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“Mechanical properties of composites containing technical embroidery made of flax fibers as reinforcement”

Abstract

In the context of sustainable development, the production of composites can pose a significant challenge due to the materials used and the complexity of the manufacturing processes. Synthetic resins and glass or carbon fibers are often used in composite production, which have a negative impact on the environment, both during the production process and at the end of the product's life. One way to improve sustainability in composite production is to use environmentally friendly materials, such as natural plant fibers (e.g., flax, hemp), which have a less negative impact on the natural environment. Additionally, composite production should consider recycling and recovery of secondary raw materials to reduce waste and minimize environmental impact. For this reason, the use of composites reinforced with natural fibers has increased in industry in recent years. The author of this work, wishing to combine ecological aspects with innovation, decided to investigate the mechanical properties of composites reinforced with technical embroidery made from flax fibers. The choice of flax as a reinforcing material is due to its renewability, biodegradability, and low environmental impact compared to traditional synthetic fibers. Traditional methods of reinforcing composites rely on the use of continuous fibers or fabrics. This work proposes an innovative approach, involving the use of technical embroidery made from flax fibers as a reinforcing element. Technical embroidery, due to its complex structure, can provide composites with unique properties, such as increased bending resistance or better stress distribution. The aim of the study is to assess the influence of various parameters of technical embroidery, such as stitch length and fiber orientation, on the mechanical properties of the resulting composites.

The research focused on technical embroideries made on a ZSK JCZA 0109-550 computer embroidery machine equipped with a type W head. Embroidery designs were created

in the dedicated GiS BasePack 10 software, which allowed for obtaining extremely accurate and repeatable patterns.

In this work, a analysis of the mechanical properties of composites containing technical embroidery made of flax fibers as reinforcement was carried out. In order to verify the usefulness of such composites, traditional composites containing woven fabric as reinforcement were also tested. In order to systematize the structure of the work, individual chapters correspond to the successive stages of the research work. These studies followed one another sequentially, and the results obtained led to the next stages. The structure of the work reflects this hierarchy in the form of subsequent chapters. The diagram below presents a schematic of the research conducted.

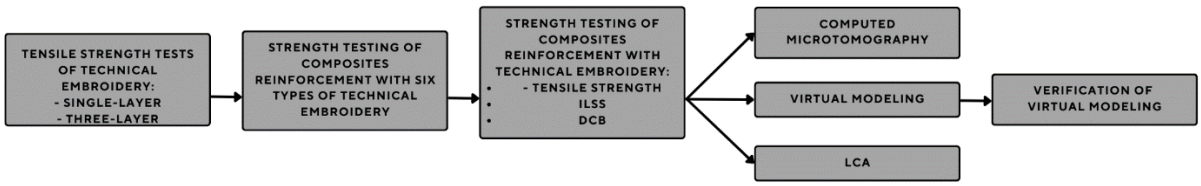

Figure 1. Scheme of research work included in the thesis

In the initial studies, the focus was on the mechanical properties of the embroidery itself. Tests were conducted on three different orientations of the flax roving the embroidery: 0°, 90°, and 45°. The strength of the embroidery consisting of three layers (with the following orientation: 0°, 90°, 0°) was also evaluated, as well as the strength of the flax roving and the securing thread forming the embroidery.

Based on the results of the strength tests of the embroidery, seven-layer embroidery variants were developed, from which composites were then produced using the infusion method. The individual variants differed from each other in the direction of the roving in the individual layers. The resulting composites were tested for tensile strength and elongation at break. These studies are described in chapter 4.

The next stage of the research involved a comprehensive study of composites reinforced with technical flax fiber embroidery. The focus was on determining the optimal stitch length. Therefore, embroidery samples with stitch lengths of 2, 4, and 8 mm were designed and produced. Composites were then produced using the infusion method. For comparison, composites reinforced with woven fabric and unidirectional fiber arrangement were also tested and subjected to a series of strength tests:

- tensile strength and elongation at break,

- bending strength: ILSS - Interlaminar Shear Strength
- fracture toughness: DCB - Mode I Interlaminar Fracture Toughness

Due to noticeable differences in the strength of composites containing technical embroidery made of flax fibers with varying stitch lengths, it was decided to investigate the structure of the embroidery using computer microtomography. This study aimed to detect micro-damages in the structure of the embroidery that occurred during the embroidery process.

The conducted strength tests of composites containing technical embroidery were used to create basic numerical models using the finite element method. An experiment plan consisting of 15 embroidery variants was then developed. All variants were modeled using the finite element method in the "Patran-Nastran" MSC Software.

Selected numerical models were verified. Samples were produced and then subjected to tensile strength and elongation at break tests. The obtained results were compared with numerical models.

The final element of the work was to conduct a Life Cycle Assessment (LCA) to compare the environmental impact of a sample product made of technical embroidery with a product made of woven fabric.