Improvement of adhesive joining of hybrid aluminum – GFRP using surface modifications

M Berczeli¹, Z Weltsch¹

¹John von Neumann University Department of Material Science,

berczeli.miklos@gamf.uni-neumann.hu

Abstract. One of the biggest research discipline todays is the weight reduction of the vehicles. The manufacturers are focusing on making new hybrid materials and innovative technologies that satisfy the newest requirements, such as light weighting. There exist many solutions to reach lower vehicle weight, reduce the air pollution and CO2 emission. One of them is the hybrid materials pairing in the different part of the vehicle body. These joining technologies have to complete the new requirements for hybrid joints for this the weakest part of the bonding have to increased. The strength of the adhesive joining can be increased with different surface preparation methods. In this research five different surface treatment were investigated to increase the tensile stress of the overlapped Glass Fiber Reinforced Plastic and Aluminum sheets. The macro geometry of the connecting materials, the tension stress and the breaking method were investigated during the analysis. The research investigates the connection between the surface properties and the adhesive technology using hybrid materials connection.

1. Introduction

Nowadays the vehicle industry has certainly begun to show signs of rebounding from the economic downturn, however, companies needs to “do more with less” as production volumes approach the levels of several years ago. Over the decades, these numbers of the new vehicles show a negative impact on the environment and human health. The increasing air pollution from the vehicle sector has led many government agencies to lay strict regulations on the automobile manufacturers to curb the harmful emissions under permissible limits [1].

Over years, the old, standard vehicles get more and more new features, new luxury elements, higher power and higher safety, these buyer requirements cause the increasing of the car weight.

Figure 1 shows the increasing of the weight for example on a Suzuki swift from 785 kg to 1200 kg over the years. The EU agency has set mandatory emission reduction targets for the automaker companies and this cause a breakpoint in the increasing weight. According to EU rules, the fleet average by cars to be achieved by 2020 must be 95°gramms of Co2/kilometer, which works out to a fuel consumption rate of around 4.1 liter/100 km of petrol or 3.6 liter/100 kilometer of diesel [2].
The weight reduction can be reached with new, innovative, hybrid material usage in the vehicles. The manufacturers are using different types of steels in the body, depending on what the function of the structural element. Where they need higher strength and stiffness, because of the safety, they use high ultimate strength steels. In case of accident, where the deformation and the energy absorption is the important, they use lower strength, generally used non-alloyed DC steels (figure 2) [3]. The most of the body contains aluminum sheets, with this the weight can be reduced, with the same strength of the body.

**Figure 1.** Trend of the vehicles weight over years [2].

**Figure 2.** Different hybrid material usage in a new 2018 vehicle [4].

The typical joining methods on the vehicle body are the riveting, welding and bolts. The hybrid combination of these materials would not be possible without the researches of new bonding technologies.

The adhesive bonding technologies are a rapidly growing disciplines. Applications of adhesives for joining elements made of dissimilar, hybrid materials. Joining of fiber reinforced plastics with aluminum alloys using adhesive bonding is by far the most conventional method with both advantages and
limitations [5]. The adhesives as the main part in the adhesive bonding should have good wettability with respect to joining components [6]. Using mechanical or chemical surface preparation on the materials the surface energy can be increased and it causes the increasing of the joining quality. The surface treatment modifies the surface roughness of the joining materials, reduce the oxide layer thickness and increase the wettability [7]. There are some treatments which has negative effect on the surface energy, these are the super hydrophobic surfaces [8] There is also manufacturing methods which can decrease the smooth of the surface of the GFRP [9,10]. To increase the adhesive strength between the materials and the adhesive, the optimal surface energy status is the hydrophilic.

Our goal is the optimization of making a hybrid adhesive joint between aluminum sheets and Glass Fiber Reinforced Plastic using different surface treatments. For this it has to be investigated the effect of the different surface treatment on the hybrid adhesive bonding.

2. Experimental procedure

The materials for the present investigation are non-coated AlSiMg1 sheet of 2 mm and Glass Fiber Reinforced Plastic (GFRP) of 2.5 mm thickness. The GFRP were vacuum laminated during 24 hours using 10 layer of 1 x 1 mm weave glass fiber and epoxy glue. The aluminum plates were mechanically sectioned to avoid heat input, into 70 x 70 mm, the GFRP into 70 x 25 mm. Before the joining method, the surface off the GFRP were grinded to remove the form separating layer. The GFRP has not modified with any treatment, only the grinding and the degreasing method by cleaning spray. The aluminum and GFRP surfaces were all cleaned and degreased with cleaning spray. 5 different surface preparation method were used during the research: the un-treated and un-cleaned surface, only cleaned 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 Loctite 9466 2 component epoxy adhesive, with this adhesive high strength of hybrid bonding can be created. First step of the adhesive method was the cleaning of all the contact surfaces (except the uncleaned type of the materials), and glue the materials on 20 x 20 mm area overlapped surface (figure 3). The hybrid joints were pressed over 24 hours in a bending machine, this time needs to reach the 100% strength of the adhesive.

![Figure 3. Adhesive procedure setup and connecting area.](image)

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 in a Instron 5900R testing machine at a cross-head speed of 2 mm/min (figure 4). 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.
3. Results

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

After the surface preparation of the aluminum sheets the surface roughness measurement were performed. In figure 5 the macroscopic topography and the roughness of the surface can be seen.

The original, as received surface is a very smooth, mirrored surface with a Rz= 5.8 µm, on this surface preparation the effect of the un-treated and un-cleaned strength of adhesive joints were investigated. The first mechanical prepared was the grinding with 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 surface, it causes 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 removed mechanically. The chemical etching in thin hydrochloride acid cause homogenous surface with Rz= 57.7 µm, also the etching has effect on the oxide removal.
3.2. Effect of the different surface modification for the tensile strength

In figure 6 the effect of the surface cleaning and degreasing to tensile strength of the hybrid joints can be seen, using aluminum surface of un-cleaned/un-treated and cleaned/un-treated. The diagrams contain the error bars of each type of surface treated joints.

![Tensile strength diagram](image)

**Figure 6.** Effect of the surface chemical cleaning on the tensile strength.

As the results show, the un-cleaned joints has tensile strength of 3485 N and 8.7 MPa. The strength of cleaned samples was 4662 N and 11.7 MPa. The chemical spray cleaning both of the GFRP and aluminum surface cause 34% increasing of the strength. The first tensile results predict, that the cleaning should be used every time before the adhesive joining.

In figure 7 the effect of the surface treatment can be seen for the tensile strength of the hybrid GFRP and aluminum joints. The diagram contains the error bars and the Rz values of each surfaces. In this case all the connecting surfaces were chemically cleaned, only the effect of the surface topology can be seen.
Figure 7. Effect of the different surface modification on the tensile strength.

The tensile strength of the adhesive joints changed using different surface preparation. The un-treated has 4662 N, 11.7 MPa, the chemically etched has 4850 N, 12.1 MPa, the grinded has 4985 N, 12.5 MPa and the sand blasted 5044 N, 12.6MPa of tensile strength. The error in case of the treated surfaces shows lower value because of the homogenous surface topography compared to the un-treated aluminum. The highest strength can be reached using sand blasted surface with these technical setups. The connection between the surface roughness and the tensile strength shows parabolic trend, so there is an optimal roughness value for this adhesive. The sand blasting preparation can increase the strength of the hybrid joints more than 10%.

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

In addition to the changing of the tensile strength, the surface modification procedures resulted in different breaking methods for the specimens. In figure 8 the connection surfaces of the un-cleaned/un-treated samples can be seen after the breaking.
Figure 8. Separation method of un-treated/un-cleaned specimens.

The adhesion between the adhesive and the aluminum is totally chased, the adhesive separated from the aluminum surface. This could be because of the dirt or remained grease, these cause the lower adhesion forces and the bad wettability properties. In contrast, the figure 9 shows the cleaned/un-treated joints.

Figure 9. Effect of the surface cleaning and degreasing on the separation method.

In this case the adhesive shows lower adhesion force to the aluminum too, but the is remaining adhesive on the aluminum surface. The adhesion force is higher on the aluminum surface locally, than on the GFRP.

The figure 10 shows the hybrid joints using etched aluminum specimens.
Figure 10. Breaking method using etched aluminum samples.

The adhesion force is higher on the aluminum, than the GFRP. The adhesive almost full remained on the etched surface aluminum sheet, then the GFRP.

Figure 11 shows the breaking method using grinded treatment.

Figure 11. Breaking method using grinded aluminum specimens.

The adhesion force is acceptable on the aluminum surface in case of grinded surfaces. All of the adhesive is separated from the glass fiber reinforced plastic. The breaking method shows that from this value of strength the weakest part of the hybrid joints is the plastic.

The breaking method of hybrid joints with the highest strength can be seen in figure 12.
The adhesive remained on every part of the aluminum, the sand blasting increased the wetting properties between the adhesive and the aluminum sheets. During the strain one layer of the GFRP ripped out from the plastic in the 20 x 20 mm connection area, with the blasting the strength limit of the GFRP has been reached.

4. Conclusion
In this research, the optimization of hybrid GFRP and aluminum sheets joints were investigated using high strength epoxy adhesive and different surface modifications only on the aluminum surface. The following conclusions can be drawn from this study:

• Different surface treatments can be used to create homogenous surfaces for adhesive procedures.
• The wetting properties of the connection surfaces can be changed with surface treatments for adhesive technologies.
• The chemically cleaning increased the tensile stress of GFRP and aluminum with 34 percent, compared to the un-cleaned situation.
• In case of bad wetting condition there is no remaining adhesive on the aluminum surface after the separation.
• The connection between the surface roughness and tensile strength shows parabolic trend using high strength 2 component epoxy adhesive, GFRP and aluminum.
• 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%.

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