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Effects of Femtosecond Laser Surface Treatment on Glass Fiber Reinforced Composites Produced by Pultrusion

Dániel VACZKÓ,[1] Zoltán WELTSCH,[2] Róbert KERESZTES[3]

[1] *Department of Innovative Vehicles and Materials, John von Neumann University, Kecskemét, Hungary, vaczko.daniel@nje.hu*

[2] *Department of Road and Rail Vehicles, Zalaegerszeg Innovation Park, Széchenyi István University, Győr, Hungary, weltsch.zoltan@sze.hu*

[3] *Mechanical Engineering Technology Institute, Faculty of Mechanical Engineering, Szent István Univesity, Gödöllő, keresztes.robert.zsolt@uni-mate.hu*

Abstract

In this study, we evaluated the effectiveness of laser surface treatment on flat, glass fiber-reinforced profiles produced by pultrusion. The experiments used a Coherent Monaco 1035-80-60 femtosecond laser, where the main parameter was laser power. The treated samples were examined with an Olympus OLS5000 confocal microscope, measuring the depth and area of the grooves created by the laser beam. The data were plotted as a function of power. Our results show that the increase in depth is not proportional to power, while there is a close correlation between changes in depth and area. These findings shed new light on the potential industrial applications of laser surface treatment for pultrusion-manufactured glass fiber-reinforced profiles, particularly concerning surfaces prepared for bonding.

Keywords: *laser surface treatment, femtosecond laser, pultrusion, bonding technology, glass fiber.*

1. Introduction

Pultrusion is a continuous manufacturing process specifically used for the production of glass fiber reinforced plastics. In this process, reinforcing fibers, such as glass fibers, are first drawn through a resin bath and then pulled through a long, heated die where the resin polymerizes, creating long and rigid composite elements with the desired profile. Pultrusion enables the rapid and cost-effective production of high-strength and corrosion-resistant composite structural elements [1]. The process is illustrated in Figure 1.

The extensive use of glass fiber reinforced plastics in the industry, especially in vehicle manufacturing and construction, is advantageous due to their high strength and corrosion resistance. However, the weak surface energy of glass fiber reinforced plastics limits their adhesive properties, presenting challenges for bonding technologies, particularly in the areas of adhesion and lamination [2].

The femtosecond laser uses short laser pulses, allowing for the modification of surface microstructures without thermally damaging the substrate. This surface treatment method is particularly beneficial for preparing plastic surfaces, as it improves surface tension and thereby the quality of bonds [3].

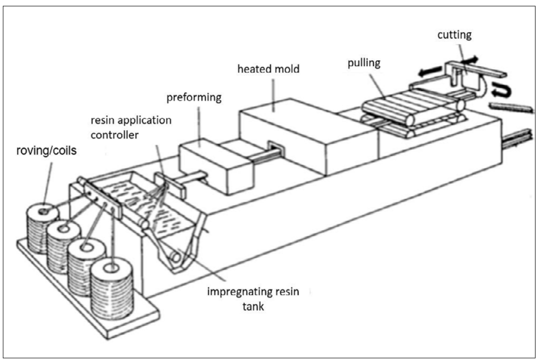

Fig. 1. *The pultrusion process.* [5]

Research by Banks and colleagues demonstrates that femtosecond lasers can be used to create complex, high-precision cuts and holes in various materials without causing damage to the surrounding material. During such operations, the laser pulses can be directed with such precision that the structural integrity of the remaining material remains completely intact, which is critical for certain industrial applications [4].

The aim of this study is to investigate the effects of surface treatments conducted with the Coherent Monaco 1035-80-60 femtosecond laser on pultrusion-manufactured profiles, particularly in terms of improving bonding properties such as bond strength and surface energy. The results highlight the potential industrial applications of femtosecond lasers in the surface treatment of composite materials.

2. Experiments

2.1. Surface Treatment and Sample Preparation

In the research, we used flat glass fiber-reinforced plastic profiles produced by pultrusion, with the following composition: glass content 64%, Barcol hardness 48, aluminum trihydrate (ATH) 21.8 %, and the base resin ISO NPG. The preparation of the samples included cutting to size and cleaning the surfaces with methanol before treatment to remove any surface contaminants. The surface treatment was conducted using a Coherent Monaco 1035-80-60 femtosecond laser (Figure 2), with power as the variable. The other parameters were: pulse duration 277 fs, pulse frequency 750 kHz, and feed rate 1 m/s. The laser power was adjusted in 10 % increments from 10 % to 100 %. By varying the power, we produced different samples, which were later examined with a confocal microscope.

2.2. Microscopic Analysis

To examine the effects of the laser treatment, the surface structure of the samples was analyzed using an Olympus OLS5000 confocal microscope, with a 20× objective for more detailed investigation of the surface structure (Figure 3). The microscopic examinations were conducted in a climate-controlled room to ensure minimal environmental impact on the samples and the accuracy of the measurements.

Data collection and analysis were conducted using the microscope's proprietary software, which allowed for accurate and reliable evaluation of the measured data. During the measurements, the depth and area of the grooves created by the laser beam were measured. The software is capable of creating 3D topographies (Figure 4). The image may include minimal noise, which appears as spikes; these were reduced with noise filtering.

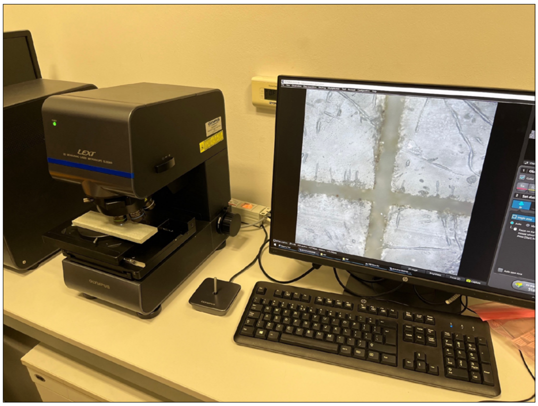

Fig. 3. *Olympus OLS5000 Microscope.*

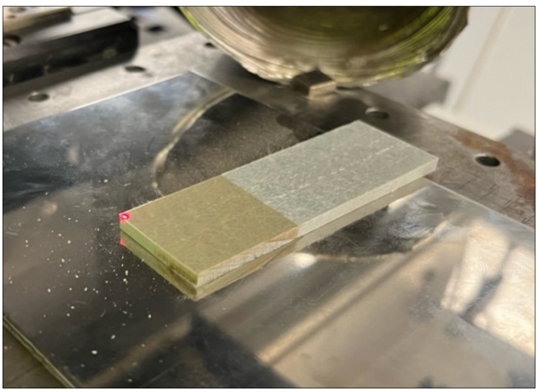

Fig. 2. *Surface Treatment with Femtosecond Laser.*

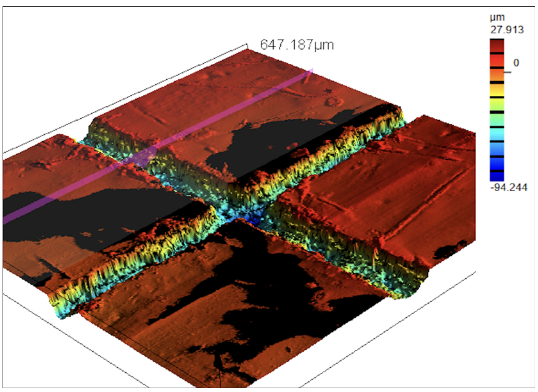

Fig. 4. *3D Topography, with Depths Indicated by Colors.*

For depth and area measurements, a cross-sectional image of the groove was necessary, and the average dimensions of a 300 µm section of the groove were considered.

3. Results

During the investigation, the microscopic analysis of plastic profiles treated with the Coherent Monaco 1035-80-60 femtosecond laser provided important information on the impact of laser power on surface structure.

The graph shows that both the depth and area increase significantly with the rise in laser power. At the 10 % power level, the groove depth was approximately 10 µm, while the area was around 1000 µm². As the power increased to 100 %, the groove depth approached 60 µm, and the area exceeded 2500 µm².

In the 0–20 % range, the laser power is too low to create significant changes, so the depth and area remain low. In the 20–40 % range, as the power increases, the depth and area grow rapidly since the laser provides enough energy to modify the surface structures. In the 40–50 % range, the growth rate slows down, indicating that the laser power is nearing its maximum efficiency. However, in the 80-100% range, the growth slows down again, and a slight decrease can be observed, likely due to partial melting of the resin, which flows back into the microgrooves, reducing their depth and area.

Based on the obtained data, we created a graph that illustrates the changes in groove depth and area as a function of laser power. This graph clearly shows the relationship between the increase in power and the size of the groove (**Figure 5**).

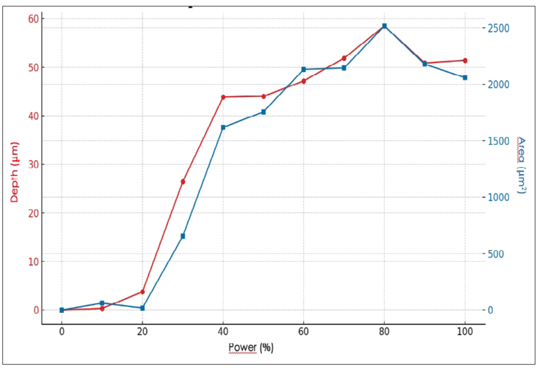

Fig. 5. *Variation of Depth and Area as a Function of Power.*

4. Conclusions

The microscopic analyses conducted during the research and the thorough evaluation of the obtained data allowed us to gain a comprehensive understanding of the effects of using a femtosecond laser for surface treatment of pultruded, glass fiber-reinforced plastic (GFRP) profiles. The results clearly demonstrated that increasing the laser power proportionally increases the depth and area of microgrooves on the GFRP surfaces, which significantly influences the surface morphology.

Based on the analysis of the graph, the changes in depth and area with increasing power do not follow a simple linear or exponential trend but show different patterns at various stages. In the low-power range, the increase is minimal; at medium power, rapid growth is observed, while in the high-power range, the growth slows down and sometimes even decreases. This correlation supports the applicability of laser treatment for targeted modification of plastic surface properties.

Microscopic examinations revealed that surface treatment with higher power results in a more uniform microstructure, which could be more favorable for adhesive processes. A uniform microstructure can enhance adhesion, facilitating better bond strength.

Due to the melt occurring at high power levels, it will be worthwhile to investigate how the base material responds to multiple treatments under optimal settings in the future.

The study’s results may contribute to the advancement of industrial plastic processing, particularly in areas where surface properties such as adhesiveness and mechanical durability are crucial.

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