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Optimize the joining technology of CFRP and aluminium sheets using hybrid and high strength adhesive

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Abstract. In order to reduce the weight of a vehicle the designers have to use different materials pairing. During the light building the vehicle needs to complete the mechanical and structural requirements, these quality properties are especially important in the competition racings. To fulfil the needs while minimize the weight hybrid material usage and bonding are used. One of the critical joining is the Carbon Fiber Reinforced Plastic (CFRP) and aluminium pairing. In this paper we investigated the adhesive joining technologies of these hybrid pairings using hybrid and high strength adhesive. Our goal is to optimize the hybrid bonding while different surface treatment methods are used on the aluminium substrate. The mechanical properties, the surface roughness and the breaking method were investigates using tensile test and macro geometry inspection. In the results the connection between the surface topography and the mechanical properties were analysed.

1. Introduction

Development of processes to join aluminum sheets with other plastic materials is necessary and important in order to allow aluminum to be applied broadly in the automotive industry, as the aluminum plates itself has a low bending and tensile strength. Other pairing materials as reinforcing the aluminum can be used dual phase steels [1], fiber reinforced composites [2], and any special usable materials [3]. There is a lot of method to join hybrid materials together, such as brazing [4], soldering [5-7], but this paper deals with the adhesive joining methods using two different type of glues.

Adhesive bonding is the process of binding two different components using a suitable binder. Applications of adhesives for joining elements made of dissimilar materials are commonly employed in aviation, automotive and building industries [8]. Joining of CFRPs with aluminum alloys via adhesive bonding is by far the most conventional method with both advantages and limitations. The investigated researches used, CFRP with aluminum, but we could use these experiments to joining aluminum foams with adhesives in the future. Since adhesive bonding is an irreversible process, attempts to dissemble the joints can be expensive, which results in the complete material damage involved in the joints [9,10].

Adhesive bonding not only seals the joints, but also prevents crevice and galvanic corrosion between two dissimilar materials. Almost any pair of dissimilar materials such as metals, polymers or ceramics can be joined with this method [11]. Adhesive bonding is the only viable method to achieve structures involving the joining of thin-walled elements, among which an element has substantial dissimilar thickness. Adhesive bonding offers light-weighted structures with respect to other assembly technologies and developments, particularly in aviation industries. In addition, stress concentration becomes less significant without the requirement of bolt holes, thus avoiding structure weakening [12]. Adhesive joining technologies can be calculated using numerical methods such as in other manufacturing methods like deep drawing [13]. The adhesives as the main elements in adhesive bonding should have good wettability with respect to joining components, such as CFRPs and aluminum alloys.

2. Experimental procedure

The substrates for the research are non-coated AlSi1 sheet of 5 mm and Carbon Fiber Reinforced Plastic (CFRP) of 1.2 mm thickness. The CFRP was vacuum laminated during 24 hours using 2 layer of 1 x 1 mm weave carbon fiber and epoxy glue. After the lamination heat treatment was used to increase the adhesive and cohesion force in the CFRP, the temperature of the heating was 80°C and the time was 2 hours. The materials were mechanically sectioned to avoid heat input, into 30 x 50 mm, the CFRP into 15 x 50 mm. Before the joining method, the surface off the CFRP were grinded to remove the form separating layer. The CFRP has not modified with any treatment, only the grinding and the degreasing method was used. The aluminum and CFRP surfaces were all cleaned and degreased with cleaning spray. 4 different surface modification method were used on the AlSi1 during the research: the un-treated surface, grinded surface with a P10 grinding stone, sand blasted surface using 0.3-0.7 mm abrasive and chemical etched with hydrochloride acid mixed with distillated water in 1:5 ratios for 5 minutes.

The adhesive joining method of the overlapped joints was performed using two different type of adhesive, the firs was Loctite 4080 which is a 2 component cyanoacrylate / acrylic adhesive, it is recommended for adhesive joining of different type of materials. The second was Loctite 9466 2 component epoxy adhesive, with this adhesive high strength of bonding can be created. First step of the adhesive method was the cleaning of all the contact surfaces, add glue on the materials on a 15 x 10 mm area, the joints were overlapped (figure 1). The hybrid joints were squeezed over 24 hours in a bending machine, this time needs to reach the 100% strength of the adhesive.

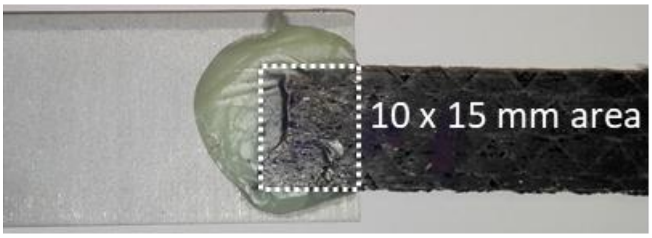

Figure 1. Adhesive procedure setup and connecting area.

In order to analyze the effect of the different surface preparations to the tensile strength of the hybrid CFRP and aluminum joints surface roughness measurement was performed. The macroscopic structure of the surfaces was investigated. Shear tensile test were carried out on Instron 5900R testing machine at a cross-head speed of 2 mm/min (figure 2). Five samples were tested for each surface modification method. The breaking method was investigated to find out which component has lower adhesion force to the adhesive.

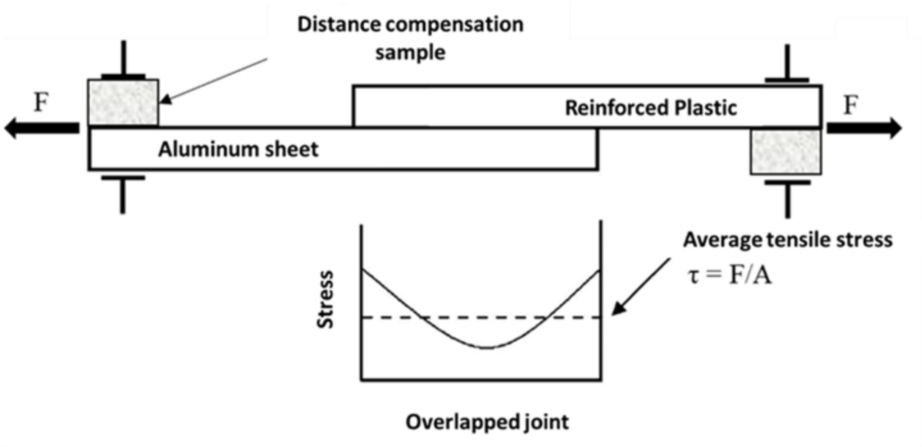

Figure 2. Test setup of tensile strength measurements.

3. Results

3.1. Effect of the different surface modification for the macroscopic topography and surface roughness

After the surface modification of the aluminum sheets the surface roughness measurement were performed. In figure 3 the macroscopic topography of the surfaces can be seen after the adhesive process.

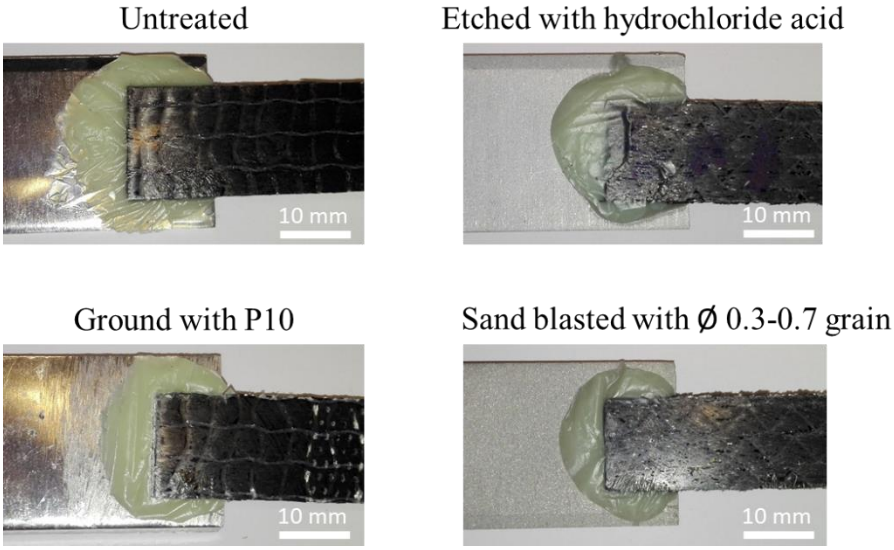

Figure 3. Surface macro topography and roughness using different preparations.

The manufactured and rolled surface of the AlSiMg1 is a very smooth, mirroring surface with a Ra= 0.5 µm and Rz= 5.8 µm, on this surface preparation the effect of the un-treated strength of adhesive joints were performed. The first mechanical prepared was the grinding with Ra= 7.5 µm Rz= 34.9 µm, unfortunately the grinding is not enough homogenous surface preparation and only can be used on flat surfaces properly. A homogenous preparation could be the diameter of 0.3 – 0.7 mm sand blasting on the aluminum substrate surface, it causes Ra= 5.6 µm Rz= 40.4 µm. It both take the surface homogenous and can be used on any type of surface. With these methods the oxide layer can be modified using commercial and standard mechanical equipments. The chemical etching in thin hydrochloride acid cause homogenous surface with Ra= 6.7 µm Rz= 57.7 µm, also the etching has effect on the oxide removal.

3.2. Effect of the value of the carbon fiber layers to the lamination method and the tensile force

In figure 4 and table 1 the tensile force of the different amounts of carbon fiber layers can be seen using vacuum lamination.

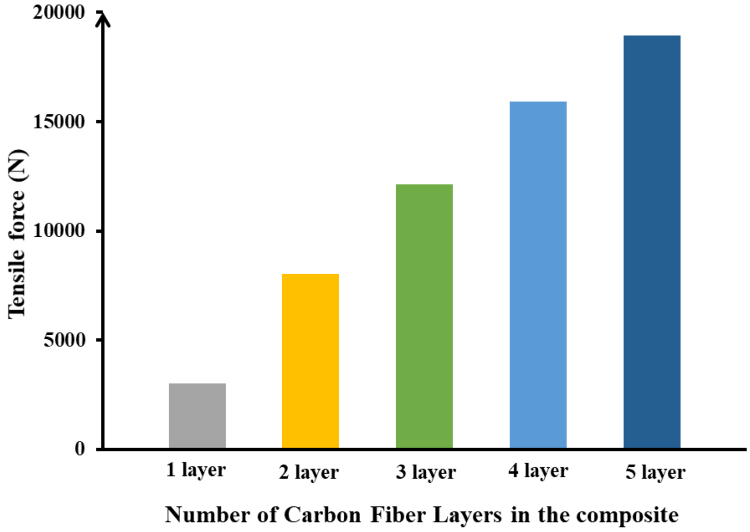

Figure 4. Effect of the carbon fiber layers for the strength of laminated plastics.

Table 1. The tensile force of the different amounts of carbon fiber layers.

Effect of Carbon Fiber layers to the Composite lamination	
Number of fiber layers	**Tensile force (N)**
1 layer	3030
2 layer	8017
3 layer	12149
4 layer	15938
5 layer	18935

The connection between the amount of carbon fiber layers and the tensile force of the plastics shows correlation coefficients. In the beginning adding one more layers increased the tensile force with about 5000 N, but adding additional carbon fiber layers decreases the increase of the force. From 2 to 3 layers it cause 4000 N, from 3 to 4 layers 3800 N and from 4 to 5 carbon fiber layers the force only increase with 3000 N. The laminated CFRP specimens broke in the vertical centre line of the plastics along the lamination glue, because the strength of the carbon fiber is about 1000-1200 MPa. The two component lamination glue is the weakest part between the carbon fibers in every case of the specimens. CFRP specimens with 2 layers of fiber can be used for the adhesive joining research, because the adhesion force between the substrates and the adhesive will be lower than in the base materials.

3.3. Effect of the different surface modification for the tensile force using cyanoacrylate / acrylic hybrid adhesive

The tensile force of the aluminium and CFRP hybrid joints can be seen in figure 5 and table 2 using cyanoacrylate / acrylic hybrid adhesive and different surface preparations.

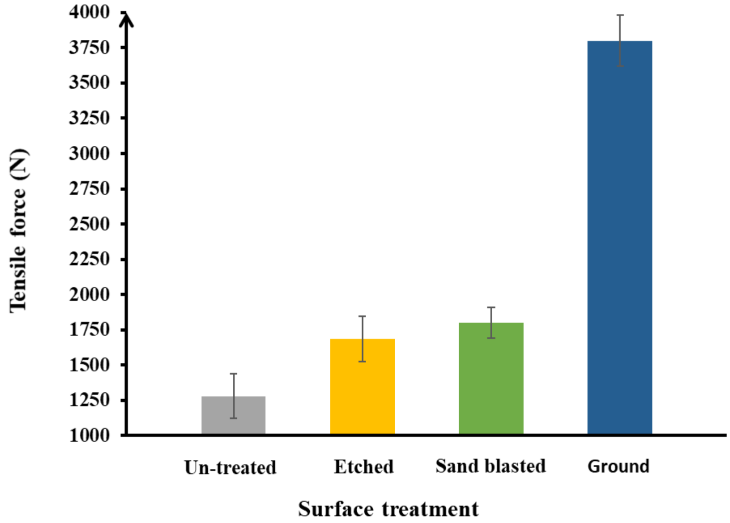

Figure 5. Effect of the different surface modifications for the Al – CFRP hybrid joints using cyanoacrylate / acrylic adhesive.

Table 2. The tensile force of the different hybrid joints using cyanoacrylate / acrylic adhesive.

Effect of surface treatments using Loctite 4080 hybrid adhesive				
Surface treatment	**Tensile force (N)**	**Tensile stress (MPa)**	**Ra (µm)**	**Rz (µm)**
Un-treated	1278	8.5	0.5	5.8
Etched	1685	11.2	6.7	34.9
Sand blasted	1800	12	5.6	40.4
Ground	3800	25.4	7.5	57.9

The chemical and mechanical surface preparations cause the increase of the tensile force in the adhesive joints. The control results are the un-treated Al – CFRP joints. Using chemical etching and sand blasting using 0.3 – 0.7 grain the tensile force only increasing with low level. In case of etching only a low oxide layer could remove during the 5 minutes hydrochloride acid treatment, it cause a homogenous surface texture and the adhesive force of the adhesive can increase. Using sand blasting on aluminium surface the oxide layer can be removed with low level of material removal and a very rough surface created. The wettability in these type of surfaces using mixed cyanoacrylate and acrylic adhesive were in wrong condition. The ground aluminium surface using P10 grinding stone shows the best adhesive force on the aluminium surface using these setups and adhesive. The grinding method removed 1 mm material from the surface, during the procedure the thickness of the oxide layer was decreased or totally removed. The relative surface area is increased compared to the untreated aluminium surface, because the grinding stone. The connection between the surface properties and tensile force shows that the relative surface area and the oxide removal has high effect to the adhesion force on the aluminium surface using cyanoacrylate / acrylic glue.

3.4. Effect of the different surface modification for the tensile force using epoxy high strength structural adhesive

The tensile force of the epoxy high strength adhesive depending on the AlMgSi1 sheets surface modification can be seen in figure 6.

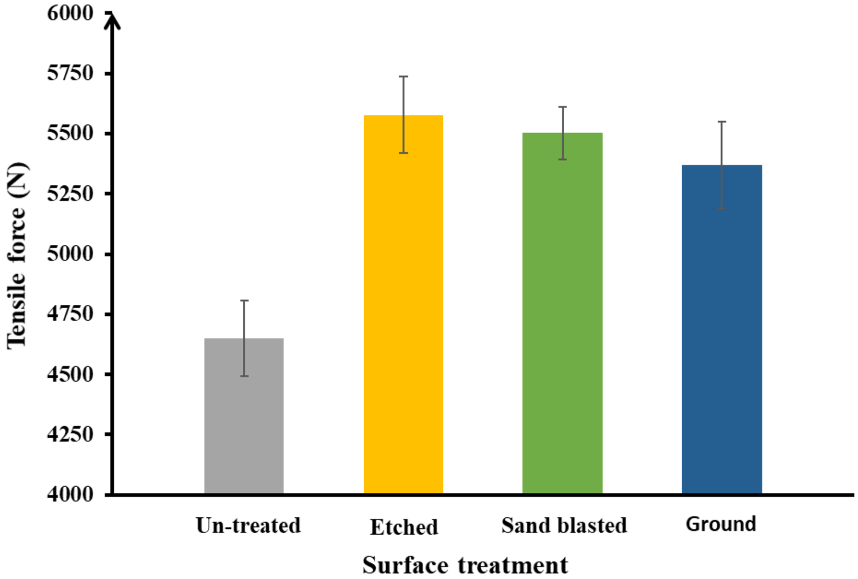

Figure 6. Effect of the different surface modifications for the Al – CFRP hybrid joints using epoxy high strength structural adhesive.

Table 3. The tensile force of the different hybrid joints using epoxy high strength structural adhesive.

Effect of surface treatments using Loctite 9466 high strength adhesive				
Surface treatment	**Tensile force (N)**	**Tensile stress (MPa)**	**Ra (μm)**	**Rz (μm)**
Un-treated	4650	31	0.5	5.8
Etched	5578	36.7	6.7	34.9
Sand blasted	5369	37.2	5.6	40.4
Ground	5502	35.8	7.5	57.9

The control results are the un-treated Al – CFRP joints with epoxy adhesive. The adhesive joint with the un-treated aluminium reached 4650 N, which is 360% higher than using the hybrid acrylic glue. The surface preparation methods changed the adhesive force between the aluminium and the glue, but the level of the increase is lower than using acrylic glue. There is no significant difference between the etched, sand blasted and ground aluminium surface, both of these surface preparation methods removed or changed the surface oxide layer on the AlMgSi1 surface and made homogenous surface topology.

3.5. Effect of the different surface modification for the breaking method

The breaking methods during the tensile test can be seen in figure 7.

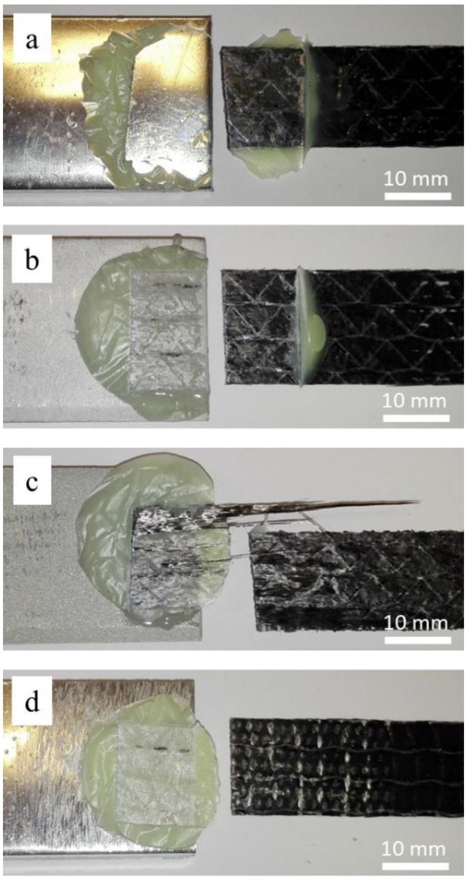

Figure 7. Breaking methods during the tensile test using epoxy adhesive and surface treatments: a: un-treated, b: etched with hydrochloride acid, c: sand blasted with 0.3 – 0.7 mm grain, d: ground with P10 grinding stone.

In case of untreated joints the aluminium surface has the original as received topology, roughness, oxide layer and these cause that the two component epoxy absolutely separated from the aluminium surface. The adhesive and wetting properties had wrong condition on the un-treated surface (figure 7, a). When the surfaces of the AlMgSi1 were modified the epoxy adhesive remained all over on the surface of aluminium (figure 7, b,c,d), during these test the adhesion force between the glue and the CFRP shows the weakest point of the hybrid joints.

4. Conclusion

In this research, the adhesive joining technology of Carbon Fiber Reinforced Plastic and AlMgSi1 sheets hybrid joints were investigated using cyanoacrylate mixed acrylic and high strength epoxy structural adhesive, to improve the strength of the joints 4 different surface preparation method was used only on the aluminum surface. The following conclusions can be drawn from this study:

- The highest tensile strength can be created with sand blasting surface preparation with this technical parameter. The increasing of the strength is more than 10%.

5. References

[1] G Béres, Z Weltsch, 2018 Estimation of Strength Properties from Microhardness Results in Dual Phase Steels with Different Martensite Volume Fraction, *PERIODICA POLYTECHNICA-TRANSPORTATION ENGINEERING*, 4 pp. 1-7.
[2] H Chung, K Rhee, B Lee, J H Lee, 2009 Effect of oxygen plasma treatment on the bonding

strength of CFRP/aluminum foam composite, *Journal of Alloys and Compounds*, Volume 481, Issues 1–2, Pages 214-219,

[3] Z Weltsch, K Klam, A Lovas, 2017. The Comparison of Hardness and Coercivity Evolution in Various Fe–B Based Glasses (Including FINEMET Precursor) during Relaxation and Crystallization, *ACTA PHYSICA POLONICA A* 131:(4) pp. 669-671.

[4] M Berczeli, Z Weltsch, 2018. Experimental Studies of Different Strength Steels MIG Brazed Joints, *PERIODICA POLYTECHNICA-TRANSPORTATION ENGINEERING* 46:(2) pp. 63-68.

[5] 2. G Gergely, D Koncz-Horvath, Z Weltsch, Z Gacsi, 2017 Development of crack detection method with 2 dimensionally generated 3 dimensionally reconstructed images in THT solder joints, *ARCHIVES OF METALLURGY AND MATERIALS* 62:(2) pp. 1033-1038.

[6] J Hlinka, Z Weltsch, 2013. Relation between the Wetting Property and Electrical Conduction of Silver-Gold (Ag-Au) Alloys, *PERIODICA POLYTECHNICA-TRANSPORTATION ENGINEERING* Vol 41:(No 2) pp. 95-98.

[7] I Salacz, Z Weltsch, 2013. Alloying Effects on Wetting Ability of Diluted Cu-Sn Melts on Graphite Substrates, *PERIODICA POLYTECHNICA-TRANSPORTATION ENGINEERING* Vol 41:(No 2) pp. 123-126.

[8] A Dezso, G Kaptay, 2016. On the configurational entropy of nanoscale solutions for more accurate surface and bulk nano-thermodynamic calculations", *Entr.*, vol. 19, no. 6, pp. 248-259,

[9] R D Hussein, D Ruan, G. Lu 2017. Cutting and crushing of square aluminium/CFRP tubes", *In Comp. Str.*, vol. 171, pp. 403-418,

[10] R Neugebauer, Ć C Lies, Ć Hohlfeld, Ć . Hipke, 2007. Adhesion in sandwiches with aluminum foam core *Prod. Eng. Res. Devel.*, vol. 1, pp. 271–278.

[11] G Kim, F Ajersch, 1997. Surface energy and chemical characteristics of interfaces of adhesively bonded aluminium joints, *J. Mater. Sci*., vol. 29, no. 3, pp. 676–81.

[12] A Pramanik, A K Basak, Y Dong, P K Sarker, M S Uddin, G Littlefair, A R Dixit, S Chattopadhyaya, 2017. Joining of carbon fibre reinforced polymer (CFRP) composites and aluminium alloys – A review, *I. Comp. Part A: Apl. Sci. and Manuf.*, vol. 101, pp. 1-29.

[13] G Béres, Z Weltsch, Zs Lukács, M Tisza, 2018. Prediction of stress- and strain-based forming limits of automotive thin sheets by numerical, theoterical and experimental methods, *AIP CONFERENCE PROCEEDINGS* 1960: Paper 160002.

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