TESTING OF MULTI-MATERIAL ADHESIVE JOINTS FOR PROTOTYPE VEHICLES

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Abstract

This work examines the properties of bonded joints used in prototype vehicles with an emphasis on factors that affect joint strength and service life. Selected materials, including EN AW 5754 aluminum plates, S235 structural steel and carbon composites, are bonded with various adhesives after surface preparation by sandblasting and cleaning. The study examines the durability of these joints and compares them to assess their durability and effectiveness in automotive applications. The practical part describes the experiment from the selection of materials, the preparation of surfaces for gluing and the selection of glue. This is followed by the implementation of the experimental part, which includes the gluing process itself and testing the resistance of the joint using a tear test. In the final section, an evaluation of the measurement results, to which a final summary was completed, is carried out.

Keywords: Adhesive joints; surface roughness; interlacing; simply lap joint; shear load

1. INTRODUCTION

The topic of bonded joints encompasses a complex set of challenges and issues associated with the process of bonding materials that profoundly affect the functionality and reliability of the resulting joint. This issue is of paramount importance in various industries, including industrial manufacturing, automotive, aerospace, electronics and medical, where bonded joints are prevalent. One of the main obstacles relates to the adhesion between the surfaces of the material being joined, which has a direct impact on the strength and stability of the joint. The strength of adhesion is subject to various factors such as surface contaminants, material chemistry and surface finish prior to bonding. Another challenge is the precise dosage and application of the adhesive to achieve optimum joint performance and mitigate the risk of joint defects.

Joining of different materials is a common practice in the automotive industry. Bonding technology is used for joining due to its simplicity and speed in mass production. Compared to older techniques of joining of different materials, bonding brings several benefits. For example, the absence of thermal stresses on the base materials, which leads to maintaining their strength while allowing lighter joints to be achieved.

Modern vehicles also use composites, aluminium and magnesium alloys, or carbon or Kevlar fibres to reinforce the body, but bonded joints remain an essential part of their construction. The materials used for the bodywork, as well as the adhesives, are required to meet high standards of quality, functionality, durability and workability.

At first glance, the bonding technology looks so simply, but designing the bonded joint to ensure its strength and desired mechanical properties is a fairly complex discipline. In general, the guaranteed strength of the adhesive as stated by the manufacturer in the technical data sheet of the adhesive type cannot be relied upon, it is also necessary to verify the designed surface preparation technology that matters most. The surface roughness has a great influence on the strength of the bonded joint [1]. Another major influence on the strength of the bonded joint is the thickness of the adhesive [2, 3]. To verify the strength of the bonded joint, tensile testing is most often used, where the test specimen is defined by ČSN EN 1465 (668510). In the case of joining different materials using adhesive bonding technology, the situation is even more complicated, because the selected type of adhesive may not have a guaranteed adhesion on different material surfaces. Therefore, it is

necessary to test the properties of the bonded joint of different types of materials. The bonding of different types of materials is determined by the development of the prototype.

All materials were surface treated by sand blasting in a sand blasting box with brown corundum abrasive F090. After blasting, the surface roughness of each sample was measured. In our case, we investigated the bonded joint of two different materials with different types of adherend. In the first case, the bonded joints of two aluminium alloys EN AW 5754 (marked Al), aluminium alloy EN AW 5754 + Carbon composite (marked C), aluminium alloy EN AW 5754 + steel S235JR (marked Fe), Carbon composite + Carbon composite, Steel S235JR + Carbon composite and the joint of two plates of steel S235.

2. EXPERIMENTAL

At the beginning of the experiment, an experimental program was established, see **Table 1**, where the types of adhesives and materials of the bonded joints were determined. To ensure that the measurements were telling and reproducible, 5 specimens were made for each type of bonded joint. Thus, the strengths of 3 types of adhesives were compared on a total of 6 different types of bonded joints listed in the table.

Table 1 Experimental program

Type of Glue	Experimental materials					
DP460, 3M Scotch-weld	EN AW 5754 + EN AW 5754	EN AW 5754 + Carbon fibre	EN AW 5754 + Steel S235 JR	Carbon Fibre + Carbon Fibre	Carbon Fibre + Steel S235 JR	Steel S235 JR + Steel S235 JR
7260 B/A FC, 3M Scotch-weld						
LOCTITE EA 9497, Henkel Adhesives						

2.1. Specifications of the used adhesives:

DP 460 3M Scotch-weld – It is a two-component epoxy adhesive, hardened at room temperature. It is a modified epoxy adhesive, and the hardener is a modified amine. The processability of the adhesive is 60 minutes, final hardened after 120 hours.

7260 B/A FC, 3M Scotch-weld – is a fast hardened two-component epoxy adhesive. It contains 0.3 mm glass beads to create a precise adhesive thickness when bonding. The processability of the adhesive is 120 min. Final adhesive hardening after 7 days.

LOCTITE EA 9497, Henkel Adhesives – It is a two-component epoxy adhesive that hardened at room temperature. Working time 165 - 255 minutes. Final hardening after 7 days.

2.2. Precision bonding agent

For the repeatability of the bonding process, a product was used that guaranteed accurate bonding of the samples and also the correct thickness of the adhesive, which was set according to the technical data sheet at 0.3 ± 0.05 mm for all samples.

The bonded area of the specimen was 12.5 ± 0.25 mm long and the width of the bonded joint was 25 mm ± 0.25 mm. Thus, the total length of the bonded test specimen was 187.5 mm. These dimensions were based on ČSN EN 1465.

2.3. Sample surface preparation and surface roughness measurement.

The surface of the selected materials was prepared using the shot blasting method in the SBC 420 shot blast box. The abrasive used was brown corundum abrasive F090.

For the EN AW 5754 material, the measured value of Ra = 3.14 ± 0.15 µm for the carbon composite material, the surface roughness value Ra = 3.82 ± 0.2 µm and, the surface roughness value for the S235JR steel material was measured to be Ra = 2.91 ± 0.15 µm. The measurements were carried out using a Mitutoyo SJ 410. After mechanical cleaning using the shot blasting method, the surfaces at the bonding point were cleaned using isopropyl alcohol, which ensured the cleaning and degreasing the surface before gluing. Subsequently, samples were also created without surface treatment and only cleaned with isopropyl alcohol.

The carbon fibre cloth samples were prepared by using a vacuum infusion method, where the carbon composite was formed from 3 layers of fabrics. The first layer of carbon fabric was Industrial Carbon, twill, 2/2, 245 g/m^2, the other two layers of carbon fabric were Industrial Carbon, twill, 2/2, 600 g/m^2.

2.4. Tensile test

The tensile test according to ČSN EN 1465 (668510) - Determination of shear strength under tensile stress of re-soldered glued assemblies was performed on the SHIMADZU AG-X plus 50 kN tear-off machine. The specimens were tested using a tensile strength test where the specimen was clamped between two jaws vertically.

3. RESULTS

In the context of the large number of samples and tensile tests performed, bar charts were reated for clarity and contain the standard deviation based on individual tensile test measurements for seven samples for one given adhesive type.

3.1. Glued joints Al – Al

Interesting values for the bonding of the EN AW 5754 aluminium alloy joint were achieved by the bonded joint with DP 460 adhesive, which showed the highest tensile stress of 26.0 MPa, the value of the average tensile stress was 24.9 MPa, the value of the standard deviation was 0.95 MPa. The average elongation value was 1.46 mm. The bonded joint formed with S-W 7260 adhesive showed the highest tensile stress 25.8 MPa, an average tensile stress value of 22.9 MPa and a standard deviation of measurement of 1.2 MPa. The average elongation value here was around 1.01 mm. The bonded joint formed with EA 9497 adhesive showed the highest tensile stress value 17.4 MPa, an average tensile stress of 15.6 MPa, and a standard deviation of 1.01 MPa. The average elongation value was 0.39 mm. A graph comparing the results is shown in (**Figure 1**).

3.2. Glued joints Al – C

The bonded joint of aluminium and carbon composite formed by DP 460 adhesive showed the highest tensile stress value of 24.3 MPa, the average tensile stress value was calculated 20.9 MPa, the standard deviation in this case was 0.98 MPa. The value of the average elongation was 0.93 mm. The bonded joint formed with S-W 7260 adhesive showed the highest value of tensile stress 23.9 MPa, the average value of tensile stress was calculated to be 20.5 MPa, the standard deviation in this case was 1.10 MPa and the average elongation was 1.02 mm. The bonded joint formed with EA 9497 adhesive showed the highest value of tensile stress 14.1 MPa, an average tensile stress value of 13.0 MPa, a standard deviation of 0.79 MPa and an average elongation of 0.42 mm. A graph comparing the results is shown in (**Figure 1**).

3.3. Glued joints Al – Fe

The bonded joint of aluminium alloy and steel, formed with DP 460 adhesive, showed the highest value of tensile stress of 29.9 MPa, the average tensile stress was 26.6 MPa, the standard deviation of the measurement was 0.99 MPa and the average elongation of the bonded joint was 1.27 mm. The bonded joint formed with S-W 7260 adhesive showed the highest values of tensile stress 32.8 MPa, the average value of tensile stress was calculated to be 28.5 MPa and the standard deviation was 1.19 MPa. The average elongation of the bonded joint was 1.54 mm. The bonded joint formed with EA 9497 adhesive showed the

highest value of tensile stress 16.0 MPa, the average tensile stress value was calculated to be 15.6 MPa, the standard deviation of the measurement was 0.74 MPa and the average elongation was 0.37 mm. A graph comparing the results is showen in (**Figure 1**).

3.4. Glued joints C – C

The bonded carbon composite joint formed by DP 460 adhesive showed the highest measured tensile stress value of 32.2 MPa, the average tensile stress value was 24.6 MPa. The standard deviation of the measurement was calculated to be 1.32 MPa. The value of the average elongation was 0.95 mm. The bonded joint formed with S-W 7260 adhesive showed the highest value of tensile stress 28.3 MPa, the average value of tensile stress was 20.6 MPa with a standard deviation of 1.52 MPa and an average elongation value of 1.02 mm. The bonded joint formed with EA 9497 adhesive showed the highest tensile stress value 16.1 MPa, the average tensile stress value was 14.9 MPa with a standard deviation of 0.96 MPa. The average elongation of the bonded joint was 0.70 mm. A graph comparing the results is showen in (**Figure 1**).

3.5. Glued joints Fe – C

For the bonded joint of steel material and carbon composite, which was formed with DP 460 adhesive, the bonded joint showed the highest value of tensile stress 34.4 MPa, the average tensile stress value was 28.8 MPa, with a standard deviation of 1.35 MPa. The average elongation during tensile testing was 0.91 mm. The bonded joint formed with S-W 7260 adhesive showed a maximum tensile stress value of 30.5 MPa, an average tensile stress value of 27.9 MPa, with a standard deviation of 1,02 MPa. The average elongation value in tensile test was 0.91 mm. The bonded joint formed with EA 9497 adhesive showed the highest tensile stress value 20.6 MPa, the average value of tensile stress was 17.6 MPa, with a standard deviation of 0.91 MPa. The average elongation of the bonded joint was 0.52 mm. A graph comparing the results is showen in (**Figure 1**)**.**

3.6. Glued joints Fe – Fe

The best results were achieved by the bonded joint formed with DP 460 adhesive for steel materials, where it showed the highest tensile stress value of 32.1 MPa, the average tensile stress value was 31.4 MPa, with a standard deviation of 0.69 MPa and an average elongation value during tensile testing of 0.63 mm. The bonded joint formed with S-W 7260 adhesive also showed the best results for bonding steel materials, here it showed the highest tensile stress value of 36.9 MPa, an average tensile stress value of 34.3 MPa, with a standard deviation of 1.21 MPa and an average elongation value of 0.74 mm. In contrast, the bonded joint formed with EA 9497 adhesive exhibited a maximum tensile stress value of 29.1 MPa and an average tensile stress value of 26.4 MPa, with a standard deviation of 1.12 MPa and an average elongation value of 0.52 mm. A graph comparing the results is showen in (**Figure 1**)**.**

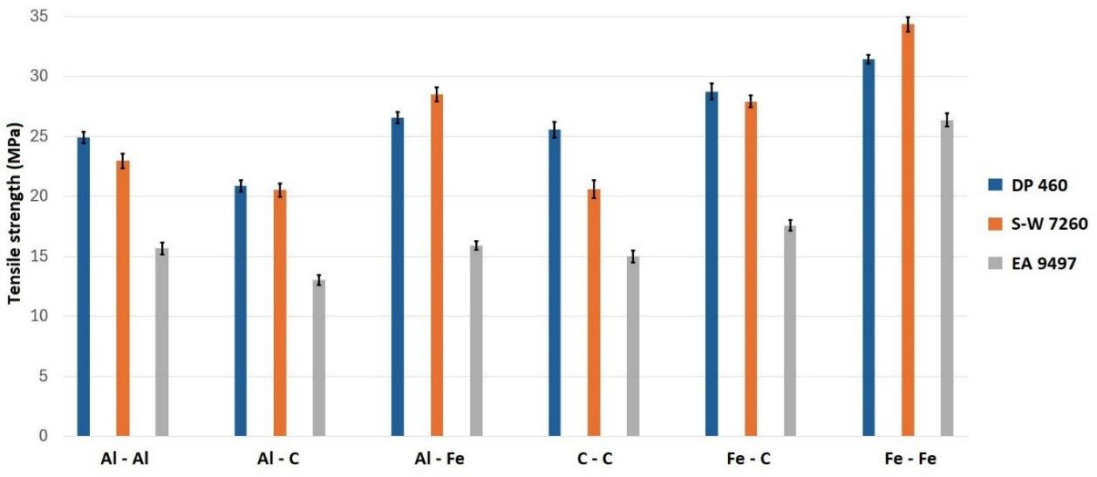

Figure 1 Summary tensile test results for individual materials

4. CONCLUSION

Measured tensile test data for individual adhesives and materials are clearly displayedin (**Figure 1**). This graph shows the strength measurement results for each type of bonded joint. The graph shows the mean strength value, and the measured standard deviation determined from 7 measurements of the same type of specimen.

Interesting values of bond strength are achieved by 2 types of adhesives for all materials tested. These adhesives are DP 460 and S-W 7260. These adhesives clearly show very similar bond strengths for all the different materials.

When bonding the different types of materials, aluminium showed the best bond strength, and aluminium was bonded with DP 460 (24.9 MPa). For the materials aluminum and carbon composite, the adhesive labeled DP 460 (20.9 MPa) and S-W7260 (20.5 MPa) achieved the highest bonded joint strength, as these adhesives exhibit almost identical bonded joint strengths. For the bond between aluminium and structural steel, S-W 7620 (32.8 MPa) achieved the highest bond strength. For bonding carbon composite parts, DP 460 (26.6 MPa) showed the best properties as it was clearly the best adhesive, and the bonded joint of this adhesive achieved the best result. The highest bonding strengths for bonding steel and carbon composites were exhibited by DP460 (28.8 MPa) and S-W 7260 (27.9 MPa) respectively, both adhesives showing similar results. For bonding steel materials, S-W 7260 (34.3 MPa) had the best properties.

A comparison of standard bonded joints of the same materials with the values reported by the adhesive manufacturers can be seen in **Table 2.**, here the reported values for the base materials such as aluminium alloy, steel and composite material are selected. The results of our measurements are then compared with these baseline values from the adhesive manufacturers. The differences in the strengths of these joints are due to the different methods of surface preparation before bonding. For the DP 460 and SW 7260 adhesives, the bond strength of the bonded joint for composite material and aluminium alloys is lower than the manufacturer's specifications.

Table 2 Comparison of achieved strength values of bonded joints of basic materials with values from technical data sheets of adhesive manufacturers

Adhesive type	Aluminium alloys		Steel		Composites	
	Specified (MPa)	Measured (MPa)	Specified (MPa)	Measured (MPa)	Specified (MPa)	Measured (MPa)
DP 460	31.0	24.9	19.3	31.4	37.2	25.6
S-W 7260	30.1	22.9	33.8	34.3	37.2	20.6
EA 9497	15.0	15.7	20.0	26.4	8.0	15.0

For bonded joints of two different materials, DP 460 and S-W 7260 joints achieved the highest bond strength. Considering the bond strength values and the values of the standard deflection of the two different bonded materials, it is possible to conclude that the bond strengths of these adhesives are very similar and almost identical, see (**Figure 1**).

The bond strength values were measured at 22.1 °C. As a further direction of development in bonded joints for composite materials, it would be useful to measure the effect of ambient temperature on the bonded joint strength, where the suitability for use in bonding automotive components that can reach temperatures higher than 21°C was verified, where the different composition of these types of strength adhesives could affect the mechanical properties.

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