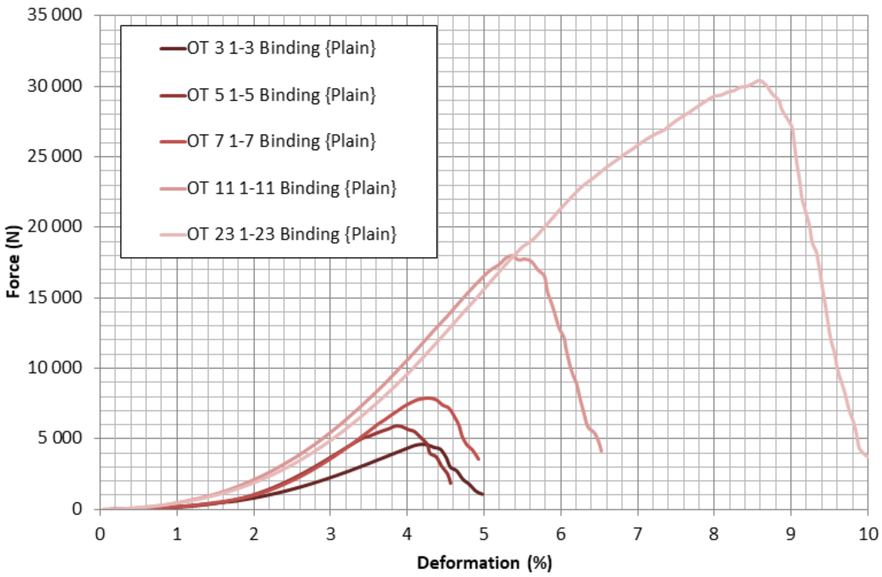

Figure 2

Results can also be interpreted thank to the work. Figure 3 displays work versus the number of layer. Work is calculated by integrating the force-displacement curve from zero to the displacement at maximum load. Results show a linearity between the work and the number of layer of the structure (R^2 =0.978).

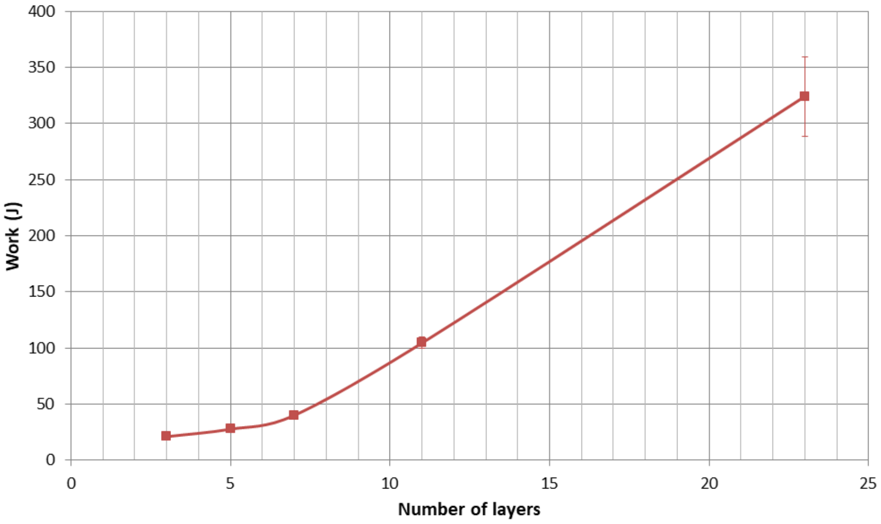

Figure 3

4. CONCLUSION

From 1000 Tex, five 3D warp interlock with different numbers of layers have been woven on a prototyping machine. The combination of beam and frame allows weaving the structures with different number of layers based only one drawing in. Characterization shows that binding warp crimp, weft density, thickness, and areal density is function of the number of layers. Tensile properties in weft direction, are related to the density of the sample, and consequently to the number of layers. Moreover, structural and mechanical behaviour of dry fabric was linked by characterization. This study demonstrates the feasibility of this type of architecture with natural bast fibres. In a short future, this study will be the finishing touch to composites behaviour made with this 3D warp interlock fabrics.

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