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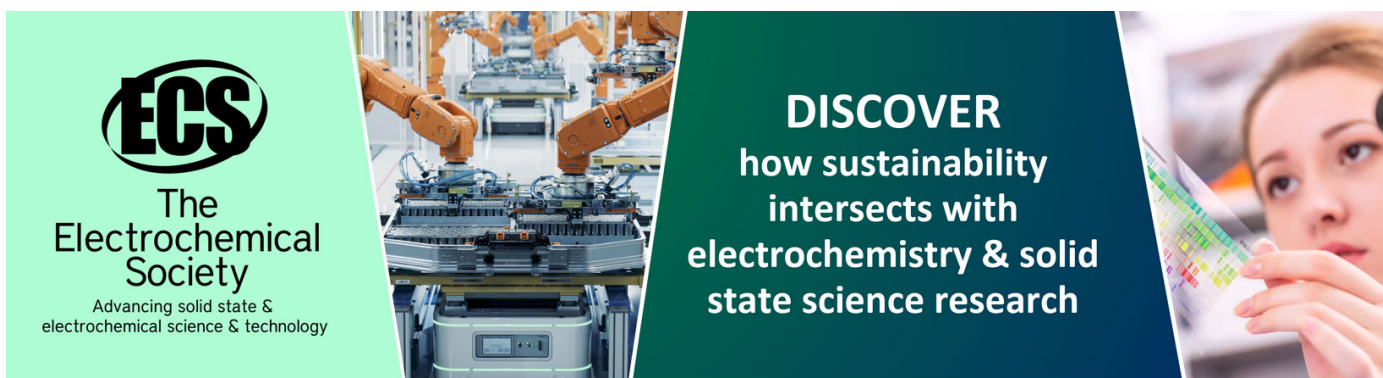
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Bending and tensile test of glued aluminium foams

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Abstract. The hybrid material usage is an innovative way to improve the strength performance of the vehicles without causing useless weight increasing. One of the main goals of the competition sports are to lose more and more weight, meanwhile the vehicle needs to accepted on the certifications. That is the reason why new and special materials, like the aluminum foam what belongs to the metal matrix composites should be used. The purpose of this research is that the aluminum foam can be used safely as supporting element in the motorcycle body. In this paper a frame and swing arm of a racing motorcycle using aluminum foam and carbon fabric composite has been made. Adhesive bonding was used to create the hybrid material pairing. To investigate the strength properties of this hybrid aluminum foam and composites tensile and bending tests were performed. The results are used for calculations of the motorcycle body parameters, base information to the designing.

1. Introduction

1.1. Properties of aluminum foams

Composite and foam materials have begun to replace traditional materials because of the necessity for a more economical use of energy. Metal foams can be used in a wide range of fields from mechanical to thermal applications thanks to their superb strength/weight ratios.

Metal foams offer unique physical and mechanical combinations such as high resistance and lower specific gravities or high gas permeability and superior thermal conduction. Despite the many advantages features of metal foams for using in industry must have the appropriate assembly techniques. Research of foam materials are generally limited to production of foam, studies on secondary operations of foam are insufficient [1].

Metal foam is cellular material as wood, so they can be joined with techniques for developed woods joining such as wood screws, adhesive joints and embedded links. Also using joining techniques of metals is possible for metal foams [1-3].

Metal foams have properties which make them attractive in light-weight construction, for energy absorption devices and for acoustic or thermal control. All these fields are relevant for automotive industry, which has been extremely interested in them since they were first developed. Potential applications also exist in ship building, aerospace industry and civil engineering [1, 2].



Light-weight construction: foams can be used to optimize the weight-specific bending stiffness of engineering components. For example, the bending stiffness of flat foam panels of a given weight, width and length is approximately proportional to their thickness, and therefore inversely related to density.

1.2. Advantages of using aluminium foams in the competition sports

True optimization, however, calls for more elaborate solutions as will be discussed below. In any case, light-weight construction exploits the quasi-elastic and reversible part of the load-deformation curve [3].

Energy absorption: owing to their high porosity, foams can absorb a large quantity of mechanical energy when they are deformed, while stresses are limited to the compression strength of the material. Foams can therefore act as impact energy absorbers which limit accelerations in crash situations. This mode exploits the horizontal, irreversible part of the load-deformation diagram. As metal foams can have much higher collapse strengths than polymer-based foams – up to 20 MPa – they can find applications in areas not accessible to foams up to date [4].

Acoustic and thermal control: foams can damp vibrations and absorb sound under certain conditions. Moreover, their thermal conductivity is low. These properties are not outstanding – polymer foams are much better sound absorbers – but they could be useful in combination with other features of the foam. This application makes use of the internal configuration of a foam, namely the labyrinth of struts and the associated air-filled voids [5, 6].

In this paper the mechanical testing of these aluminum foams are usually the tensile and the bending test, the results could give us in this paper information about the energy absorption effect of the parts [7, 8]. Our goal was to using the mechanical test results, the competition race parts could be optimized and simulated.

2. Experimental procedure

2.1. Manufacturing of aluminum foams

Nowadays we meet with special hybrid material pairing in the race cars or motorcycles body. The aluminum foam is one of them, that belongs to the metal matrix composites groups. In this research the foam was made with molding process for building, because of this process we had to work with fix size aluminum foam tables. More over by the frame's production we could not work with just one aluminum foam table, because of the frame's size. The sizes of these frames have limitation because of the manufacturing processes. To increase the useful are of the aluminum foam frame's joining technologies should be used. After examining of advantages of the binding methods and considering the properties of this hybrid material agglutination was used [11]. It should be mentioned the aluminum foam have a way better damping effect so less sound damping material should be needed. The rider's safe is very important, but also the vehicle's safe too [12, 13]. To increase the mechanical properties of these foams carbon fiber reinforced composite (CFRC) should be used over the foam.

2.2. Preparation of tensile tested specimens of adhesive joined aluminum foams

In order to investigate the possibility of adhesive joining of aluminum foam frames Al 6061 aluminum with 0.6 gramm/ccm foam density was used for the tensile test specimen. Two types of glue and four types of connection profiles were used. The two type glue was: Loctite 9466 two component high strength adhesive and Terokal 5055 two component structural adhesive. The four different connection profile can be seen in figure 1.

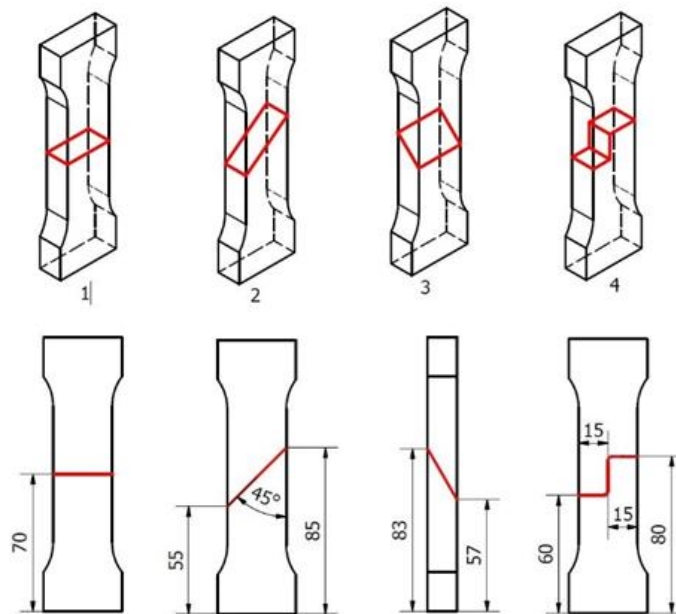


Figure 1. 4 different type of connection profile for adhesion possibility test, 1-4 type from left to right.

The motivation of the different cutting planes were to increase the useful surface for the adhesive bonding technology. The specimens were prepared for the tensile test using milling machine. The geometry of the standard tensile test specimen of the aluminum foam can be seen on figure 2. The final aluminum foam specimens with 4 different type can be seen on figure 3.

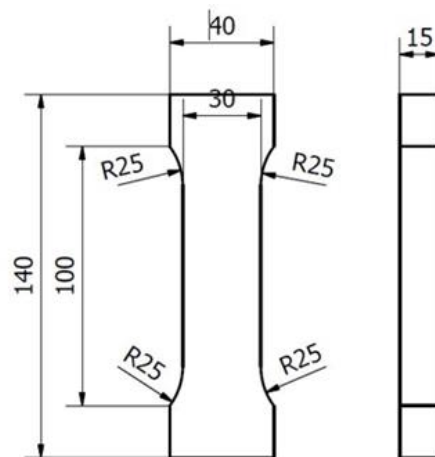


Figure 2. Geometry of tensile test specimen.



Figure 3. Tensile test specimens before the adhesive procedure, 1-4 type from left to right.

For the tensile test an Instron 4482 general tensile test machine was used with a cross head speed of 10 mm/min.

2.3. Preparation of bending tested specimens of CFRC coated aluminum foam wing arm

We used AlSi 10 and 0.5 gramm/ccm density foam made by melt gas injection method.as core part of the wing arm (figure 4).



Figure 4. Motorcycle wing arm made from aluminum foam as core part.

The separated foam frames were connected using adhesive joining method. The used glue was a Loctite Terokol 5055 two component glue. After the joining of the foams the part was coated with a micro ballon layer. (UD) carbonfiber layers were used to increase the stiffness of the arm using longitudinal direction during the vacuum lamination process. Heat treatment was used to increase the adhesive and cohesion force between the connected parts.

The final profile of the cross sectioned arm can be seen in figure 5.

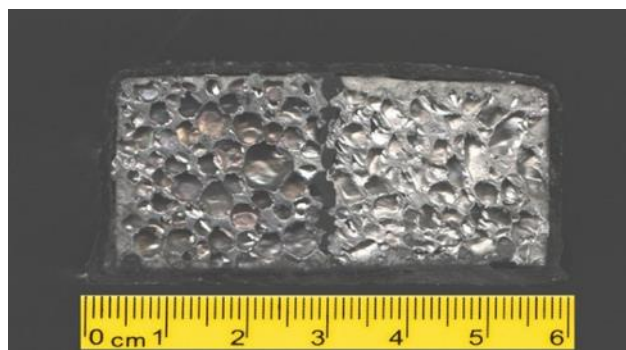


Figure 5. Motorcycle wing arm made from 2 aluminum foam frames as core part and CFRC as reinforce part.

For the bending test a smaller part was cutted out from the wing arm with a length of 400 mm. The bending test was made with Instrion 4482 general tensile machine using 3 point bending test. The figure 6 and 7 shows the setup of the bending procedure. The bending test was carried out until the specimen did not slip down on the support elements.

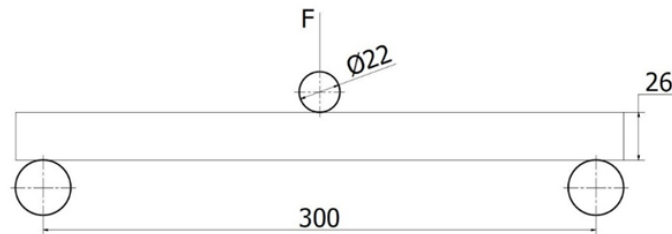


Figure 6. Setup of the 3 point bending test.



Figure 7. End point of the bending test.

3. Results

3.1. *Effect of the different type of connection surfaces for the adhesive joining of aluminum foam specimens*

The experiment shows that the chosen glues were stronger than the aluminium foam tensile strength even at the smallest cross-section of the specimens. Type 2 sectioned specimen break method can be seen in figure 8, the breaking plane is much above from the connected surfaces. As a result, both of the yield strengths and the tensile strengths were the Al 6061 0.6 gram/ccm aluminium foam mechanical properties, the differences could be due the preparation and production technology. It can be seen from the comparison of the samples' tensile strength with its weight that there is no significant connection between the weight and the tensile strength of the aluminium foams (table 1).

This is due to the fact that there might be some material defects inside the samples that weaken the structure of the samples at a given cross-section. Based on the measurements the tensile strength of the tested foam type is: $R_m = 7.65$ MPa, while its yield strength is $R_{ha} = 2.64$ MPa.

Table 1. The summarizing results of the tensile test of the 4 different type of connection surfaces using 2 different glue.

Number of test specimens	Weight without glue (gramm)	Weight with glue (gramm)	Weight of glue (gramm)	Type of the glue	Geometry type of the connection surfaces	Yield point (MPa)	Tensile strenght (MPa)
1	45.27	45.53	0.26	Loctite 9466	1	2.01	6.91
2	40.69	40.93	0.24	Terokal 5055	1	2.21	7.32
3	33.51	34.49	0.98	Loctite 9466	2	2.82	5.94
4	34.72	35.39	0.67	Terokal 5055	2	3.05	6.38
5	46.02	46.37	0.35	Loctite 9466	3	2.51	8.63
6	44.79	45.03	0.24	Terokal 5055	3	2.47	8.87
7	37.98	38.64	0.66	Loctite 9466	4	2.83	7.58
8	40.01	40.32	0.31	Terokal 5055	4	2.96	7.74

**Figure 8.** The breaking line is above from the connected plane.

The aim of the test was to find out as to what extent it is necessary to extend the bonding surface so that they can be applied safely and securely. The test revealed that in the case of the 0.6 gram/cm foam – made with Al6061 aluminium alloy – the chosen glues did not require the extension of the bonding surface when the two parts were put together.

3.2. Bending properties of adhesive joined of aluminum foam frames with Carbon Fiber Reinforced Composite

The result of the bending test can be seen on figure 9.

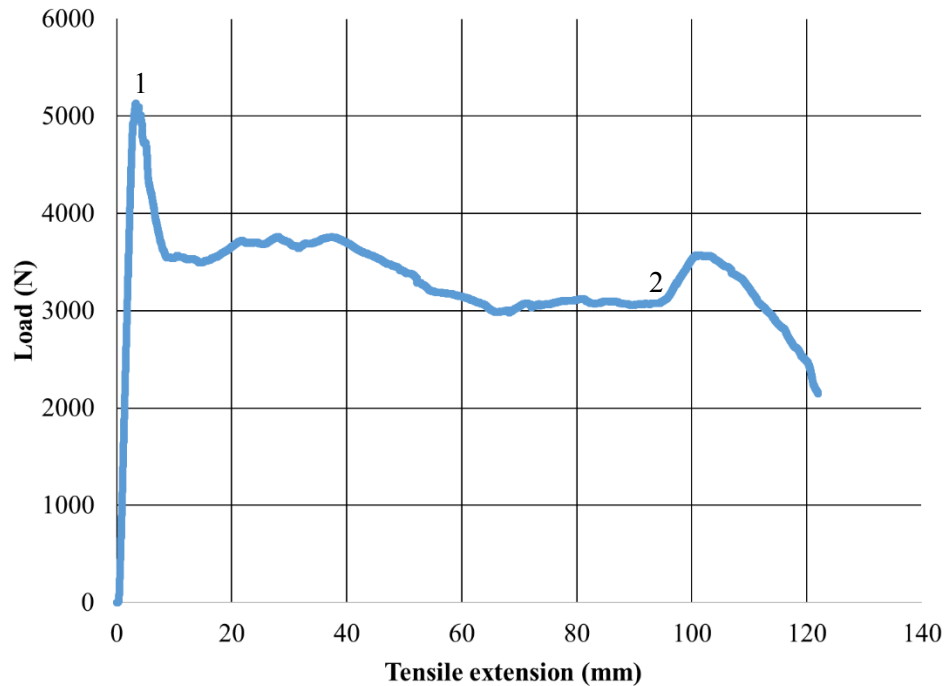


Figure 9. The results of the 3 point bending test.

The maximum load was 5140 N during the measurement, the R_{mh} bending strength can be calculated in the point 1. The calculation to measure the available maximum stress at fracture (1 point):

$$R_{mh} = \frac{M_{max}}{K} = \frac{384750 \text{ Nm}}{6480 \text{ mm}^3} = 59.4 \frac{\text{N}}{\text{mm}^2} \approx 60 \frac{\text{N}}{\text{mm}^2} \quad (1)$$

,where R_{mh} the sought bending strength, M the maximum bending moment on the specimen, K is the factor of cross-section.

The calculation of M_{max} (2), and K factor (3):

$$M_{max} = \frac{F_{max} \cdot l}{4} = \frac{5130 \text{ N} \times 300 \text{ mm}}{4} = 384750 \text{ Nmm} \quad (2)$$

$$K = \frac{a \cdot b^2}{6} = \frac{57.5 \text{ mm} \times 26 \text{ mm}^2}{6} = 6478.23 \text{ mm}^3 \approx 6480 \text{ mm}^3 \quad (3)$$

Using these results, the optimization of the wing arm for bending can be calculated, designed. At the bending marked points in figure 10 the effect of the load increasing can be seen. In this optimization method and design of the hybrid pairing of wing arm, only the result data before the highest load could be used. After the moment when the part cause deformation on the 3 point bending support elements, the results can cause mistakes.

The purpose of the test is that the determination of the flexural strength on the thinnest cross-section of the motorcycle swing arm. The flexural strength is $R_{mh} = 59.4 \text{ N/mm}^2$, with this data the simulation and optimization of the swing arm can be reached.



Figure 10. Picture of the bended test specimen with the surface damage that made by the support element of the bending tool.

4. Future plan

In good engineering practices it is necessary to be aware of nature and attributions of the tested material, which we take into account in the engineering process. With these information in mind, we are able to develop products more effectively and economically. With the application of such innovative materials in the vehicle industry as aluminium foam, it is crucial that we use the engineered party safely. In the present test, we measured the possible weaknesses of an oversized construction. The tests justify that if we laminate the sample with appropriate carbon fibre layer and using these glues before tensing, the bonding would not have any weaknesses. These results were successful in the case of the prototype. The real challenge for the foams is to gain ground in a broader market. In order for it to be more affordable, further tests need to be implemented. In the case of composite materials, there is a great potential in the simplification of its production process, as well as in the more optimal choice of the fibre direction. In the case of bonding, it is more expedient to repeat the above test/experiment with cheaper glue.

5. Conclusion

In this research, the tensile properties of the different type of connection surfaces using two different type of glue and the bending properties of adhesive bonded aluminum frames coated with CFRC were investigated. The following conclusions can be drawn from this study:

- In case of adhesive joining of aluminum foam frames using the standard geometry of tensile specimens and different connection surfaces plains does not cause any joining problem.
- Both of the Loctite and Terokal glues were able to create an adhesive joining which has higher tensile strength than the aluminum foams.
- In every case of tensile test the aluminum foam broke far from the adhesive connected surfaces.
- The tensile strength of the tested Al 6061 0.6 gram/ccm foam is $R_m = 7.65$ MPa, the yield strength is $R_{ha} = 2.64$ MPa
- The maximum bending moment on the cross section of wing arm was 384750 Nmm.

- The flexural strength of the arm is $R_{mh} = 59.4 \text{ N/mm}^2$.
- Results from this paper can be used to optimize and simulate the adhesive bonded lightweight vehicle parts made from aluminum foam and carbon fibre reinforced composite.

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