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Investigation of Bonded Joints in Glass Fiber Reinforced Flat Profiles

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Abstract

Nowadays, raw material shortage is a characteristic problem that affects every sector of the industry. Composite materials reinforced with fiberglass, manufactured through the pultrusion process, have extremely favorable properties. In our research, we examined the application of surface treatments on pultruded profiles to enhance surface energy. We roughened the surfaces to be bonded using manual sanding and sandblasting techniques, and then performed wetting measurements using various degreasing agents. To demonstrate the occurrence of surface treatment and determine its magnitude, we inspected the surfaces with a roughness tester. The bonds were created using two different structural adhesives as well as epoxy resin. The shear strength values of the flat profiles were compared through tensile tests, and the effects of the surface treatments were determined. Based on the results, the appropriate surface treatment and adhesive type greatly influence the developed bond strength.

Keywords: *bonding, pultrusion, composite, surface energy, glass fibre.*

1. GFRP profiles

The profiles produced by pultrusion, which are glass fiber reinforced plastic (GFRP) composite materials, are used in the pultrusion process to manufacture continuous fiber-reinforced polymer matrix composites. During pultrusion, the fibers and resin are typically pulled through a heated die, where the resin cures and solidifies, taking on a solid shape.

The pultrusion process enables the production of high-strength, lightweight, and durable composite components and structural elements. This method is increasingly popular in the construction, automotive, electrical, and other industries that rely on strong, lightweight, and durable materials resistant to corrosion and chemicals. One of the main advantages of pultrusion is its ability to manufacture complex shapes with consistent dimensions and high precision, which is why more and more people choose this process for producing structural elements. Pultruded materials exhibit excellent corrosion and chemical resistance. Despite their low weight, these structural elements have high mechanical strength, providing them with great stability and reliability [1].

The surface energy of pultruded profiles is typically low due to the surface treatment applied during the manufacturing process. As a result, bonding such components can present a challenge. By implementing appropriate surface treatments, it is possible to increase the surface energy and the area of the bonded surface, thereby significantly improving the adhesion [2].

In our research, we treat the surfaces using manual sanding and sandblasting techniques, followed by cleaning with various degreasing agents. We examine the effects of these treatments through wetting angle measurements and surface roughness analysis, and then determine the shear strength of the bonded joint using a tensile testing machine.

The ratio of the length of the test specimen to the bonded area is 4:1. We applied this ratio based on the clamping length, so the bonded area is far enough from the clamping point. The flat profiles are 6mm thick, 50mm wide and 100mm long. The bonding and clamping lengths are both 25mm. The bonded area is 1250mm2 in size. The required number of samples for the flat profile is listed in **Table 1.** We conducted three breaks for each type of test specimen. The labels of the test specimens are shown in the table below, where the numbers of breaks within each type of test specimen are indicated in parentheses.

2. Boundary surface analysis

One fundamental aspect of bond strength is the ability of the adhesive material to adequately wet the adherend surface. The wetting ability can be determined by the spreading of a liquid on a solid surface. The contact angle (θ) serves as a measurement of the contact angle formed at the interface of the three phases. The contact angle was examined on untreated, manually sanded and sandblasted surfaces. In their study **[3],** Stazi, F., Giampaoli, M., Rossi, M., and Munafò, P. achieved better results with manual sanding and sandblasting compared to untreated surfaces. Therefore, we roughened the test samples' surfaces using conventional manual sanding with P80 grit sandpaper.

2.1. Surface roughness measurement

We employed two types of surface roughening techniques on the test specimens: sandblasting and manual sanding, in addition to the untreated surface. To measure the surface roughness, we conducted roughness measurements on the roughened surfaces. The roughness we measured serves only to determine the differences between the surfaces.

Table 1. *Ahe labels used during the experiments*

Types of surface treatments	Types of adhesives		
	Loctite HY4090	**Sikapower 4720**	**Ipox MR 3010 gyanta**
Untreated	Lo_S_(1-3)	S_S_(1-3)	Gy_S_(1-3)
Sandblasted	Lo_H_(1-3)	S_H_(1-3)	Gy_H_(1-3)
Polished	Lo_Cs_(1-3)	S_Cs_(1-3)	Gy_Cs_(1-3)

Table 2. *Interpretation of the results obtained from the roughness test*

	Untreated	Polished	Sandblasted
R_a (μm)	1.77	3.72	3.73
R_z (μm)	8.38	21.51	22.20
R_t (μm)	11.22	31.73	33.63

We examined the surfaces using a Mitutoyo Formtracer SV-C3100 instrument. The average roughness (R_a) is twice as high for the sanded and sandblasted surfaces compared to the untreated surface. **Table 2** presents the averaged values obtained from the measurements.

The surface roughness parameter known as the peak-to-valley height (R_z) is significantly increased due to the surface treatments. In fact, compared to the untreated surface, this value has grown to slightly more than 2.5 times higher. When considering the average maximum peak-to-valley height (R_t), the values for the sanded and sandblasted surfaces are nearly three times higher than that of the smooth surface.

2.2. Wettability test

We captured the contact angle using a video camera. The droplets were applied to the surfaces using an Accumax Pro pipette, and we used distilled water as the probing liquid. The number of measurements we conducted is the product of the surface type and the number of cleaning agents (including one without any treatment). Therefore, we performed 12 measurements, using 3 droplets per measurement. The left and right contact angles were calculated using image analysis. We measured three different surface types: untreated, sandblasted, and manually sanded surfaces. In terms of degreasing, we applied four cleaning methods. Initially, we examined an untreated surface as a reference for comparing the different degreasing agents. We used two types of degreaser: acetone and Loctite Super Cleaner cleaning spray, as well as methanol as an alcohol-based degreaser **[4]**.

The images of the two extreme values obtained from the measurements can be seen in **Figure 1.** The droplet with the highest spreading occurred on the smooth surface without degreasing, while the other image shows the least spreading droplet on the sanded surface without degreasing.

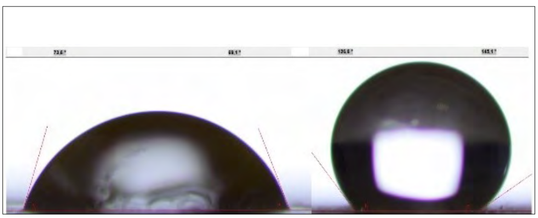

Figure 1. *The most widely spread (left) and the least widely spread (right) drop during the measurements.*

There are significant differences among the results. The most wettable surface was the untreated surface without any surface treatment or degreasing. We observed that the untreated surface showed better results compared to the other cleaning surfaces when Loctite Super Cleaner cleaning spray was applied, but still not better than the untreated surface without degreasing. For the manually sanded and sandblasted surfaces, degreasing with methanol proved to be the most effective, as it resulted in an average contact angle of 94.18° for the sanded surface and 94.25° for the sandblasted surface. In the case of the roughened surfaces, we noticed that acetone showed approximately 8-9° higher values compared to methanol in terms of contact angle deviation.

Based on the measured results, the wetting ability of the untreated surface without any treatment or degreasing reached the partially wettable range with contact angle values below 90°. Since the spreading of adhesives depends on viscosity, it would be beneficial to intervene. Some adhesive manufacturers specify in the instructions for use the spreading/application of the adhesive, for example, using a plastic spreader.

3. Measurements and test results

During the measurements, we compared different surface roughnesses by bonding the surfaces together, with a bonded area of 1250 mm^2 for each test specimen. We then conducted tensile tests. The measurements that yielded the best results were repeated with test specimens of two- and three-fold sizes to examine whether we obtain linearly increasing values.

The measurements were performed on an Instron 5900R 4482 tensile testing machine. For each measurement type, three tensile tests were conducted. In terms of shear strength, the performance of the adhesives was 17 N/mm^2 for Loctite (on steel test specimens), 14 N/mm^2 for Sikapower, while there is no factory-specified value for shear strength for the resin.

Based on the measurements on the untreated test specimens, the maximum load remained below 5000 N. For Loctite, two out of three tests yielded similar values (3113.1 N and 3118.3 N), while the third test resulted in a value that was approximately 800 N lower. The results obtained for Sikapower showed a higher variation, with the smallest result being 3097.3 N and the largest result being 4958.9 N. The resin exhibited the smallest variation, with values ranging between 2570.3 N and 3221.5 N. In terms of failure modes, the adhesive completely separated from the bonded surface in all cases. The values obtained for the untreated surfaces and the types of failures are shown in Table 3.The results obtained for the polished surfaces consistently showed lower values compared to the sandblasted surfaces, but they exhibited twice the load resistance compared to the untreated surfaces. The measurements results are shown in Table 4. In comparison to the untreated surfaces, the load resistance doubled, but complete detachment was still observed. The load values increased twofold compared to the untreated surfaces, but there was no difference in the nature of failure.

The results obtained on the sandblasted surfaces were better than the previous ones, as all three adhesions increased at least threefold compared to the smooth surface. The bonds made with Loctite adhesive and resin showed similar values. The Sikapower bond performed well compared to itself, as it not only showed more than three times the strength of the smooth surface bonding, but also achieved 93% of the maximum shear strength value provided by the manufacturer. Table 5 shows the values of the results obtained on the sandblasted surfaces and the types of failures.

We observed significant improvement in the quality of the bonded joint when using Sikapower adhesive on the test specimens. Besides the bond-

Table 3. *Results obtained on untreated surface*

Sample labeling	Mean maximum load (N)	Shear strength (N/mm^2)	Failure types
Resin untreated	2907.9	2.33	Peeled off the entire surface
Loctite untreated	2841.9	2.27	Peeled off the entire surface
Sikapower untreated	4896.7	3.92	Peeled off the entire surface

Table 4. *Results obtained on polished surfaces*

Sample labeling	Mean maximum load (N)	Shear strength (N/mm^2)	Failure types
Resin polished	6060.7	4.85	Peeled off the entire surface
Loctite-polished	7345.7	5.88	Peeled off the entire surface
Sikapower-polished	9115.1	7.29	Peeled off the entire surface

ed joint, the failure occurred in the counterbored hole profile, as shown in **Figure 2.**

The ratio of adhesive to cohesive failures was approximately 60-40%. In the case of resin adhesive, there was a minimal occurrence of cohesive failure. Compared to smooth surfaces, the sandblasted surfaces exhibited more than three times the shear stress values, which was consistent for all three types of adhesives. The Sikapower adhesive almost met the factory shear stress specification, as we measured an average of 93% of the specified value on the test specimens.

In **Figure 3** it is evident that the surfaces treated with sandblasting resulted in the strongest bond. During fracture, both adhesive and cohesive failures occurred on the sandblasted rough surface. When testing flat profiles, the combination of Sikapower adhesive and sandblasted surface treatment yielded the highest result. Therefore, further investigation was conducted using this combination. In the subsequent analysis, we increased the surface roughness and examined how shear forces followed this modification.

Table 5. *Results obtained on sandblasted surfaces*

Sample labeling	Mean maximum load (N)	Shear strength (N/mm^2)	Failure types
Resin-sandblast.	8851.4	7.08	Partially peeled off
Loctite-sandblast.	8987.2	7.19	Peeled off the entire surface
Sikapower-sandblast.	16339	13.07	Partially peeled off

Figure 2. *The partially peeled off adhesive bond on the sandblasted profile with Sikapower adhesive.*

4. Conclusions

The effectiveness of adhesive technology is most influenced by a properly prepared surface. In our case, the interface with low surface energy was removed using simple surface treatment (roughening) procedures, thus increasing both the surface energy and the bonding area. This resulted in a surface area favourable to bonding. In this way, the sandblasted specimens showed an improvement of over 300% over the untreated surface for all three types of adhesive. Sandblasted surfaces bonded with Sikapower performed best. There are two possible reasons for this, one is that sandblasting creates a more homogeneous surface roughness distribution, resulting in a more uniform bond. The other possible reason is that Sikapower adhesive contains 0.25mm spacer glass beads, which provide the optimum bonding gap during bonding. This ensures that the correct gap is almost guaranteed when forming the bonded joint.

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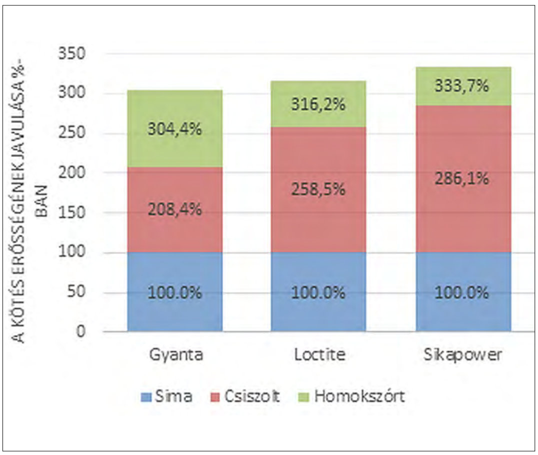

Figure 3. *Effect of surface treatments compared to untreated surface.*

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