Call: HORIZON-WIDERA-2021-ACCESS-03/Twinning

Project SustDesignTex (GA No. 101079009), title: „Sustainable Industrial Design of Textile Structures for Composites" funded by the European Union

Deliverable Report

SUSTainable industrial DESIGN of TEXtile structures for composites (SustDesignTex)

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Deliverable Title	**D3.1 (**Methodical Recommendations for business and science on processing of textile structures***)***
Deliverable Lead:	RWTH Aachen University (ITA)
Related Work Package:	*WP3:Design and processing of technical textile structures for the reinforcement composites: CSA measures*
Related Task(s):	*Task 3.1: Short-term staff exchanges and expert visits for acquaintance with know-how and acquisition of experience in the field of processing of technical textile structures (M12-M21)*
Author(s):	*Rebecca Emmerich*
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Abstract:	*The main objective of deliverable 3.1 was to transfer knowledge from the Institut für Textiltechnik of RWTH Aachen University (ITA) on processing of textile technologies to the LODZ University of Technology researchers. Under the given work packages and deliverable, TUL researchers visited the institute for two months between the 08th of January and the 8th of March 2024 for a short-term staff exchange. Five researchers visited ITA for the complete period and conducted research within the context of five different micro-projects.* *As part of this deliverable, an immense knowledge exchange was obtained between the consortium partner universities and this know-how will be also shared to the business and science communities of Lodz University of Technology as part of task 3.2 and task 3.3 under the work package 3 in the form of training and workshops.*

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1 Methodical Recommendations for business and science on the processing of textile structures

Textile preforms play a crucial role in the manufacturing of composite materials, serving as the structural foundation upon which the composite matrix is applied. These preforms are designed to impart specific mechanical properties and structural integrity to the final composite product. Various types of textile preforms are utilized, including nonwoven, woven fabrics, braided structures, and wound structures, each offering distinct advantages in terms of strength, flexibility, and formability.

Nonwoven consists of randomly oriented fibers bonded together to form a cohesive structure. They are commonly used in applications requiring isotropic properties and are produced through processes such as needle punching or thermal bonding. Woven fabrics are characterized by interlaced yarns arranged in a regular pattern, providing excellent strength and stiffness properties in specific directions. Braided structures involve the intertwining of yarns in a helical pattern, resulting in a tubular or flat preform with exceptional damage tolerance and impact resistance. Braided preforms can be produced using various braiding methods, including 2D and 3D braiding. Wound structures are formed by wrapping continuous filaments around a mandrel in a predetermined pattern. This method allows for precise control over fiber orientation and thickness, making it suitable for complex-shaped components and high-performance applications. These methods are mostly used for the high-volume production of technical textiles. When considering fully loadcase-optimized lightweight products, technical embroidery has emerged as a valuable technique in the production of preforms for composite materials. This method involves the precise placement of reinforcement fibers through automated stitching processes, allowing for customized fiber orientations and ply designs tailored to specific load requirements. Technical embroidery offers advantages such as enhanced structural integrity, improved load distribution, and reduced material waste compared to traditional lay-up methods. By strategically reinforcing critical areas with optimal fiber orientations, technical embroidery enables the creation of lightweight yet highly durable preforms that can withstand complex loading conditions encountered in various applications, including aerospace, automotive, and sports equipment [GVW19].

In the realm of composite materials, the choice of reinforcement fibers significantly shapes the mechanical attributes, longevity, and environmental footprint of the end product. There are currently three predominant types of reinforcement fibers: glass, carbon, and natural fibers.

Glass fibers, primarily comprising silica-based materials, are favoured for their cost-effectiveness, resistance to corrosion, and comparatively high strength-to-weight ratio. They find wide-ranging applications across industries such as automotive, aerospace, and construction, where characteristics like stiffness, impact resistance, and thermal insulation are imperative. Carbon fibers, derived from organic polymers like polyacrylonitrile (PAN) or pitch, boast remarkable strength, stiffness, and lightweight properties. These fibers excel in demanding scenarios necessitating high strength-to-weight ratios and fatigue resistance, notably in aerospace components, sporting goods, and high-performance automotive parts. In the context of the project SustDesignTex, natural fibers are the focus of the project materials. These fibers are being sourced from renewable reservoirs such as flax, hemp, jute, and bamboo. Due to a reduced environmental impact and biodegradability compared to man-made reinforcement fibers combined with favourable mechanical attributes, these fibers are progressively integrated into eco-conscious composites. Here, applications spanning from automotive interiors and furniture to packaging and construction are relevant [JEC21; LMA19]. To investigate different fiber types, in the project context, the focus is set on wool, flax, and hemp fibers for task 3.1. Depending on the chosen fiber type and the textile preform, different production methods can be chosen.

The processing of textile preforms into composite materials using duromere matrix systems typically involves techniques such as hand-layup, vacuum infusion, and resin transfer molding (RTM). Hand-layup involves manually placing the preform layers into a mold and impregnating them with resin. Vacuum infusion utilizes vacuum pressure to draw resin through the preform, ensuring complete impregnation and void-free consolidation. RTM involves injecting resin into a closed mold containing the preform under controlled pressure and temperature conditions, resulting in high-quality, void-free parts with excellent dimensional accuracy. Asset investment and the development of the production process are increasing along with the introduced methods. To enable an investigation of all different materials and preforms as infusion method the vacuum infusion has been chosen. Regarding the processing of thermoplastic matrix systems, a heat press was used to shape and combine fiber and matrix in the project context.

In order to investigate some combinations of materials, textile preforms, processing methods, and function integration, five micro-projects have been developed to enable a transfer of the edge-cutting knowledge present at ITA to TUL researchers.

Table 1: Overview on conducted micro-projects

#	*Name of Microproject*	*Researcher*
1	Design and implementation of a fire-resistant composite made of natural fibres dedicated to the aviation industry, taking into account the principles of sustainable development	Assoc. Prof. Marcin Barburski, Ph.D. D.Sc.
2	Design and implementation of technical embroidery using various types of fibers (primarily flax and wool) with different orientations of the roving for fireproof composite manufacturing	Agata Poniecka, PhD Candidate
3	Design and production of a fire-resistant composite made of natural fibers with built-in sensors dedicated to the aviation industry	Tsegaye Lemmi, PhD
4	Fabrication of layered composites made of nonwoven fabrics from natural fibers such as flax and PLA, giving them flame-retardant properties by wet application of flame-retardant	Assoc. Prof. Zbigniew Draczyński, Ph.D. D.Sc.
5	Preparation and preliminary assessment of selected parameters of textile structures for new, innovative materials for vehicle interiors	Emil Saryusz-Wolski, PhD

For microprojects one and three, the vacuum infusion technique was used. For projects two, four, and partially five, the hot pressing method has been used as a composite production method (see Fig. 1). For the production of high-quality parts with good mechanical properties, the coordination between the chosen process parameters and materials has to be chosen wisely. The process parameters of the preforms are partially dependent on the materials but also on their textile structures. As the advantages and disadvantages are presented in D 2.1, they also indicate what is important for high-quality parts from various preforms.

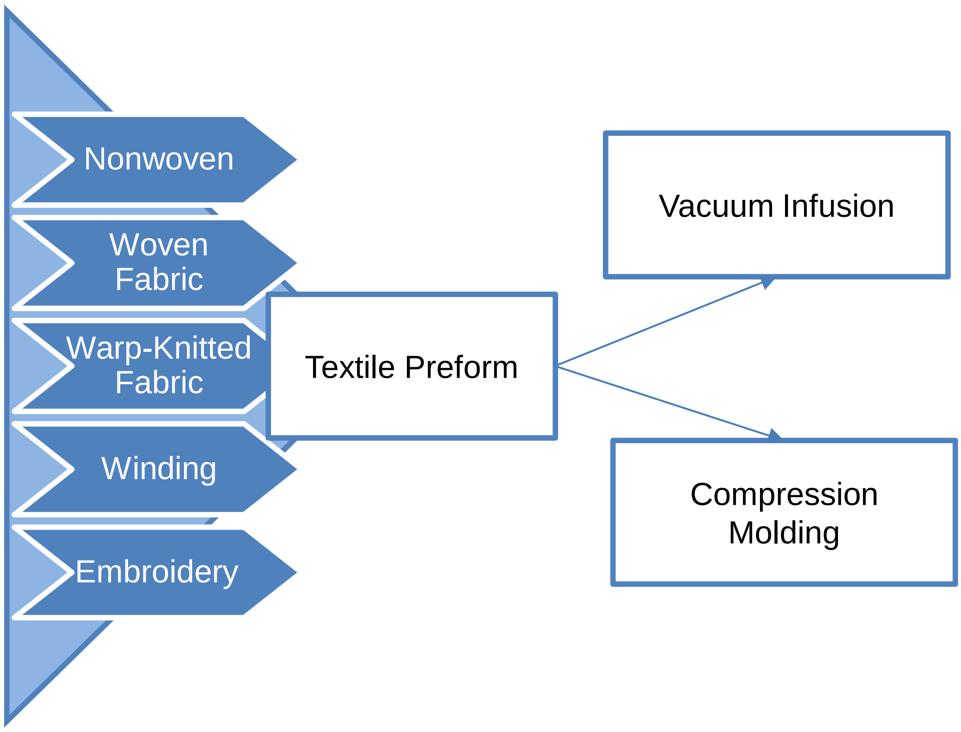

Fig. 1: Investigated Process routes in D3.1

In the following the preform production performed at ITA are presented. Here, experienced researchers from RWTH Aachen located at ITA have supervised the work of the TUL researchers and guided them during the production. The woven and warp-knitted fabrics have been produced at TUL and at HB.

Nonwoven production process

The process of preparing nonwoven fabrics from flax fibers involves several steps. Initially, flax fibers, with a length of 120 mm, are used without undergoing a drying process. These fibers are fed into a carding machine, where 330 grams of fibers are processed to create a web of parallel layered fibers. (see Fig. 2) The resulting structure is then entangled using a needle punching technique to form a felt-like material. Subsequently, the felt is cut into sheets measuring 20x25 cm². On average, the surface mass of the nonwoven fabrics obtained is 440 g/m². To impart flame retardancy, the nonwoven fabric samples are immersed in an aqueous flame retardant solution, ensuring homogeneous distribution through multiple imprints and re-immersions. Finally, the treated samples are dried in a chamber at 100 °C until a constant weight is achieved [Dra24].

Fig. 2: Carding machine (left), needle punching machine (center and right)

Embroidered Preform Production Process

The ITA Institute and the Technical University of Lodz (TUL) were equipped with similar embroidery machines to allow researchers to familiarise themselves with the operation of the new equipment. TUL has a ZSK JCZA 0109-550 embroidery machine, while ITA has a JCL 0100-585 embroidery machine from the same manufacturer. These machines have a W-shaped head, which allows placement of the selected substrate on the textile base in an X and Y-axis system. The embroidery variant was designed using GiS BasePack software version 10 with a 250 x 180 mm rectangular pattern. The research involved the design and implementation of industrial embroidery using wool fibres, resulting in four samples with specific parameters. Polyester nonwoven was used as stitching ground, 600 tex wool rovings are used as the reinforcement thread, and zig-zag stitching was done using PA monofilament (see Fig. **3** [PL24].

Wound preform

The initial plan to manufacture a braided fabric at the ITA laboratory during the short-term staff exchange visit of TUL researchers was altered based on the micro-project developed in response to the industry partner's identified problem. Instead of braiding technology, winding technology was incorporated to fabricate the demonstrator due to its suitability for the project's requirements. Samples produced using the winding method utilized flax roving with a linear mass of 600 tex and a roving density of 21 threads per 1 cm. TUL researchers, during their tenure at ITA, have been actively involved in developing a textile structure using winding technology, focusing on natural fibers for composite reinforcement. This shift in production methods demonstrates the adaptability and responsiveness of the research initiative to industry needs. The researchers remain committed to delivering a high-quality demonstrator that aligns with the revised technological approach and industry requirements. (see Fig. **3**) [PL24].

Fig. 3: Embroidered preform (left), wound preform (right)

Besides these classic textile and engineering approaches, one more design-based approach was investigated with the fifth microproject. Here, the engineers from ITA worked closely together with the designer from TUL, Emil Saryusz-Wolski. This research conducted at ITA RWTH in January-February 2024 focused on advancing previous work initiated in Borås concerning innovative materials for automotive interiors. The objective was to develop layered systems utilizing nonwovens as the core and filament-printed structures as surface finishes, potentially incorporating fabrics and knitted fabrics. With the growing interest in electric vehicles, automakers are investing more in research and development, creating opportunities for fiber suppliers to develop materials that enhance efficiency, comfort, and environmental sustainability in vehicle interiors. The research at ITA RWTH involved experimenting with direct printing on nonwoven sandwich structures, aiming to achieve free, real shaping of the third dimension of external 3D structures. Different types of sandwich structures were tested, and the experiments showed promising results, with the direct printing process posing no technical difficulties. Continuing the research at ITA RWTH based on previous work at the University of Borås proved to be a successful methodological approach, leading to the development of a comprehensive method for using 3D printing to create sandwich structures for automotive applications. Further detailed work on implementing this solution will be conducted, focusing on its potential use in vehicle interiors to enhance functionality, aesthetics, and overall user experience [Sar24].

The preform production processes were followed by the production of the actual composites using compression molding and vacuum infusion processes. Here, the researchers were supported closely by very experienced technicians and researchers at ITA. The production processes are described in the microproject reports.

The composites will be fully tested for mechanical properties such as tensile properties, impact properties, and flammability tests. Once all tests are finalized, a holistic comparison of the production parameters can be drawn. The results from the impact tests performed at RWTH have already led to some preliminary relations between production parameters and impact properties.

2 Summary

The TUL researchers got a deep insight into the processing of different processing technologies and the advantages and disadvantages of the presented methods. Here, especially the diversity of the different preforms helped to gather knowledge about the different behaviour of the preforms during processing. The researchers were able to gain knowledge in multiple techniques. This knowledge will be transferred to businesses especially in the Polish industry, during business forums, training, and workshops.

3 Literature

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