ADVANCED TECHNOLOGIES AND MATERIALS VOL. 50, NO.1 (2025), 9 - 16
DOI: 10.24867/ATM-2025-1-002

1. Received: 17 April 2025
2. Revised: 29 April 2025
3. Accepted: 19 May 2025

Advanced Technologies & Materials

http://journal-atm.org
ISSN: 2620-0325 (print), ISSN: 2620-147X (online)

Original research article

Study of abrasive action on surface roughness and worn mass of laminated composites: production and evaluation

[a]Jelena Jovanović, [a]Nikola Mitrović, [a]Sandra Gajević*, [a]Slavica Miladinović, [b]Jasmina Blagojević, [c]Aleksandar Skulić, [a]Blaža Stojanović

[a] University of Kragujevac Faculty of Engineering, Kragujevac, Serbia
[b] Metalac a.d., Metalac Inko d.o.o., Gornji Milanovac, Serbia
[c] Kosovo and Metohija Academy of Applied Studies, Leposavić, Serbia

ABSTRACT

This study examined the effect of abrasive action on the surface roughness and mass loss of laminate composites produced by the wet lay-up method. The paper describes in detail the production process of these composites and after the production process, the surface was analysed using an optical microscope. Surface roughness was monitored in the transverse and longitudinal directions, before and after processing with P3000 grit sandpaper, where a significant increase in roughness was observed with minimal mass loss. A more detailed analysis of mass loss included precise measurements in the time interval from 1 to 5 minutes, with the results showing that with extended grinding time the amount of worn material increases. Additionally, analysis using an optical microscope confirmed the successful production of laminate composites, with very little presence of trapped air bubbles recorded, indicating the high efficiency of the applied production process.
Considering the characteristics of the used epoxy resin, the obtained results indicate high wear resistance of laminate composites, which is crucial for achieving aesthetically attractive components.

Key words: *Wet lay-up; composites material; laminates; roughness; abrasive; worn mass; surface.*

1. INTRODUCTION

Composite materials consist of two or more materials with different chemical properties that cannot be dissolved into each other. From a macroscopic perspective, composite materials are composed of a weaker phase, known as the matrix, and a stronger phase, known as the reinforcement. During the processing and chemical reactions, a third phase, called the interphase, may occur. The role of the matrix in composite materials is to protect the reinforcement from external environmental conditions and to transfer the load onto it, while the reinforcement provides the newly formed material with the required strength [1, 2]. Although composite materials are relatively new in the industry, their origins date back to ancient times. Around 1500 BC, Egyptians and Mesopotamians used composite materials in the form of mud bricks for construction, while around 1200 BC, the Mongols used bamboo, silk, and bones in combination with pine resin to make bows and arrows. The period between 1930 and 1936 was crucial for the development of composite materials and their industrial application, as the first unsaturated polyester resin was patented during this time. The first appearance of fiberglass is associated with 1935 and Owens Corning, who pioneered the fiber-reinforced polymer industry [2, 3].
Composite materials exhibit exceptional such as a high stiffness, high strength to weight ratio, corrosion resistance, the ability to dampen impacts and vibrations, as well as

* *Corresponding author's.e-mail:* sandrav@kg.ac.rs
Published by the University of Novi Sad, Faculty of Technical Sciences, Novi Sad, Serbia.
This is an open access article distributed under the CC-BY 4.0 license. terms and conditions

load transfer across multiple fibers. However, their drawbacks include expensive manufacturing processes, high material costs, complex testing, and challenging recycling. Due to their beneficial properties, composite materials are used in various industries, with the automotive, aerospace, and marine being the most dominant [4, 5]. The classification of composite materials can be performed in various ways and based on different criteria. According to the type of matrix, composite materials are categorized into those with metal, ceramic, and organic matrix. Within the composite materials with organic matrix, a distinction is made between composites with polymer and carbon matrix. Depending on the form of the reinforcement, composite materials are divided into composites with discrete particles embedded in matrix, fiber-reinforced composites, and structural composites. Structural composites are formed by combining homogeneous and composite materials and are further classified into laminate composites, sandwich constructions, and cellular composites. Among the listed types, laminate composites have the greatest application [6, 7].

Not one surface of machine elements is perfectly flat. Surface roughness of solid bodies refers to the set of irregularities that form the surface relief and are observed within the limits of a specific segment size, in which shape errors and waviness are eliminated. The degree of roughness can be expressed through various parameters, most commonly through the average variation of the roughness profile from the mean line (Ra) [8].

The aim of this study is to investigate the effect of abrasive action on surface roughness and mass loss of laminate composites produced by the wet lay-up method. Special attention was given to monitoring surface roughness in both transverse and longitudinal directions, before and after treatment with P3000 grit sandpaper, in order to assess the changes induced by abrasion. In parallel, mass loss was precisely measured at defined time intervals ranging from 1 to 5 minutes, providing insight into the wear behavior over time. The study also includes microscopic analysis of the surface to evaluate the quality of composite production and confirm the efficiency of the applied fabrication method.

2. LAMINATED COMPOSITES

Laminated composites consist of layers, or laminas, from which they derive their name. A lamina represents a layer that can be made up of one or more layers with fibers oriented in the same direction. The process of creating laminates involves arranging the laminas at various angles, and the final thickness of the laminate depends on the number of laminas. The mechanical properties significantly depend on the orientation and position of the fibers within the laminate, which is why there is a tendency to orient the fibers in the direction of the applied load. If the fibers are oriented in only one direction, the resulting laminate exhibits exceptional mechanical properties in the longitudinal direction but significantly poor properties in the transverse direction. In addition to unidirectionally oriented laminates, there are also laminates with fibers oriented in multiple directions, such as in the case of quasi-isotropic laminates, where the orientation of the fiber layers is at precisely defined angles of 0°, 90°, +45°, -45°, -45°, +45°, 90°, and 0°. In these laminates, all mechanical properties are evenly distributed in all four directions [1, 9, 10]. In laminated composites, the matrix establishes the connection between the fibers, transfers loads from fiber to fiber, protects the fibers from external influences, and provides the necessary toughness to the composite. The selection of the type of matrix during the production of composites is very important because it significantly affects the final mechanical properties of the product. The matrices in laminated composites can be based on epoxy, phenolic, and polyester resins, and there are also matrices with a metal base. Epoxy resins are characterized by a range of advantages, such as corrosion resistance, minimal shrinkage during curing, fatigue resistance, chemical stability, long service life, and impact resistance [11, 12].

As reinforcement in laminated composites, glass, carbon, and aramid fibers are most used. There are also fibers made from natural materials such as jute, flax, and hemp. The reinforcement in laminated composites is typically found in the form of fabric wound onto rolls. Depending on the type of fabric, fiber reinforcements can be unidirectional, woven, braided and random mat. Among woven reinforcements, plain weave, and twill and satin weave fabrics are the most commonly used. Of the listed fibers, carbon fibers have the widest application in the production of laminated composites, especially in the automotive industry. They are characterized by high tensile strength, creep resistance, and fatigue resistance. Their elastic modulus is higher than that of glass and aramid fibers, and they also possess excellent chemical resistance and low moisture absorption [13].

Laminated composites are used in various branches of industry due to their numerous advantages. Their high strength to weight ratio allows for the achievement of good mechanical properties while reducing the mass of the products, which is particularly important in the automotive, aerospace, and space industries. Corrosion resistance, compared to traditional materials, facilitates maintenance and extends the service life of the products. Due to their flexibility, there is the possibility of designing shapes with complex geometries, which is very important under special application conditions. In the automotive industry, they are used to produce body parts, engine components, power transmission parts, and suspension parts. In the aerospace and space industries, they are applied in the manufacturing of aircraft parts and satellite equipment, and more recently, they have also found use in the sports industry for making sports equipment [14-16].

3. MANUFACTURING PROCESSES FOR LAMINATED COMPOSITES

With the development and improvement of composite materials, production techniques have also evolved.

Nowadays, there are numerous manufacturing processes for laminated composites, which can be classified into two groups: open mold processes and closed mold processes. In open mold processes, as the name suggests, the mold is of an open type, while in contrast, in closed mold processes, the mold is closed. The open mold processes include wet lay-up, Spray-up, and Filament winding processes, while the closed mold processes include RTM (Resin Transfer Molding), Vacuum bagging, Vacuum infusion, compression molding, and Pultrusion processes. Among all these processes, the wet lay-up, Vacuum bagging, and Vacuum infusion processes are the most widely used [17]. The Wet lay-up process is an open mold method that is very simple and systematic. It is suitable for making prototypes, vessels, large components, parts in small-scale production, and for creating sports equipment. Fig 1 shows the wet lay-up process, step by step. The first step in this process is the preparation of the mold, during which a release agent is applied before starting the production of laminated composites. The first layer of fabric is then placed into the prepared mold, followed by the application of a resin layer using a brush, spraying, or pouring, while shaping and expelling gases with a roller or another tool. After that, a new layer of fabric is placed, and the resin application process is repeated. The number of repetitions of layering fabric and applying resin is determined based on the required thickness of the laminated composite [17–19].

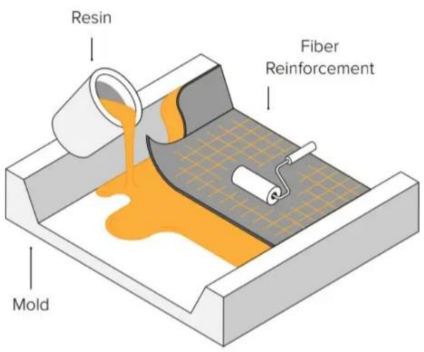

Fig. 1 *Wet lay-up process [20].*

In addition to the wet lay-up process, the most common methods for producing laminated composites are Vacuum bagging and Vacuum infusion processes. In the Vacuum bagging process, the lamination process is the same as in the wet lay-up method, with the addition of a vacuuming step after lamination. Vacuuming is carried out by placing a so-called peel ply over the last layer of fabric and resin, which serves to absorb excess resin. A special felt (breather) is placed over the peel ply, which is designed to evenly distribute pressure during vacuuming. After that, a vacuum film with specially prepared openings is set up, through which vacuum from the pump is drawn. Vacuuming is performed using a vacuum pump. The vacuumed laminate is allowed to cure at room temperature for 24 hours, after which it can be removed from the mold, and to achieve improved mechanical properties, baking at 80 °C is recommended [21].

4. EXPERIMENTAL RESEARCH ON LAMINATED COMPOSITES

4.1 *Fabrication of laminated composites*

To produce specimens of laminated composites using the wet lay-up method, it is necessary to design and manufacture a mold. The mold is made using a 3D printing process from PET-G (Polyethylene Terephthalate Glycol) material. In the mold fabrication process, the preparation of the mold for producing laminated composites was initiated, which involves applying a wax and PVA release agent to facilitate the easy separation of the finished laminate from the mold after curing.
The wet lay-up process is the simplest process for obtaining composite materials. For the purposes of the experiment, samples measuring 77x22x6.5 mm were made, while the process for producing laminate composite samples is presented and described below.

Step 1: Preparation of the reinforcement
For the reinforcement carbon fibers in the form of a twill weave were selected, with a density of 200 g/m^2, with a fiber bundle orientation of 0°/90°. In order to prevent fiber scattering during cutting, the fabric was impregnated with spray adhesive "3M 77", manufactured by 3M, which dissolves in the resin during impregnation and does not affect the quality of the laminate. After impregnation, the fabric was cut to the required dimensions. The fabric cut in this way represents one layer. Depending on the desired laminate thickness, the required number of fabric pieces was cut. Given that the weave thickness is approximately 0.25 mm, the required number of layers was 26 for a sample height of 6.5 mm. Fig. 2 shows the process of preparing the reinforcement for the production of a laminate composite.

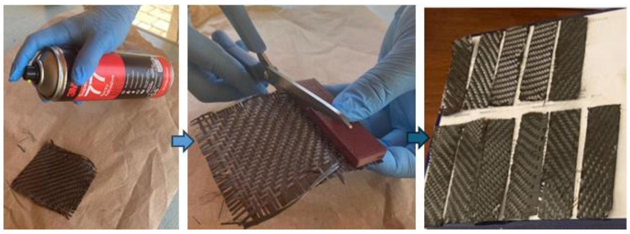

Fig. 2 *Preparation of the reinforcement.*

Step 2: Preparation of the matrix
The epoxy resin ES-TCG31 was chosen for the matrix, with the characteristics given in Table 1. The resin and hardener were also acquired from the company “DraPtec”. In order to determine the required amount of resin and hardener, a digital scale was used (Fig. 3a). The resin and hardener were combined by a mixing process, in a ratio of 100:60, by manual mixing, (Fig. 3b) which lasted 4 min.
The characteristics of ES-TCG31 resin were taken from the technical data sheet of the distributor-the company "DraPtec", which manufactures parts from composite materials and sells materials and equipment for the production of composites.

Table 1- *Characteristics of ES-TCG31 resin*

Resin characteristic	Unit	Value
Viscosity	mPa·s	650-1000
Tensile strength	N/mm^2	59
Modulus of elasticity	MPa	77
Shore hardness	Shore D	86

a b

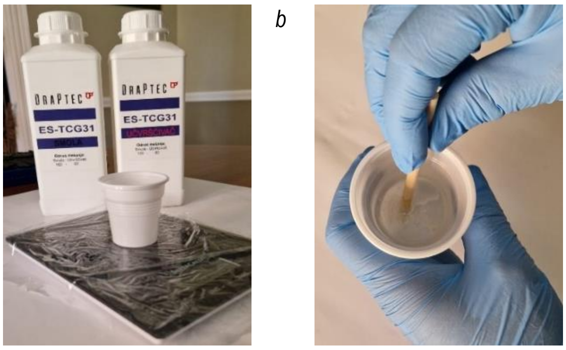

Fig. 3 *Resin preparation: (a) measuring the mass of resin; (b) mixing the resin and hardener.*

Step 3: Lamination
The resin was applied to the previously prepared mold using an 8 mm wide brush (Fig. 4a). After that, the fabric was placed in the mold (Fig. 4b), and then a layer of resin was applied again, which was carefully spread over the fabric, in order to achieve complete impregnation of the fibers and to expel the air from it. This procedure was repeated until the required laminate thickness was obtained. The duration of the lamination process was limited to a maximum of 30 minutes, because after that period the resin begins to harden, which significantly complicates or prevents further lamination.

a b

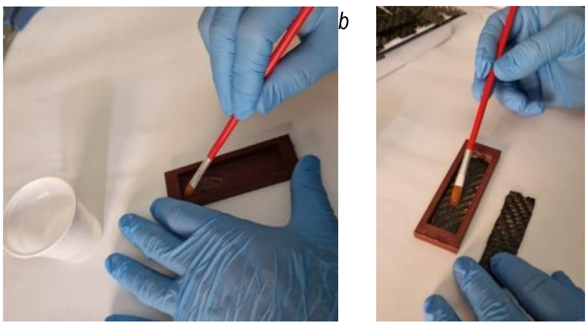

Fig. 4. *Lamination: (a) resin application; (b) fabric placement.*

Step 4: Curating of the laminate and separation of the samples from the mold
One of the characteristics of applied epoxy resin is the time required for the matrix to fully cure and bond with fibers into a laminated composite is 12 hours. After this time, the laminate is ready for removal from the mold and further processing. Fig. 5 shows the finished laminate obtained by the "Wet lay-up" process.
The ES-TCG31 resin, used in the wet lay-up process, has specific characteristics related to density, curing time, and the ability to cure without baking. Parts obtained through the wet lay-up method using this type of resin are characterized by a surface with extremely low roughness and a crystal-clear finish, allowing for a clear view of the reinforcement. The ES-TCG31 resin, in combination with this process, is utilized to achieve high-gloss parts, which is particularly important in the automotive and marine industries, where details are important.

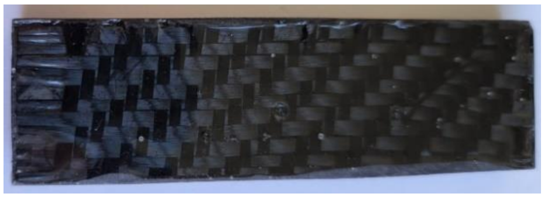

Fig. 5 *Specimen obtained by the wet lay-up method.*

4.2 Surface analysis of manufactured laminated composites

In order to perform a detailed inspection of the surfaces of the tested samples before further testing or grinding, an optical microscope, shown in Fig. 6, was used.

Fig. 6 *Microscope manufactured by "Lacerta".*

The optical microscope used for analyzing the sample surfaces is located at the Faculty of Engineering, University of Kragujevac. In addition to a lever for precise horizontal movement of the stage and a lever for precise adjustment of the eyepieces for image focusing, this microscope is also equipped with a digital camera with a magnification of x0.5, which is connected to a computer. Various additional settings can be made on the computer, as well as the creation of images. The eyepieces used have magnifications of x10, x20 and x40. After creating the images, they were sorted and compared in detail.
Fig. 7 shows the surface of the sample obtained by the "Wet lay-up" procedure before grinding. As shown in Fig. 7a, at a magnification of x5, trapped air bubbles are observed, which are arranged longitudinally. This phenomenon is a direct consequence of the movement of the brush during the resin application, which is further confirmed by observation at a higher magnification of x10 (Fig. 7b).
In the wet lay-up process, trapped gases are a common occurrence, both within the matrix itself and on its surface, forming bubbles of various sizes. These bubbles can occur due to inadequate mixing of the resin, application with a

brush or due to air trapped inside the weaving, which due to incomplete extrusion during lamination remains enclosed in the composite structure. In many cases, the bubbles are not visible to the naked eye, and their detection requires the use of optical devices such as microscope. The presence of these bubbles can have a significant impact on the quality of the final product. In addition to impairing the aesthetic appearance of the composite, which is especially important for visible and decorative components, trapped gases can lead to reduced fiber impregnation, which directly affects the mechanical strength and durability of the material. If bubbles remain trapped within the structure, they can represent initial points of weakness, which under load lead to local damage, cracking or failure of the composite. Therefore, it is necessary to pay special attention to the resin application process and to use techniques that minimize air entrapment, in order to ensure a high-quality and structurally sound laminate composite.

a

b

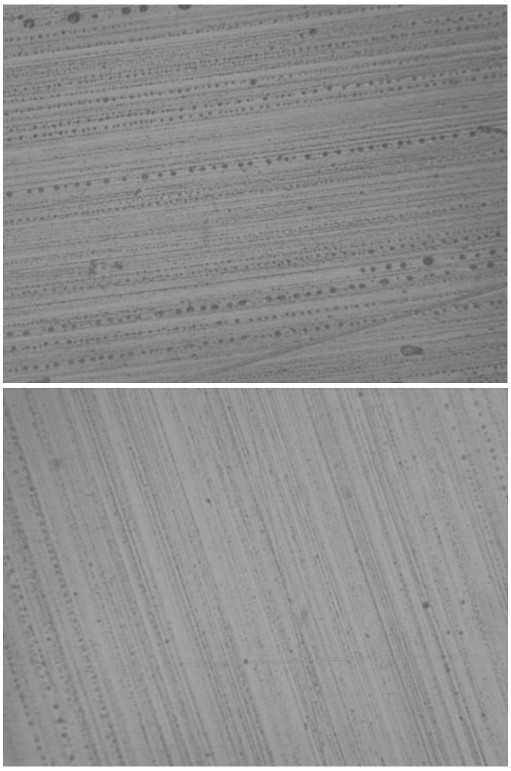

Fig. 7 *View of the sample surface under a microscope with magnification: (a) x5; (b) x10.*

4.3 Results and discussion

After the production of specimens using the wet lay-up method, surface roughness was measured before and after abrasive action on the specimen surfaces with P3000 grit sandpaper. The grinding process was performed manually by linear sliding of the sample over the surface of abrasive paper, which was firmly fixed to a flat support. During the grinding procedure, special attention was paid to maintaining a constant sliding speed, while the sample was simultaneously cooled with water in order to prevent local overheating and potential damage to the material's microstructure. The choice of this sandpaper grit is crucial for simulating real wear conditions of parts obtained through the wet lay-up process. During the sanding, water was used as an auxiliary fluid to eliminate dust and reduce the temperature at the contact point between the specimen and the sandpaper. After separating the produced specimens from the mold, surface roughness was measured in two directions: longitudinal and transverse. The surface roughness was measured using the ART300 Surface Roughness Gauge, located at the Faculty of Engineering Sciences at the University of Kragujevac. Roughness was measured on the surface that was not in contact with the mold, as this surface is most often exposed to external influences. The experimental results are presented in Fig.8 as a graphical dependency of roughness on the duration of abrasive action.

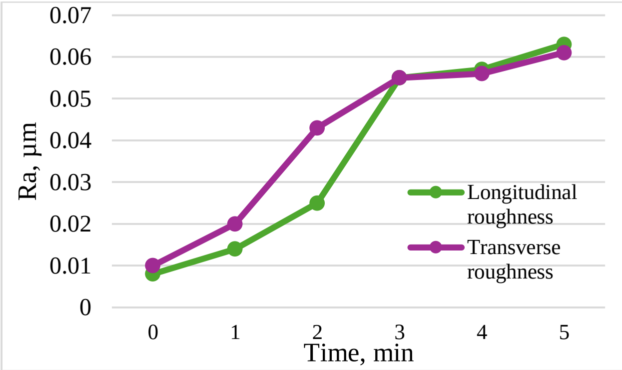

Fig. 8 *Surface roughness graph as a function of abrasive action time.*

Roughness measurements were taken three times in each of the mentioned directions to obtain the most precise and accurate results. First, the surface roughness was measured before the abrasive action, and then abrasive action was performed over a precisely defined period, after which the surface roughness was measured again. The roughness was expressed as Ra parameter.

From the graph (Fig. 8), it can be observed that the surface roughness values in the longitudinal and transverse measurement directions were approximately the same before treatment. Therefore, it can be concluded that the distributor's claim that the laminate features a crystal-clear surface with very low roughness after curing is substantiated. The graph shows the difference between the roughness in the longitudinal and transverse directions. Initially, after the production of the samples, the surface roughness is equal in the mentioned directions, which is shown in the graph at zero time. After one minute of processing, the roughness in the longitudinal direction of the action of the abrasive changed slightly, while in the transverse direction, the difference is visible. After two minutes of processing, there is a clear separation of the graphic lines, which shows that the effect of the abrasive in the longitudinal direction drastically affects the roughness in the transverse direction. Then, there is an equalization of the surface roughness value in both directions, which is the result of achieving the maximum surface roughness with this sandpaper granulation. After achieving these results, the roughness values in the further testing process did not change significantly during the grinding process.

Since abrasive action on the surfaces of the specimen leads to material wear, the mass of the specimen was measured before and after each abrasive action to calculate the worn mass of the specimen. The measurement of the worn mass of the specimen was carried out using a digital scale PS 1000.R2, with a precision of 0.001 g. Fig. 9 shows the worn mass of the specimen, expressed in grams, resulting from the abrasive action of the sandpaper over time.

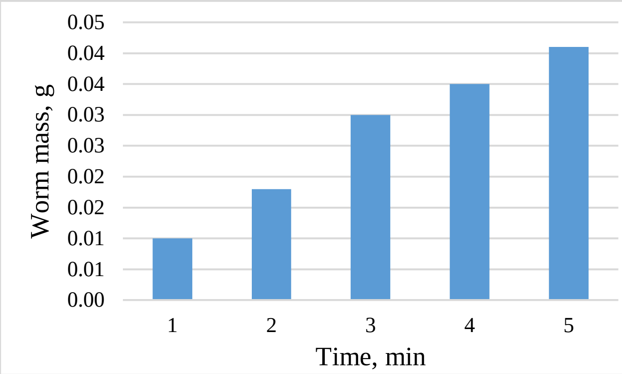

Fig. 9 *Worn mass graph as a function of processing time.*

Based on the graph (Fig.9), it can be concluded that the worn mass increases with the extension of the abrasive action period, which is understandable and expected given the characteristics of abrasive wear. From the graph, it can be clearly concluded that in the time interval from 1 to 4 min, the value of the worn mass over time has an approximately linear dependence, which is the result of constant sliding speed, equal effect of load on the surfaces in contact and constant sanding paper granulation. After this period, there is a deviation from the linear function, based on which it can be concluded that the matrix has worn out and that in this layer of material there are mainly fibers in contact with the abrasive action.
Composite materials and their applications are constantly evolving, with numerous scientists and researchers exploring and discovering new production methods, processing effects, optimization possibilities, and more. Nazari et al. [22] investigated the impact of sandpaper grit on the adhesion of laminated composites in their scientific research. They used various sandpaper grits ranging from P60 to P800. Based on their experimental results, they concluded that the optimal sandpaper grit is P240. Banakar et al. [23] focused on studying the influence of fiber orientation and layer thickness on the tensile strength of the resulting laminates. The specimens for their research were produced using the wet lay-up method, and the testing was conducted using a tensile testing machine. They concluded from their experimental results that the elongation of the specimen, as well as its fracture, depends solely on its thickness. An increase in thickness by 1 mm necessitates a 20% increase in load to cause failure. They also noted that with an increase in thickness, the tensile strength of the specimen and its modulus of elasticity decrease. Within the comprehensive development of composite materials and their research, a special place is occupied by bonded joints, which represent a key factor when joining composite parts into a single unit. That is why the investigation of the characteristics of bonded joints is extremely important, especially in the context of the influence of surface preparation, the choice and behavior of the adhesive, the geometry of the joint and the load. Yang et al. [24] investigated the effect of surface treatment (grinding with sandpaper) on the strength of bonded joints in carbon fiber reinforced composites. The goal of the research was to examine how sandpaper with different grain sizes, as well as sanding directions, affect the strength of bonded joints. They used sandpaper with the following grain sizes: 60, 220, 400 and 800, while the following sanding directions were chosen: parallel, transverse and random in relation to the fibers. The tests were performed on two different types of joints: single lap joint and Scarf adhesive joint. Based on the achieved results, they concluded the following: the highest strength of the joint as well as its better mechanical properties were achieved when the surface was sanded in a random direction, while the sandpaper granulation significantly affects the profile and roughness of the surface, as well as the contact angle in the joint and the adsorption of the adhesive.

5. CONCLUSIONS

To highlight the significance of studying the surface roughness and worn mass of laminated composites, specimens were fabricated using the wet lay-up method, followed by detailed measurements of surface roughness in both the transverse and longitudinal directions. Roughness was measured before and after exposure to the abrasive action of P3000 grit sandpaper. Before abrasive action, the average roughness value was 0.010 μm in the transverse direction and 0.008 μm in the longitudinal direction. After 5 minutes of processing, the roughness increased to 0.061 μm in the transverse direction and 0.063 μm in the longitudinal direction, which is a result of the abrasive action of the sandpaper. Additionally, the measurement of worn mass showed a negligible material loss due to abrasive action, with the worn mass of the specimen after 5 minutes of processing amounting to 0.041 g. These results provide important insights into the changes that occur during the wear of composites, which is crucial for assessing their durability and applicability.
In this study, the abrasion process was examined across six time intervals: 0, 1, 2, 3, 4 and 5 minutes, enabling a comprehensive understanding of how both surface roughness and material loss evolve over time. The worn mass showed an approximately linear increase between 1 and 4 minutes, which can be attributed to the consistent sliding speed and abrasive pressure applied during testing. However, a deviation from linearity was observed after 4 minutes, indicating the onset of matrix depletion and direct exposure of reinforcing fibers to the abrasive medium.
Regarding surface roughness, the initial measurements confirmed uniformity in both the transverse and longitudinal directions, supporting the distributor's claim of a crystal-clear surface after curing. As abrasion progressed, noticeable differences developed—particularly after 2 minutes—highlighting the directional

influence of wear. Eventually, the roughness values stabilized, suggesting that the surface had reached its maximum roughness achievable with the applied grit.

In addition to the results obtained, it is important to emphasize that this research is of exceptional significance, especially in the context of using resins as a finishing layer in various products. Therefore, assessing the initial roughness is crucial, and this study has confirmed that these resins achieve a very low roughness right at the production stage. Furthermore, the state of roughness after the abrasive action of sandpaper has been analysed, which is essential for evaluating the performance of these materials.

A full manufacturing procedure was also documented in detail, including the preparation of reinforcement fabrics, matrix formulation, layering technique and curing process. This step-by-step insight adds value by increasing the reproducibility and technical transparency of the research. In addition, optical microscopy revealed the presence of air bubbles formed during the manual lamination process. These defects, mostly aligned with brush strokes, can compromise both the visual appeal and mechanical reliability of the final composite product. Such findings underline the importance of proper resin application techniques and the potential impact of microdefects on long-term durability.

The research also holds significance for laminated composites, as parts exposed to abrasive action can be easily restored using appropriate pastes, bringing them back to their original surface condition without compromising their mechanical properties. This is confirmed by the low mass of the abraded material, as well as a visual inspection of the surface condition. Additionally, the materials and components made from laminated composites exude a luxurious and modern appearance, while also being environmentally friendly, which further enhances their market value. These findings contribute to a better understanding of the durability and preservation of the quality of products that utilize these materials.

REFERENCES

[1] Đorđević, Z. (2018). *Composite Structures* (in Serbian). Faculty of Engineering, University of Kragujevac, Kragujevac.

[2] Singh, S., Kumar, D. (2022). *Fabrication and Machining of Advanced Materials and Composites: Opportunities and Challenges*. CRC press-Taylor and Francis group, Boca Raton. DOI:10.1201/9781003327370.

[3] Šerifi, V., Tarić, M., Jevtić, D., Ristovski ,A., Isović, M. Š. (2018). Historical development of composite materials. *The Annals of the University of Oradea, Economic Sciences, 27(17) (3)*, 1-8. DOI:10.15660/AUOFMTE.2018-3.3392.

[4] Gajević, S. (2021). *Development and optimization of aluminum nanocomposites for the production of tribological components* (in Serbian), Doctoral dissertation. Faculty of Engineering, University of Kragujevac, Kragujevac.

[5] Egbo, M.K. (2021). A fundamental review on composite materials and some of their applications in biomedical engineering. *Journal of King Saud University-Engineering Sciences, 33(8)*, 557-568, DOI: 10.1016/j.jksues.2020.07.007.

[6] Altenbach, H., Altenbach, J., Kissing, W. (2004). Classification of Composite Materials. In: H. Song, T. A. Nguyen, G. Yasin, N. B. Singh, R. K. Gupta (Ed(s).), *Mechanics of Composite Structural Elements*. Springer, Berlin, Heidelberg, 155-161, DOI: 10.1007/978-3-662-08589-9_1.

[7] Gajević, S., Miladinović, S., Stojanović, B. (2022). Metallic nanocomposites: An introduction. In H. Song, T. A. Nguyen, G. Yasin, Nakshatra B. Singh, R. K. Gupta (Ed(s).), *Nanotechnology in the Automotive Industry*, Elsevier, 155-161, DOI:10.1016/B978-0-323-90524-4.00008-6.

[8] Tanasijević, S. (1989). *Fundamentals of tribology of mechanical systems* (in Serbian). Naučna knjiga, Beograd.

[9] Djordjević, Z., Jovanovi, S., Stanojevi, M., Blagojević, M., Velicković, S. (2018). Optimization of fiber orientation angle of a hybrid Al/composite cardan shaft. *ACTA TECHNICA CORVINIENSIS– Bulletin of Engineering, 11(2), 99-101*.

[10] Veličković S., Djordjević Z., Stojanović B., Blagojević J., Miladinović S. (2018). Influence of angles of fiber orientation on improving the characteristics of composite cardan shaft using factorial experiment. In *IOP Conference Series: Materials Science and Engineering, 393(1)*, 012086, DOI:10.1088/1757-899X/393/1/012086.

[11] Campbell Flake, C. (2010). *Structural Composite Materials*. ASM international, Materials Park, Ohio.

[12] Saba, N., Jawaid, M., Alothman, O.Y., Paridah, M.T., Hassan, A. (2016). Recent advances in epoxy resin, natural fiber-reinforced epoxy composites and their applications. *Journal of Reinforced Plastics and Composites, 35(6)*, 447-470. DOI: 10.1177/0731684415618459.

[13] Qureshi, J. (2022). A review of fibre reinforced polymer structures. *Fibers, 10(3)*, 10(3), 27, DOI:10.3390/fib10030027.

[14] Khan, F., Hossain, N., Mim, J.J., Rahman, S.M., Iqbal, M.J., Billah, M., Chowdhury, M.A. (2024). Advances of composite materials in automobile applications–A review. *Journal of Engineering Research*, DOI: 10.1016/j.jer.2024.02.017.

[15] Linganiso, L.Z., Anandjiwala, R.D. (2016). Fibre-reinforced laminates in aerospace engineering. In S. Rana, R. Fangueiro (Ed(s).), *Advanced composite materials for aerospace engineering*, Woodhead Publishing, 101-127.

[16] Tang, D.Z. (2014). The application of carbon fiber materials in sports equipment. *Applied Mechanics and Materials, 443*, 613-616, DOI: 10.4028/www.scientific.net/AMM.443.613.

[17] Biswas, S., Anurag, J. (2019). Fabrication of composite laminates. In: P. K. Bajpai, I. Singh (Ed(s).), *Reinforced polymer composites: processing, characterization and post life cycle assessment*, 39-53, DOI:10.1002/9783527820979.ch3.

[18] Hall, W., Javanbakht, Z. (2021). Design and Manufacture of Fibre-Reinforced Composites, In series: A. Öchsner, L.F. M. da Silva, H. Altenbach (Ed(s).), *Advanced Structured Materials, 158*, Springer, DOI:10.1007/978-3-030-78807-0.

[19] Cooley, J. (2018). *An introduction to common hand-layup methods with composite materials*, Doctoral dissertation. Brigham Young University, Idaho.

[20] Formlabs How to Manufacture Carbon Fiber Parts, from *https://formlabs.com/blog/composite-materials-carbon-fiber-layup/?srsltid=AfmBOooDC9Tv0O2jfumkmLrVzg3aRtiCFXXUQOT8LVP90w517WIzGrFf* accessed on 2025-04-03.

[21] Abdurohman, K., Satrio, T., Muzayadah, N. L., Teten. (2018). A comparison process between hand lay-up, vacuum infusion and vacuum bagging method toward e-glass EW 185/lycal composites. *Journal of Physics: Conference Series, 1130(1)*, 012018, DOI:10.1088/1742-6596/1130/1/012018

[22] Nazari, R., Hakimi, R., Daneshfar, M., Talebi, B. (2024). Synergistic Influence of Surface Sanding Technique and Multi-Walled Carbon Nanotube Incorporation on the Mode I Fracture Behavior of Glass Composite Laminates. Preprint in *Discover Applied Sciences*, DOI:10.21203/rs.3.rs-4621542/v1.

[23] Banakar, P., Shivananda H. K., Niranjan H. B. (2012). Influence of fiber orientation and thickness on tensile properties of laminated polymer composites. *International Journal of Pure and Applied Sciences and Technology*, *9(1)*, 61-68.

[24] Yang, G., Yang, T., Yuan, W., Du, Y. (2019). The influence of surface treatment on the tensile properties of carbon fiber-reinforced epoxy composites-bonded joints. *Composites Part B: Engineering*, 160, 446-456, DOI:10.1016/j.compositesb.2018.12.095.