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EFFECT OF SURFACE PREPARATION ON THE SHEAR STRENGTH OF ALUMINIUM ALLOY ADHESIVE SINGLE-LAP JOINTS

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Abstract. *Surface preparation for adhesive bonding is crucial for optimum bonding performance and has a major impact on the quality and durability of bonded joints. The effects of two different mechanical surface preparations (with Scotch-Brite abrasive pad and P180 sandpaper) on the strength properties of bonded joints were investigated. The prepared surface of aluminium alloy AW 5754 was characterized based on surface roughness parameters (Ra and Rz), wettability and mechanical properties (tensile lap-shear strength). Adhesively bonded single-lap joints were produced, and fracture surfaces were observed. It was found that the bonded joints of aluminium alloy AW 5754 had different strengths based on the surface preparation method and adhesive utilized. This indicates that joining aluminium alloys using the same adhesive and different surface preparations results in significant differences in the strength of bonded joints.*

Key words: A*dhesive bonding, Surface preparation, Aluminium alloy, Single-lap joints*

1.INTRODUCTION

Adhesive bonding is successfully replacing established joining techniques (riveting, screwing or welding) due to its many advantages. By evenly distributing stress within the materials to be bonded, structures that are structurally comparable or stronger than conventional assemblies can be produced at a lower cost and with less weight [1, 2]. In addition, adhesive bonding reduces stress concentrations, has a high strength-to-weight ratio, is corrosion resistant and is easy to manufacture [3-5].

Adhesive bonded aluminium alloys are used as materials in aerospace, shipbuilding, construction, automotive and other industries. The surface of aluminium alloys is covered

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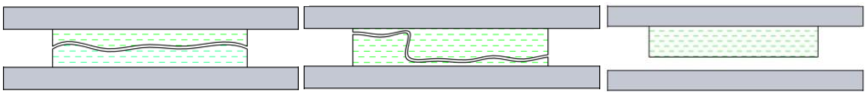
with organic and inorganic contaminants, such as lubricant residues and ash deposits [6]. For this reason, surface preparation of aluminium alloys is usually required for adhesive bonding. Proper surface preparation should ensure maximum adhesion or adhesion strength between the adhesive and the surfaces of the parts to be joined [7-9]. To improve adhesion, all impurities must be removed from the aluminium surface and a high initial bond strength must be ensured.

The selection of surface preparation and adhesive bonding properties should ensure that the weakest bond in a bonded joint occurs within the adhesive layer and not at the contact of the parts to be bonded. Cohesion failure is the best failure mode that perfectly demonstrates the performance of bonded joints. The basic failure modes are shown in Fig. 1 [10].



a) b) c)

Fig. 1 Failure modes of adhesive bonded joints (a) Cohesion Failure (CF); (b) Special Cohesion Failure (SCF); (c) Adhesion Failure (AF) [10]

In terms of surface preparation to achieve good joint performance and surface condition, a number of researchers [11-14] have suggested that mechanical removal methods can be used prior to bonding to remove contaminants from the material surface and create geometric patterns on the surfaces of the materials. This improves the contact area and intermolecular interactions between the adhesive and the bonded part, leading to better bonding results.

The surface preparation of aluminium alloys for bonding was investigated by Arenas et al. [15]. By using different methods of surface preparation, it was found that sanding for aluminium alloys has a significant role in surface preparation and is suitable for bonding structures. According to Mirski [8], aluminium alloys are difficult to join using traditional joining techniques, because they have a complex oxide layer on their surface. Therefore, it is important to pay special attention to suitable surface preparation for bonding as a factor for the proper functionality of the joints. Da Silva et al. [16] described the influence of groove patterns on the surface of aluminium alloys on the strength of the bonded joint. Several patterns with different orientations were applied and compared with samples without patterns. It was found that the patterns can increase the strength of the bonded joint compared to the bonded joint without preparation. Increasing the surface roughness of the bonding surfaces improves the surface contact between them and enables sufficiently high mechanical adhesion. Preparation with sandpaper is an extremely cost-effective method of increasing the roughness. In addition to sandpaper, abrasive pads such as Scotch-Brite can also abrade the surface, leaving tiny cuts with less dirt and dust. Previous research on surface preparation with Scotch Brite has been limited [17].

The current research focuses on the effect of different surface preparations for establishing strong adhesive bonded joints on the surfaces of aluminium alloy, which are tested using the single-lap shear test with two different epoxy adhesives (epoxy hybrid adhesive SikaPower®-492 G and epoxy adhesive Loctite® EA 9466 ™). The effects of surface roughness and contact angle on the experimental shear strength properties of two different surface preparations on aluminium alloy AW 5754 were investigated.

2.MATERIALS AND METHODS

2.1 Materials

Aluminium alloy AW 5754 was used as the substrate material. It is suitable for a wide range of applications in various industries due to its good strength-to-weight ratio, excellent ductility and machinability, as well as its corrosion and heat resistance. The mechanical properties and chemical composition of aluminium alloy AW 5754 are described in Table 1[18].

Table 1 Chemical composition and mechanical properties of aluminium alloy AW 5754 [18]

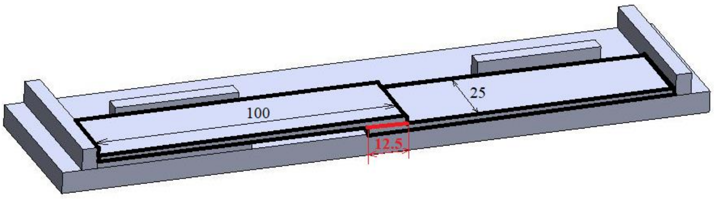
Chemical components [%]									
Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	other	Al
0.4	0.4	0.1	0.5	2.6-3.6	0.3	0.2	0.15	0.15	balance

Mechanical Properties			
Yield strength	Elongation to break	Tensile strength	Module of elasticity
80 MPa	12 %	220 - 270 MPa	68 GPa

The panels were cut to the dimensions 100 mm × 25 mm × 2 mm in accordance with the EN 1465 standard [19]. The samples were used to produce bonded joints with an overlap of 12.5 mm and thickness of the adhesive layer of 0.3 mm and then subjected to static shear tests. A standard mould was used for ten samples to ensure correct placement and overlap during bonding. The geometry of the mould and the dimensions of the samples are shown in Fig. 2 (a) and (b).

Two different adhesives were selected in this paper. The first was the one-component (1C) epoxy hybrid adhesive SikaPower®-492 G, which is suitable for high structural bonding of various types of metal. The epoxy-based adhesive was heated to a temperature of 55 °C for 15 minutes, then applied to the surfaces and cured in an oven [20]. The second of the adhesives selected for the tests was the so-called two-component (2C) epoxy adhesive Loctite® EA 9466 ™ [21], which is a cured, industrial-grade adhesive with an extended service life. Loctite EA 9466 ™ cures for 5 days at room temperature to form a tough bond and provides high shear strength for a variety of metals and plastics. After the curing time, the dimensions of the bonded joints were checked with a caliper gage and the strength of the bonded joints was tested.

a)



b)

Fig. 2 Mould for bonding (a) and dimensions of the test specimens for the single lap-shear test (b)

2.2 Surface preparation

The tested samples were subjected to mechanical surface preparation, i.e., sanded by hand. Sanding was carried out with green, fine-grained abrasive Scotch-Brite pads and P180 sandpaper. Before and after sanding, and prior to bonding, each sample was thoroughly cleaned with a solvent-based heavy-duty cleaner SIKA Remover-208 (samples bonded with SikaPower-492 G) or LOCTITE SF 7063 (samples bonded with Loctite EA 9466).

2.3 Analysis of Surface Characteristics

A Mitutoyo SJ-301 profilometer was used to measure the roughness of aluminium alloy AW 5754 after both surface preparations. The roughness values are given as average values of the parameters Ra (arithmetic average height) and Rz (ten-point height) of the surfaces.

For the chemical composition analysis, the 20 mm x 25 mm x 2 mm samples were cleaned in an ultrasonic bath with ethanol. Subsequently, an analysis was performed using a Thermo Scientific Quattro ESEM scanning electron microscope.

2.4 Strength test

The bonded joints were subjected to shear tests in accordance with the ISO 4587 [22] tensile lap-shear test standard. The tensile shear test was performed using a Shimadzu AGS-X 10 kN testing machine at a speed of 1 mm/min and room temperature. The ratio between the maximum load and the bonded area of the joints was used to calculate the average shear strength. Fig. 3 shows the setup for the lap-shear test on the machine.

Fig. 3 Setup for the shear test with a single lap joint on Shimadzu AGS-X

3. Results and Discussion

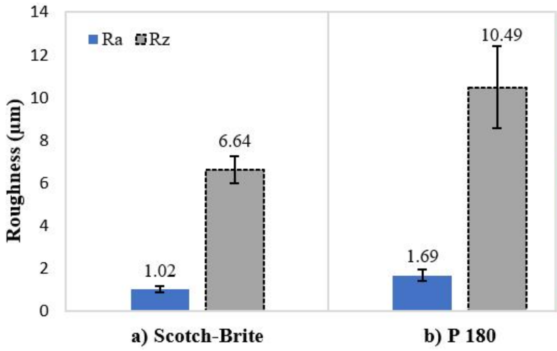
3.1 Analysis of Surface Characteristics

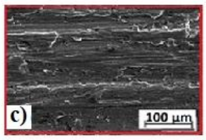
The effects of different surface preparations of aluminium alloy AW 5754 on the surface roughness, chemical composition and surface contact angle are explained in the following sections.

The surface roughness of the samples prepared with Scotch-Brite abrasive pads and P180 sandpaper was measured longitudinally along 10 mm of the sample ends at a speed of 0.15 mm/s on all surfaces examined. The measurement results of two surface roughness parameters, Ra and Rz, in relation to the different surface preparations are shown in Fig. 4 (a,b).

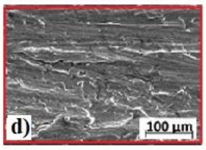
The surface roughness of the samples after surface preparation with Scotch-Brite were characterized by lower roughness. The average Ra and Rz values were ± 1.02 µm (from 0.9 to 1.12 µm) and ± 6.64 µm (from 5.94 to 7.54 µm), respectively. The surfaces of aluminium alloy prepared with P180 sandpaper exhibited a higher surface roughness. The average Ra and Rz values were ± 1.69 µm (from 1.46 to 1.91 µm) and ± 10.49 µm (from 8.65 to 12.33 µm), respectively.

Fig. 4 (c, d) shows the chemical composition after surface preparation. During preparation with P180sandpaper, the proportion of element O was 2.3%. Due to oxidation, the concentration of element O increased to 3.8% after the Scotch-Brite preparation compared to the P180 sandpaper preparations. Changes in the chemical composition of the surface of an aluminium alloy prepared with Scotch-Brite, as well as decreased surface roughness, would have an impact on wetting.





Element	*Wt.[%]*
O	3.8
Mg	2.7
Fe	0.9
Al	91.2

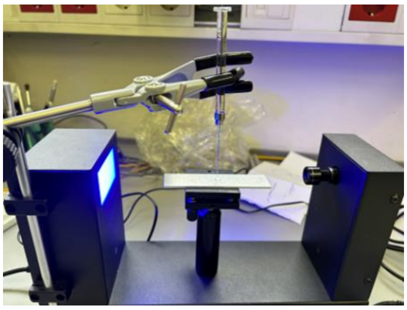


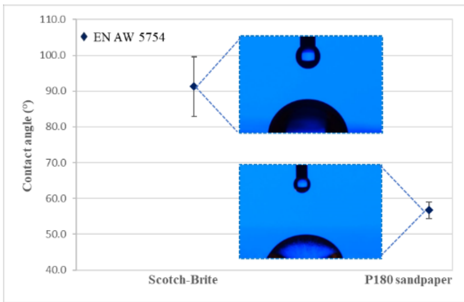
Element	*Wt.[%]*
O	2.3
Mg	2.7
Fe	0.5
Al	92.7

Fig. 4 Effect of Scotch-Brite abrasive pads and P180 sandpaper on the surface characteristics of aluminium alloy AW 5754, (a,b) average surface roughness; chemical composition of the aluminium alloy samples after preparations with (c) Scotch-Brite and (d) P180 sandpaper

3.2 Wettability

The wettability of surfaces was determined by measuring the static contact angle with doubly distilled water in order to investigate its effect on the adhesion of aluminium bonding surfaces. The Osilla goniometer was used to measure the contact angles (Fig. 5 (a)). Fig. 5 (b) shows the contact angle values of the different surface preparations. The surfaces prepared with Scotch-Brite showed higher contact angles, indicating almost neutral wetting, compared to the surface prepared with P180 sandpaper. This discrepancy can be attributed to the different degree of surface roughness of the two preparations. The P180 sandpaper with its coarser grit, leads to deeper scratches and a higher surface roughness. Consequently, the greater roughness increases the total surface energy, which facilitates the wetting of the liquid droplets, so that the surface shows better behaviour. This means that the surface shows better wetting after preparation with P180 sandpaper.





a) b)

Fig. 5 a) The Osilla Contact Angle Goniometer; (b) average contact angle values for the aluminium alloy AW 5754 depending on the surface preparation.

3.3 Tensile lap-shear strength

The results of the static tensile shear test of the single-lap bonded aluminium joints in relation to two different surface preparations and adhesive types are shown in the form of a graph in Fig. 6. The highest strengths and improved mechanical properties were observed when the surfaces were prepared with the same preparation method for both adhesives, namely P180sandpaper. Moreover, the standard deviation of the P180 sample is lower compared to the sample prepared with Scotch-Brite. The experimental results show that the surface preparation with P180 sandpaper provides uniform and consistent surface properties compared to Scotch-Brite.

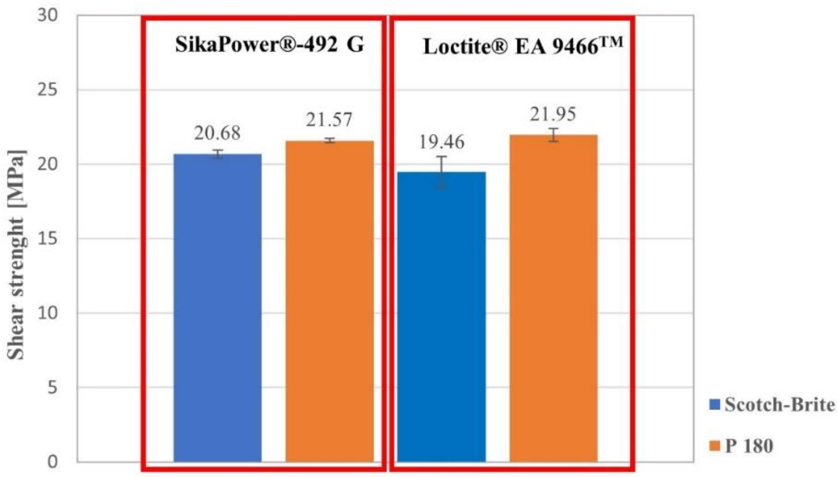


Fig. 6 Average shear strength of adhesive bonded joints in relation to the method of surface preparation for aluminium alloy AW 5754

The results show that the Loctite 9466 adhesive is more sensitive to the surface preparation method, with a deviation in bond strength of up to 3 MPa when prepared with P180 sandpaper. By cleaning the surface appropriately, the method described above resulted in adequate surface expansion and therefore increased surface adhesion.

The strength results obtained after applying the SikaPower-492 G adhesive to the surface of the parts to be joined are much more uniform, indicating that the adhesive provides good results regardless of the previous surface preparation method.

3.4 Failures modes

Fig. 7 and Fig. 8 show examples of fractures in bonded joints made with the SikaPower®-492 G and Loctite® EA 9466 adhesive. Cohesive failure or special cohesive failure dominated with the 1C adhesive 492 for both preparations of aluminium adhesive bonds. Adhesion failure dominated for the 2C 9466 adhesive after preparation with Scotch-Brite, which is certainly related to the fact that the static shear test results showed low strength for these surface preparations with this adhesive. However, preparation with P180 sandpaper gave very consistent results, mostly cohesive failure and increased the shear strength value. This indicates that joints made with Loctite 9466 with different surface preparations had different strength values and failure modes, suggesting that this adhesive reacts very sensitively to surface preparation methods.

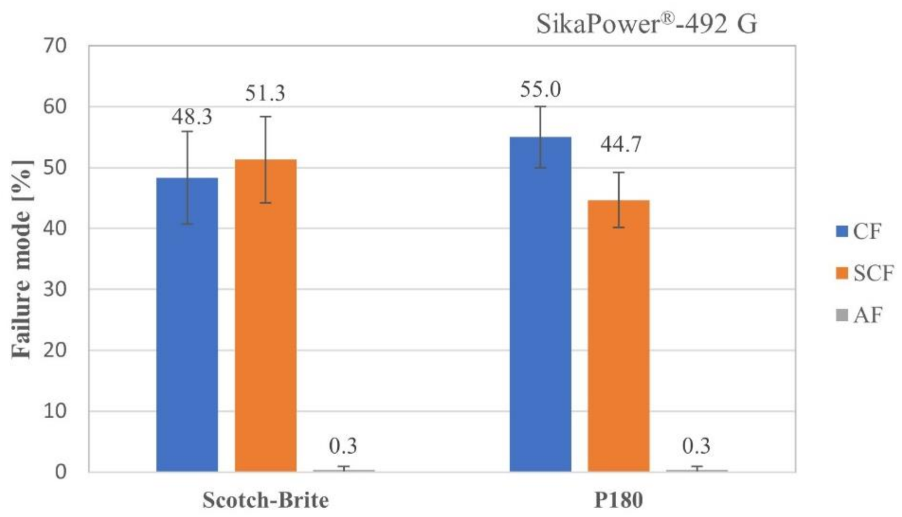


Fig. 7 SikaPower®-492 G, CF- Cohesion failure; SCF- Special cohesion failure; AF- Adhesion failure

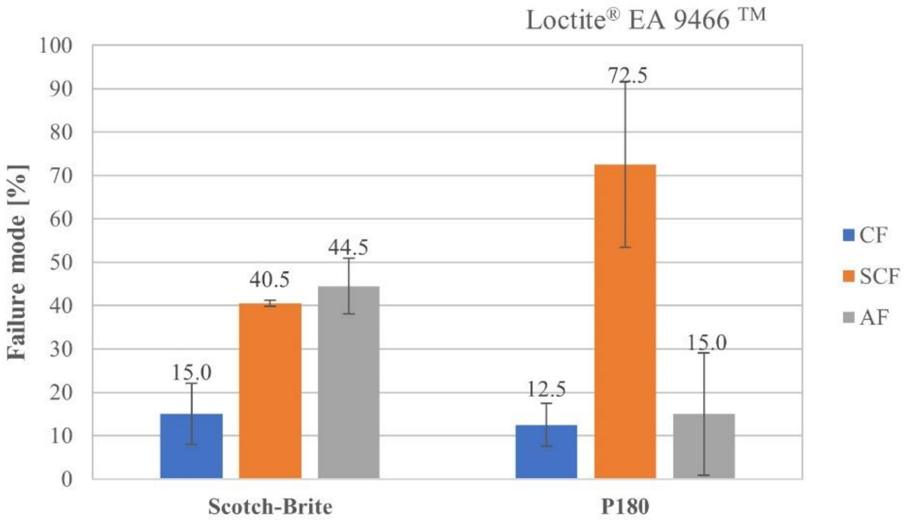


Fig. 8 Loctite®EA 9466 ™, CF- Cohesion failure; SCF- Special cohesion failure; AF- Adhesion failure

4. CONCLUSIONS

In this study, two different surface preparations were applied to aluminium alloy AW 5754 to determine the effect of the different surface preparations on the properties of bonded joints with two different epoxy adhesives (epoxy hybrid adhesive SikaPower®-492 G and epoxy adhesive Loctite® EA 9466). Based on the research done and the examination of the findings acquired, the following conclusions were reached:

- The increased strength of the bonded joint, good wetting and adsorption of the adhesive was related to the removal of surface contaminants and uniform development of the bonded surface.
- The most suitable surface preparation for aluminium alloy AW 5754 bonded joints is preparation with P180 sandpaper for all adhesives. Higher surface roughness, better wetting behaviour and predominantly cohesive failure led to very uniform results and maximum shear strenght of the bonded joints compared to preparation with Scotch-Brite abrasive pads for both adhesives.
- The application of epoxy adhesive SikaPower®-492 G for bonding materials showed good results for all surface preparations of aluminium alloy AW 5754, it had a high shear strength and cohesive failure or special cohesive failure was dominant in both surface preparations. Loctite® EA 9466 adhesive is more sensitive to the method of surface preparation, with a deviation in bond strength of up to 3 MPa and different surface preparations resulting in significantly different failure modes.

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