NEW SOLUTIONS IN THE PRODUCTION OF COMPOSITES - MECHANICAL PROPERTIES OF COMPOSITES REINFORCED WITH TECHNICAL EMBROIDERY AND WOVEN FABRIC MADE OF FLAX FIBERS

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ABSTRACT

The main purpose of the article is to present the new possibilities of producing natural fiber composite reinforcement. In this case, a computer embroidery machine by ZSK type JCZA 0109-550 was used. A technical embroidery with a stitch length of 2 mm was made on the machine. The embroidery was made of flax roving with a linear density of 400 tex. The woven fabric was made of the same flax roving as the embroidery, with a surface mass of 400 g/m^2. Composites were then produced from the technical embroidery and woven fabric using the infusion method with epoxy resin. The individual configurations differed from each other in the orientation of the roving in the embroidery samples. Samples for tensile strength and tensile elongation tests consisted of 4 layers, while samples for the DCB test consisted of 6 layers, with the addition of a separating foil between the 3rd and 4th layer. Composites were then subjected to strength tests - tensile strength, tensile elongation and DCB test (Double Cantilever Beam test), on the INSTRON machine. During the action of force along the direction of the fibers, composites containing technical embroidery as reinforcement were characterized by higher strength than composites containing woven fabric as reinforcement. Additionally, embroidery is a barrier to the formation of interlayer cracks. Technical embroidery is made on the basis of Tailored Fiber Placement (TFP) technology. This technology allows optimizing the mechanical values of the composite reinforcement.

KEYWORDS

Technical embroidery; Flax fibres; Composites; Mechanical properties; Tailored fiber placement.

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INTRODUCTION

The composite production technology is faced with the challenge of minimizing the resulting production waste. This idea is reflected in the Tailored Fiber Placement (TFP) method, which includes technical embroidery. It consists in placing the medium on the surface of a flat textile product in any direction of the X and Y axes. The embroidery can also reach a certain dimension in the direction of the Z axis by overlapping embroidery layers. The height of the stacking sequence can be up to 8 mm. The amount of production waste in this kind of preforms is minimized thanks to the production of a precisely designed pattern, without the need to cut an element from a larger surface. The main waste generated during the production of technical embroidery is non-woven fabric or other types of backing on which the embroidery was made. The amount of this waste can be reduced by using an appropriate hoop size [1]. Electric wires, optics, glass or carbon fibers, electrically conductive yarns and others are used to perform technical embroidery increasing the performances of the final application [2].

Technical embroidery is now mainly used in textronics, to create heating mats (e.g., in car seats), connecting sensors, shielding, conductive interconnections and interfaces. Technical embroidery can be also used to create antennas or as an alternative to solid copper to make a coil for unilateral nuclear magnetic resonance systems. [3–7].

In the case of the following tests, linen roving was used to make the samples. The use of this material in the production of composites has increased significantly since 2012 [8]. Composites containing natural fibers exhibit a high level of vibration damping and a low weight [9-10].

The characteristics of the reinforcement itself, used for the production of composites, i.e. the arrangement of the fibers, the type of weave, the linear density of the yarn, the density of the yarn arrangement in the fabric, have an impact on the out-plane fracture toughness of the composite. Z-pinning, fiber stitching and the use of 3D fabrics can enhance these properties. The disadvantage of these methods is a reduction in tensile strength, a reduction in the modulus of elasticity and fatigue performance [11-18]. The answer to these disadvantages is the use of technical embroidery technology. As proven in previous studies, the use of technical embroidery for the production of composite reinforcements improves strength of composites, compared to ones containing woven fabric as reinforcement. [19-20].

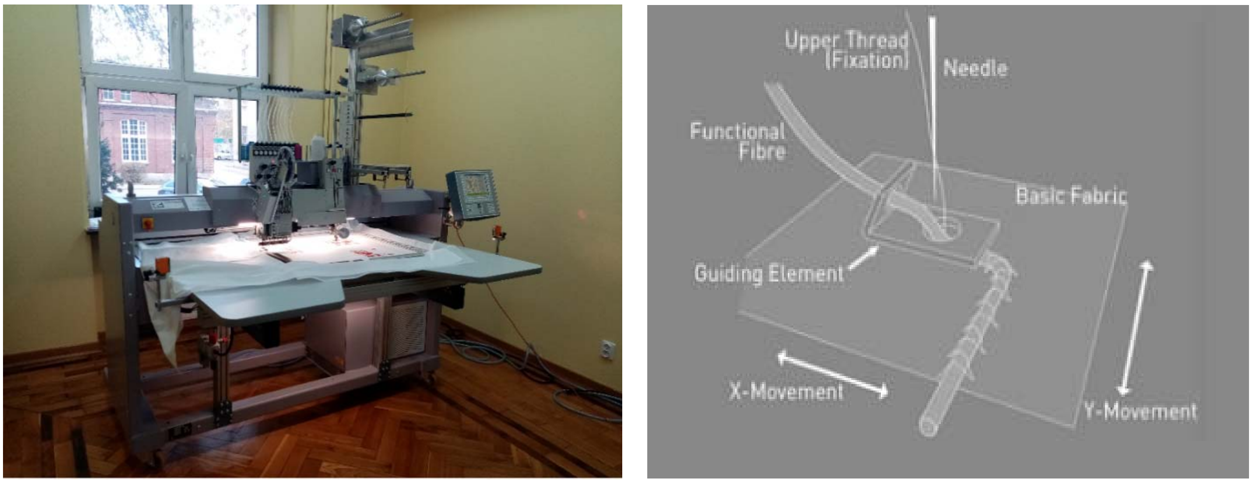
EXPERIMENTAL

Materials

The GiS BasePack version 10 program was used to make the embroidery pattern. The embroidery were made on a ZSK embroidery machine, type JCZA 0109-550 (Figure 1a). This machine is equipped with a W-type head designed for technical embroidery. The rule of the operation of this head is shown in Figure 1b.

The subject of the research was composites containing two types of flax fiber reinforcements: technical embroidery and woven fabric. The embroidery was made with the use of Safilin linen roving with a linear weight of 400 tex. Gunold monofilament with a linear weight of 11 tex was used to make the fastening zig-zag stitch. The length of the zig-zag stitch was 2 mm and the width was 1.2 mm. In the case of manufacturing samples for the DCB test, an induced crack was created, leaving an area without stitching yarns and placing a plastic foil after making three layers of embroidery, and then three more layers of embroidery were placed. The tensile strength of the flax roving was 7,37 cN/tex and the tensile elongation was 1,69 %. Embroidery was made on a base of cotton fabric with an area weight of 280 g/m2 and non-woven fabric with an area weight of 35 g/m^2.The flax woven fabric was made from the same roving used for the embroidery. The surface mass of the fabric was 400 g/m^2. All reinforcement samples were then impregnated with the following resin system: SR GreenPoxy 33 epoxy resin and SD4772 hardener at a ratio of 100:32. Composite samples were made using the infusion method.

In total, the following variants for tensile strength and tensile elongation tests were prepared:



(a) (b)

Figure 1. (a) - ZSK embroidery machine, type JCZA 0109-550 [own source]; (b) - Scheme of laying the medium on the base [21].

Table 1. Configurations for tensile strength and tensile elongation tests.

Reinforcement	technical embroidery	technical embroidery	technical embroidery	woven fabric	woven fabric
Fiber orientation	0°	±45°	90°	0/90°	±45°

For interlaminar fracture toughness test, the following variants were prepared:

Table 2. Configurations for interlaminar fracture toughness test.

Reinforcement	technical embroidery	woven fabric
Fiber orientation	0°	0/90°

Methods

The tensile strength and tensile elongation tests were performed according to the PN-EN ISO 527-4 standard [22]. The samples were stretched at a constant speed until the breakage was attained. The relative elongation at maximum force, maximum force, breaking force and relative elongation at break values were collected during the testing. The tests were carried out using a 100 kN load cell on an INSTRON universal testing machine, model 8032. A 50 mm gauge length extensometer was used to measure the specimens' elongation. The test parameters were as follows: grips distance: 100 mm; speed of testing: 1 mm/min; sample size 250×25×3.5 mm; number of samples: 5 of each variant. The test findings are presented in the graph of tensile stress as a function of elongation.

Mode I interlaminar fracture toughness test (DCB - Double Cantilever Beam Test) was carried out based on the ASTM D 5528-01 standard [23]. The test consisted of opening by the crosshead movement, until the samples broke. During stretching, the values of the load (P) and delamination length (δ) were recorded. The test was stopped when the delaminating crack spreads to at least 45 mm from the apex of the initial fracture or when the crack growth at delamination was from 3 to 5 mm. The tests were conducted on a INSTRON universal testing machine with a 50 kN load cell. The velocity of the test was 5 mm/min. The test parameters were as follows: grips distance 0 mm; speed of testing: 5 mm/min; sample size: 160×25×5 mm; number of samples: 5 of each variant.

Both tests were made on the INSTRON universal testing machine, presented in Figure 2a and 2b.

(a)

(b)

Figure 2a and 2b. 2a - Tensile strength and tensile elongation test; 2b - Interlaminar fracture toughness test [own source].

RESULTS AND DISCUSSION

Tensile strength and tensile elongation tests

Tensile strength and tensile elongation values are presented on the Figure 3.

As shown in Figure 3, based on performed tests, it can be concluded that the tensile strength is greatest when a force is applied along the fibers (0° variant). In these variants, most fibers are involved in the stretching process. The composite with technical embroidery placed at an angle of 0° to the acting force showed by far the highest tensile strength (142 MPa). Its strength was almost twice as high as that of a composite containing woven fabric as reinforcement, although the woven fabric contains two systems of threads in its structure - weft and warp. The strength of the composite with embroidery placed at an angle of 90° to the acting force as reinforcement turned out to be by far the smallest. In this case, none of the roving fibers is involved in the stretching process. Only the resin and the base on which the embroidery was made is responsible for the strength of the sample. In the case of samples ±45°, the strength of the embroidery variants and the woven fabric were on a similar level.

However, the failure strain in ±45° woven samples is twice than in ±45° embroidery samples. This is due to the fact that the roving in the woven fabric structure has a significant crimp, which increases the elongation. In addition, when a tensile force is applied, shear and bending forces first act in the composite. The fibers in the composite first have to travel from the ±45° direction to the 0° direction - then they are subjected to a tensile force. In the case of composites containing embroidery as reinforcement, the 0° system showed a greater elongation than the 90° system. This is due to the tensile force along the axis of the fibers.

Interlaminar fracture toughness

In Figure 4 it can be clearly seen that the composite containing woven fabric as reinforcement showed a greater degree of delamination. For about the first 2 millimeters of opening the sample, both variants showed almost identical characteristics. On the other hand, at about 4 mm opening, the composite containing embroidery as reinforcement cracks. The embroidery is therefore a barrier to delamination of the sample. The composite containing the fabric as reinforcement was delaminated - it broke when it opened about 35 mm.

In the case of samples containing embroidery as reinforcement, the type of the crack formed was also influenced by the sample manufacturing technology itself. The roving layers themselves could be divided in half, while one of the parts always contained fabric, fleece and a backing thread - which increased the strength of this layer. The crack always occurred in the layer not containing these systems.

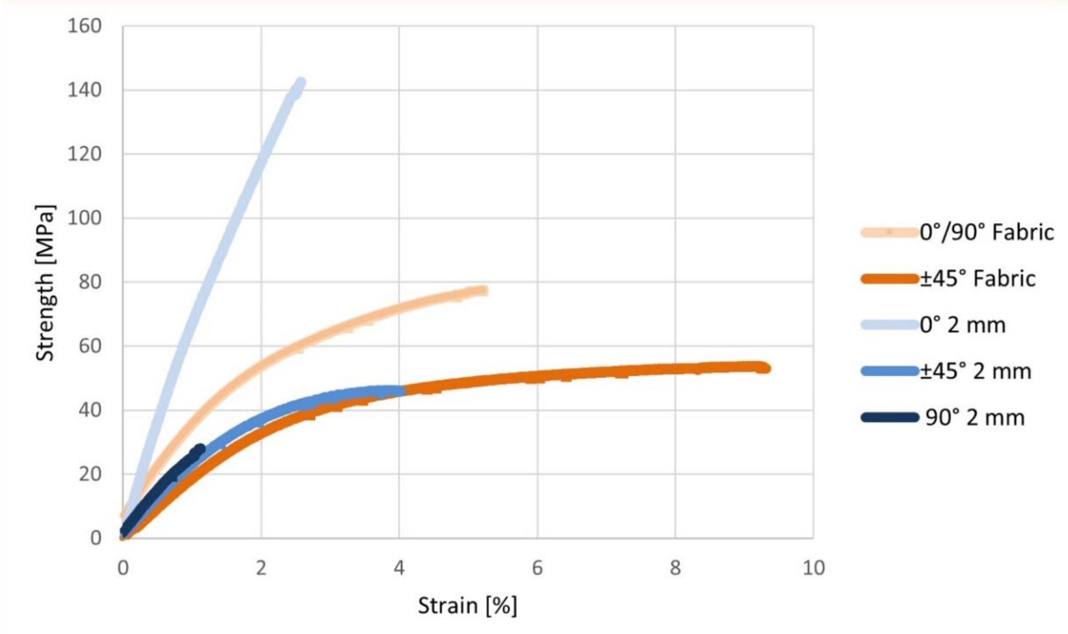


Figure 3. Tensile strength and tensile elongation of produced samples.

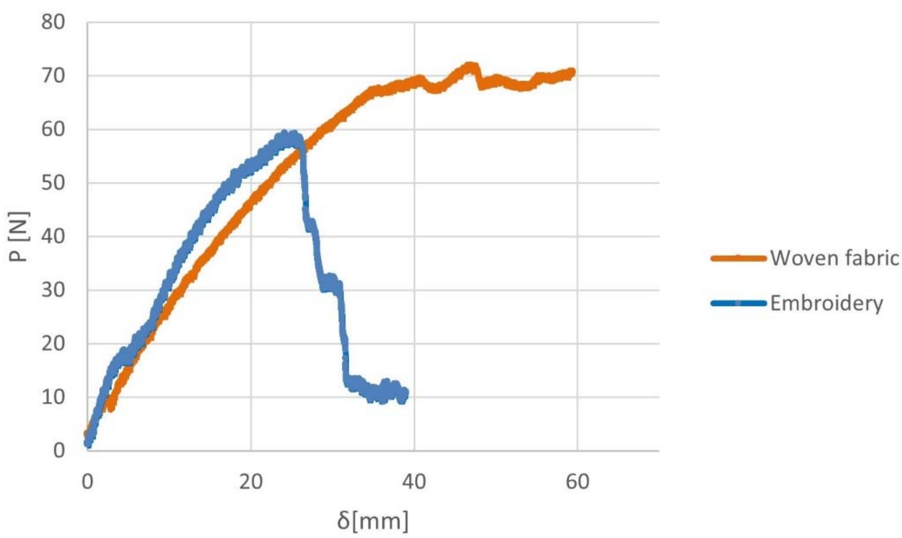


Figure 4. Interlaminar fracture toughness of produced samples.

CONCLUSIONS

The use of embroidery as a reinforcement of a composite increases its tensile strength in the direction of fiber stretching, compared to a composite containing woven fabric as reinforcement. Whereas composites containing woven fabric as reinforcement, in each variant of fiber arrangement, showed higher strain.

As a result of the conducted tests, it can be concluded that the vertical stitching of embroidery prevents the delamination of the composite, because the composite with technical embroidery as reinforcement does not undergo the opening process during the test.

It is possible to adjust the strength properties of the composite, containing technical embroidery as reinforcement, to the expected loads affecting the finished product. This fact should be considered when designing finished products with embroidered patterns as reinforcement. In the case of beam systems, it is recommended to arrange the strengthening medium in the direction of the acting tensile forces.

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