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COMPARISON OF COMPOSITES CONTAINING TECHNICAL EMBROIDERY AND WOVEN FABRIC AS REINFORCEMENT

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ABSTRACT

The following research present a comparison of the strength values of composites containing two types of reinforcements: technical embroidery and woven fabric. Both types of reinforcements were made of flax roving with a linear mass of 400 tex. The technical embroidery was made on a computerized embroidery machine ZSK, type JCZA 0109-550. The use of technical embroidery technology is in line with the idea of sustainable development by minimizing waste generated in the production of composite reinforcements. Tensile strength and tensile elongation tests were carried out. As a result of the conducted research, it was proved that the composite containing the technical embroidery as the reinforcement showed higher tensile strength in the longitudinal direction, compared to the composite containing the fabric as the reinforcement. On the other hand, the composite containing fabric as a reinforcement showed a greater elongation.

KEYWORDS

Technical embroidery, composite, woven fabric, sustainable development.

INTRODUCTION

The world is currently facing the risk of a climate catastrophe. For this reason, new technological solutions are sought, enabling the reduction of production waste and the recycling of already manufactured products. Currently, the most commonly used materials for the production of composite reinforcements are flat textiles (woven fabrics, knitted fabrics, non-wovens) and 3D structures (loosely arranged fibers). In the use of composites, fabric are characterized by low fatigue and stiffness resistance characteristics when applied to shear stress. Composites made of flat structures are weaker and tensed to delaminations, compared to 3D structures [1]. It was decided to investigate the strength properties of composites containing technical embroidery made of flax fibers as reinforcement. The technology of technical embroidery is in line with the principle of sustainable development. Main principle of technical embroidery is to create a precisely planned shape - the resulting waste from the cutouts is therefore reduced to a minimum. Automation of the embroidery process gives full control over the execution of the pattern and the consumption of raw materials. A computer embroidery machine uses a technique known as Tailored Fiber Placement (TFP). For this reason, the research presented below focuses on the use of technical embroidery as a reinforcement for composites [2].

Currently, technical embroidery is mainly used in textronics. Sensors, digital components or electronics are attached to flat textiles. Technical embroidery is also used as antennae, connecting in between electronic components and textile sensors, as well as coils for unilateral nuclear magnetic resonance system as an alternative to a solid copper [3–5].

In the following studies, flax was used to strengthen the composite. Compared to other natural fibers, flax is the most ecological in cultivation, while at the same time having the highest strength properties. Additionally, the cultivation of flax is pollution-free, and the waste generated during fiber processing is non-toxic and harmless. Therefore, it is an excellent alternative in the production of composites, compared to the previously used synthetic or glass fibers. Moreover, the mechanical properties of composites containing natural fibers are comparable to those of composites made of glass fibers [6–12].

Technical embroidery used to create composite preforms is new and innovative issue. There are few publications on this topic [13,14], at the same time technical embroidery is not used in the industry to create reinforcements for composites. Therefore it was decided to take on this research topic.

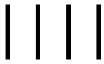
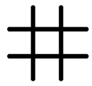
MATERIALS AND METHODS

The subject of the research are composites containing two types of reinforcements:

- Technical embroidery, stitch length 2 mm, made of flax fibers,
- Flax woven fabric.

Each reinforcement system consisted of four layers and was made in three variants: 0°, 90° and ±45°. The sample for 0° and 90° woven fabrics is the same. Individual variants of samples are presented in Table 1.

Table 1. Types of produced reinforcements

VARIANT	NAME	ORIENTATION OF ROVING IN EACH LAYER	AREAL MASS OF DRY SAMPLE
Embroidery 0º 2mm	0º 2mm		1424 g/m^2
Embroidery 90º 2mm	90º 2mm		1515 g/m^2
Embroidery ±45º 2mm	±45º 2mm		1387 g/m^2
Fabric 0º/90º	fabric 0º/90º		1802 g/m2
Fabric ±45º	fabric ±45º		1867 g/m^2

The embroidery was made on a computerized embroidery machine ZSK type JCZA 0109-550 using Safilin flax roving with a linear weight of 400 tex. It was attached with a Gunold polyamide monofilament with a linear mass of 11 tex. The tensile strength of the flax roving was 7.37 cN/tex and the tensile elongation was 1.69%. The embroidery was made on a base of a cotton woven fabric with an area weight of 280 g/m^2 and non-woven fabric with an area weight of 35 g/m^2. The use of both fabric and non-woven fabric for embroidery is necessary to eliminate wrinkling of the sample and for the correct execution of the embroidery.

The woven fabric was made of the same roving as embroidery. Its area weight was 400 g/m^2. Plain weave with a density of 6 threads/cm. Composites were then made by infusion method. The vacuum of 1 Bar was maintained until the composite cured (minimum 4 hours). The mixture consisted of the epoxy resin SR GreenPoxy 33 and the hardener SD4772 in the ratio 100:32.

The produced samples were then subjected to strength tests - tensile strength and tensile elongation. Tests were carried out based on the PN-EN ISO 527-4 standard. The test consisted of stretching the prepared samples with a constant speed until they break. During stretching, the values of relative elongation at maximum force, values of maximum force, values of breaking force and values of relative elongation at break were recorded. The tests were conducted on INSTRON universal testing machine with a 50 kN load cell. The velocity of the test was 1mm/min. The elongation of the specimens was measured with the extensometer with a gauge length of 50 mm. Test's parameters were as follow: grips distance: 100 mm; speed of testing: 1 mm/min; sample size: 250 mm × 25 mm × 3.5 mm; number of samples: 5 of each variant. Test results were given in the form of a numerical data and a graph of tensile stress as a function of elongation.

RESULTS AND DISCUSSION

Both composites with embroidery and fabric as reinforcement showed the highest tensile strength when subjected to a force of 0° (Figure 1). Then the most fibers are involved in the stretching process. Due to the presence of two thread arrangement perpendicular to each other in the fabric, tensile strength values at 0° and 90° are the same. Among the 0° variants, the composite with embroidery as reinforcement showed higher tensile strength. The fabric has two arrangement of threads, intertwined at right angles along the entire length of the sample. Theoretically, with four layers of fabric, 8 threads contribute to the stretching, but in fact half of them are at an angle of 90° to the applied tensile force, so they do not carry a significant amount of loads. For this reason, the sample containing the fabric showed almost two times lower strength than the samples containing the technical embroidery as reinforcement. At the same time, it was the cause of a greater elongation of the composite containing the fabric as reinforcement.

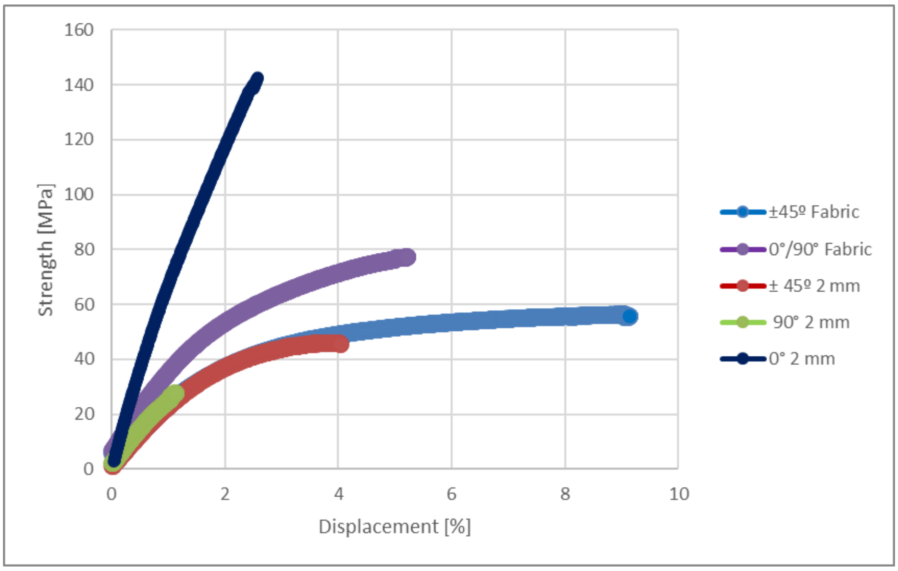


Figure 1. Strength and elongation of the produced composites.

When considering systems arranged at an angle of 90 ° to the acting force, the composite containing the fabric showed a much higher strength. The reason for this is the structure of the fabric itself - half of threads were placed at an angle of 0° to the tensile force, so they were responsible for the strength of the sample. In the case of embroidery, there was no such situation, all rovings were arranged at an angle of 90° to the acting force. In such cases, the embroidery monofilament is the only one that transfers the loads of the tensile force - the tensile forces act perpendicularly to the direction of the flax fibers, and microcracks occur in the resin itself. Therefore, composites containing 90° embroidery showed the lowest tensile strength of all tested variants. The technology of embroidery production allows it to be placed in a carefully planned direction. If directions of the action of forces on the finished product are known, it is possible to arrange the fibers in such a way that they are at the most 0° angle to the acting force, and thus the composite will be as strong as possible.

In the case of arranging the roving at an angle of ±45°, the sample containing fabric as reinforcement showed higher tensile strength. Both reinforcements consisted of four layers, but the fabric contained two thread arrangement in one layer, so the number of load-bearing threads was twice as high. Despite this, the sample with embroidery was only 20% less durable.

In the case of a force acting at an angle of ±45°, more fibers are involved in the tensile (compared to the force acting at an angle of 90°) and shear forces occur. Therefore, the 2 mm embroidery strength value was almost twice as high for the force acting at an angle of ±45° than for the 90° force.

For each direction of fiber orientation, composites containing fabric as reinforcement showed higher elongation values than composites containing embroidery (Figure 2). In the 0° variant, the composite with the fabric showed about twice the elongation than the composite containing the embroidery. In the 90° variant, this difference was almost five times, and in the ±45° system - two and a half times. This was due to the construction of the fabric itself. It contained two sets of threads perpendicular to each other, so more fibers participated in the stretching process. There is a roving in the fabric, which, during stretching, causes the threads to straighten out, showing greater elongation. However, due to the fact that the threads are wavy, the tensile force acting along the fibers does not spread to shear and bending forces, which results in lower strength.

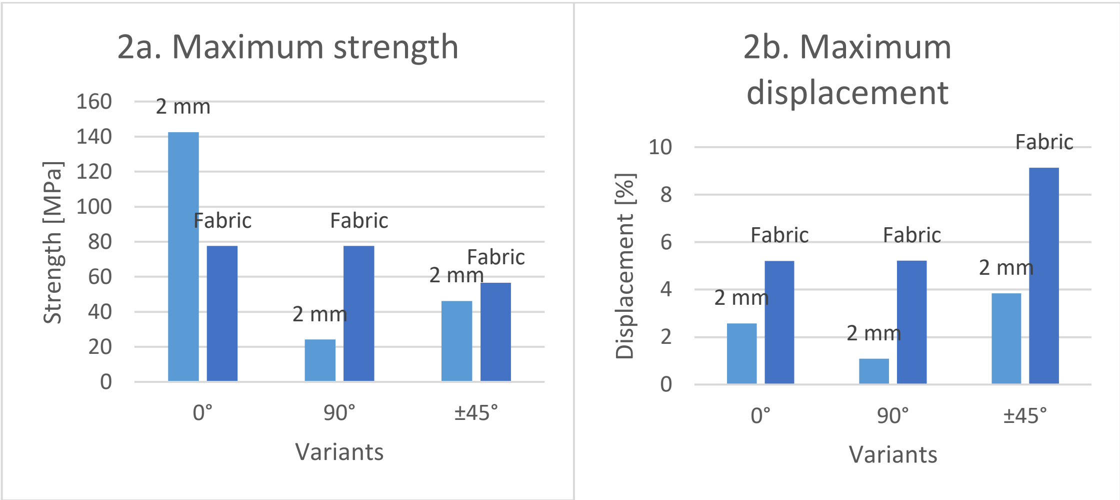


Figure 2. a Strength and b elongation of the produced composites.

The embroidered 0° samples showed a greater elongation than the 90° samples. This is due to the tensile force along the axis of the fibers, while the strength values of the fabric are the same for both 0° and 90°.

The ±45° embroidery system showed about 60% greater elongation than the 0° embroidery variant. This is because when a tensile force is applied, the composite first experiences shear and bending forces. The fibers in the composite tend from ±45° to 0° direction - then they are subjected to a tensile force.

CONCLUSION

1. In the case of a force acting in the longitudinal direction towards the fibers, the use of embroidery as a reinforcement of a composite increases its tensile strength, compared to a composite containing fabric as reinforcement.
2. Composites containing woven fabric as reinforcement, in each variant of fiber arrangement, showed higher elongation.
3. Despite the twice as many threads in each layer of the woven fabric as compared to embroidery, the composite containing fabric as a reinforcement showed only 20% higher tensile strength when applied at an angle of ±45°. This means that the use of embroidery as a reinforcement of the composite has a positive effect on increasing its strength.

4. The technology of technical embroidery allows it to be placed on a surface at any angle. Therefore, it is possible to adjust the strength properties of the composite, containing technical embroidery as reinforcement, to the expected loads affecting the finished product.

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