MECHANICAL PROPERTIES OF LASER CLEANING SURFACE, USED FOR BONDING JOINT OF ALUMINIUM METAL SHEET EN AW 5754

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Abstract

This paper deals with the testing of the properties of a bonded joint made of aluminum alloy EN AW 5754, where the laser cleaner MRJ FL C120 was used for the preparation of the bonded surfaces. Different laser beam settings were used to achieve the desired roughness. The bonded joints were formed using a two-component high strength epoxy adhesive. The research analyzes the effect of surface roughness created by MRJ FL C120 laser cleaner on the strength of the bonded joint under tensile test. The adhesion of the adhesive to the surface of the bonded material is analyzed. Furthermore, the tensile strength test results as a function of the surface roughness of the material are evaluated. In the evaluation of the results, the effects of different surface roughness produced by the laser cleaning method on the strength of the bonded joint were determined.

Keywords: Laser, surface, bonding, mechanical properties, aluminum, EN AW 5754

1. INTRODUCTION

Bonding of aluminium alloy materials is one of the modern technologies for joining materials. In some applications it replaces the welding process. During the welding process, the mechanical properties of the materials are altered, which may not be favourable or suitable for the application. During the actual bonding of aluminium materials, it is necessary to remove the aluminium oxide layer Al_2O_3, various types of impurities and grease on the surface of the material. Conventionally, cleaning of the surface of the aluminium material has been carried out using pickling technology and then surface treatments are applied or bonding of joints takes place. Thus, the use of chemical means and precise technological procedures are needed. Subsequently, problems arise with the disposal of the chemical material. It is therefore advisable to replace this technology. Currently, there are a many types of different cleaning lasers on the market, that use a laser beam to clean the surface of the material and adjust the surface roughness. These laser cleaners have a variety of settings that change the surface roughness of the material during cleaning, which is also advantageous for bonding the material. Thus, there are many of settings that can lead to improved bond strength.

In general, it can be stated that the mechanical properties more suitable for bonding, has a material with a rougher surface. The surface roughness is used to form bonds between the adhesive and the base material, which is formed by irregularities on the surface (voids, grooves), that are filled with adhesive during bonding. In polished materials this bond is negligible. [1],[2] Surface treatment of adherends involves a set of operations that achieve optimum surface quality of bonded components in terms of improved adhesion, surface wettability and surface cleanliness. Different methods and combinations of methods are used depending on the nature of the materials to be bonded and the durability of the joint. Chemical, electrochemical, laser technologies, thermal (plasma, flame), mechanical cleaning (sandblasting, grinding) can be used to clean the surface of the material [3] [4].

For example, the effect of surface treatments on joint strength was investigated by Hongfan Yang et al. in [4], where they focused on the effect of different surface treatments and their combinations on the surface texture (roughness) of the aluminium material and on the resulting joint strength. In this paper, they used sandblasting, electrochemical etching, and a combination of sandblasting and electrochemical etching for the treatment. These different surfaces treatments resulted in different surface roughness and texture. About the R_a values: for the original surface R_a = 0.98 μm to R_a = 3.85 μm for the sandblasted surface (R_a - Mean Arithmetic Deviation of the profile). They used a special mixture of epoxy resin and additives as adhesive. As a result, the highest bond strength was achieved when combining sandblasting with electrochemical treatment, with a roughness value slightly lower than the maximum specified. It can be concluded from this paper, that the use of appropriate treatment combinations can increase the bond strength. [4]

2. EXPERIMENT

For the experiment itself, 5 sets of aluminium sheet samples were created. Each set of samples contained 7 pcs of EN AW 5754 material. Prior to bonding the specimen, its surface was cleaned with the given parameters of MRJ FL C120 laser cleaner, embedded in the fixture and immediately bonded to the counterpart using 3M Scotch-Weld 7260 B/A FC epoxy adhesive. The width and length of the bonded area was 25 x 12.5 mm, and the dimensions of the sample were based on ČSN EN 1465. The bonded specimens were left in the adhesive for a week to allow sufficient curing and then tested using a tensile test to verify their shear strength on a Shimadzu AGS-X 50 kN tear tester machine. The effect of surface roughness of the bonded surface was investigated. Different roughnesses were achieved by laser cleaning of the bonded surface.

SPECIMEN MATERIAL

The material of the tested samples was the already mentioned aluminium alloy EN AW 5754. This is an aluminium-magnesium alloy with the chemical composition shown in **Table 1**. This type of aluminium alloy is also used for structural elements of automobiles. Its advantages are good weldability and very good resistance to corrosion and seawater. The main mechanical properties are included in **Table 2.**

Table 1 Chemical composition of specimens

Chemical composition EN AW 5754 [%]									
Si	**Fe**	**Cu**	**Mn**	**Mg**	**Cr**	**Zn**	**Ti**	**Mn+Cr**	**Al**
≤ 0.40	≤ 0.40	≤ 0.10	≤ 0.50	2.6–3.6	≤ 0.30	≤ 0.20	≤0.15	0.10–0.6	Rest

Table 2 Mechanical properties of specimens

Mechanical properties EN AW 5754 -processing H111, thk. 0.2-12.5 mm		
Yield strength Rp	**Ultimate strength Rm**	**Elongation A_{50}**
80 [MPa]	190 - 240 MPa	max 18 [%]

The specimens were externally cut to the required size, which was 100 x 25 ± 0.25 mm. This dimension was specified in EN 1465 [5]. The thicknesses of the samples were 3 mm. The specimens had to be edge-treated by shrinking the burrs from the factory.

3. RESULTS AND DISCUSSION

The MRJ-FJ-C120C laser cleaning machine, which is a powerful cleaning laser class 4 with a power of 120 W, was used to produce the bonding samples. Every sample was clamped in the fixture, the laser area was adjusted to the desired dimension. Subsequently, the sample was cleaned for 15 s to safely clean the specified area.

The pulse length of the laser cleaner was set to the following values: 50; 100; 200; 400 ns. This was followed by cleaning of the sample surfaces. This resulted in different surface roughnesses, which were subsequently measured using a Mitutoyo SJ 410 roughness meter. The individual test samples can be seen in **Figure 1** - on the left, on the right the measurement of the surface roughness of the lasered part of the sample using the Mitutoyo SJ 410.

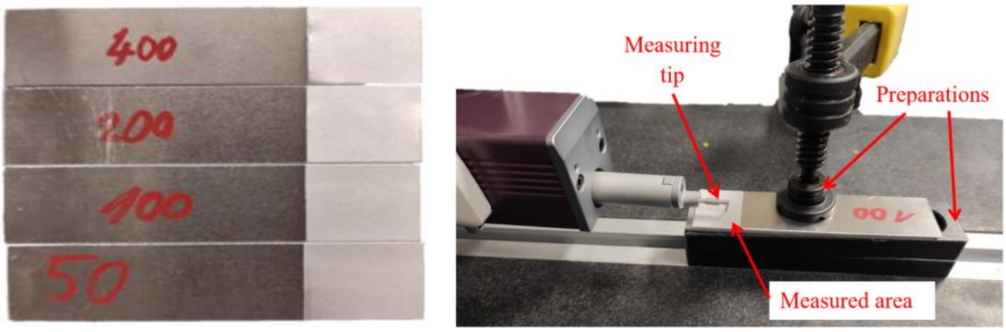

Figure 1 Measured specimens with surface treatment.

The results of the roughness measurements from the individual measurements are shown in **Table 3**, where the difference in roughness at different pulse lengths can be seen. At the bottom of the table, the mean values of the measured surface roughnesses are given. The result of the measurements was the mean arithmetic deviation of the profile R_a [μm], measured at a length of 10 mm. The measurements were taken seven times on the same surface at different locations and the average R_a roughness value for a given pulse length was calculated from the seven measurements. (see **Table 3**).

Table 3 Results of roughness measurements

	Pulse length				
No. of measurements	**50 ns**	**100 ns**	**200 ns**	**400 ns**	**500 ns + sand**
1	1.229	2.47	2.435	2.796	4.195
2	1.203	2.38	2.270	2.439	4.942
3	1.272	2.18	2.343	2.841	4.885
4	1.128	2.07	2.576	2.472	4.518
5	1.214	2.26	2.229	2.617	4.824
6	1.315	2.07	2.406	2.399	4.802
7	1.216	1.97	2.568	2.810	4.602
Diameter	**1.23 R_a**	**2.20 R_a**	**2.40 R_a**	**2.62 R_a**	**4.68 R_a**

4. EVALUATION OF MEASURED DATA

Measured data are divided into groups according to the investigated bonding parameter for clarity. For each of the parameters the following data was measured: tensile test as a dependence of force [N] on elongation [mm], from the maximum force the maximum shear stress was calculated:

$$\tau = \frac{F_{max}}{S} = \frac{F_{max}\,[N]}{l \cdot w\,[mm^2]}\,[MPa] \quad (1)$$

Where: τ = strength of the bonded joint $[MPa]$, F_{max} = maximal force [N], S = area of bonded surface [mm^2], l = length [mm], w = width [mm].

PARAMETER - SURFACE ROUGHNESS

Shear stress measurements were first carried out on specimens with different surface roughness, the overlap of these specimens was constant at 12.5 mm and the adhesive thickness was also constant at 0.3 mm. The tested samples had a surface roughness R_a: 1.2; 2.4; 2.6; 4.7 μm (original surface roughness before treatment R_a 0.13 μm). These samples were also subjected to scanning electron beam surface measurements and metallographic analysis at the joint. For a surface roughness R_a of 2.6 μm, a test was also conducted to see if pushing the adhesive into the surface with a squeegee would refine the results.

All measurements were recorded in plots of elongation versus loading force, one plot with seven measurements for each roughness. From all the measured tensile tests, the shear strength was calculated using **equation (1)** and the measured maximum force. The converted shear stress values are recorded in **Table 4.**

Table 4 Shear strength measured by roughness

	Shear strength [MPa]									
No. of measurements	1	2	3	4	5	6	7	**diameter**	**standard deviation**	**relative deviation [%]**
1.2 R_a	23.60	21.48	22.10	22.20	24.73	21.76	20.40	**22.32 MPa**	0.50	2.2
2.4 R_a	23.06	20.58	21.67	22.88	21.60	22.70	22.47	**22.14 MPa**	0.31	1.4
2.6 R_a	22.78	28.60	25.73	23.54	24.79	23.10	27.40	**25.13 MPa**	0.78	3.1
4.7 R_a	24.50	28.30	25.10	23.40	22.00	23.60	22.10	**24.14 MPa**	0.76	3.1
2.6 R_a + squ.	22.75	23.48	21.59	22.14	25.24	23.91	22.96	**23.15 MPa**	0.42	1.8

One set of specimens (7 joints) was added to the results and the adhesive overflows were wiped off. These overflows were suspected to affect the measurements, which can be observed in **Figure 2** for the R_a 2.6 μm and R_a 2.6 μm +grit roughness. The difference is visible in the average measured value and the value of standard deviation. The average shear stress results from each observed roughness are graphically depicted in **Figure 2**, where a small increase in strength can be observed between the R_a 1.2 μm and R_a 4.7 μm roughness. The difference between these two roughnesses was approximately 1.8 MPa. Detail of the picture on the right side shows sample after testing.

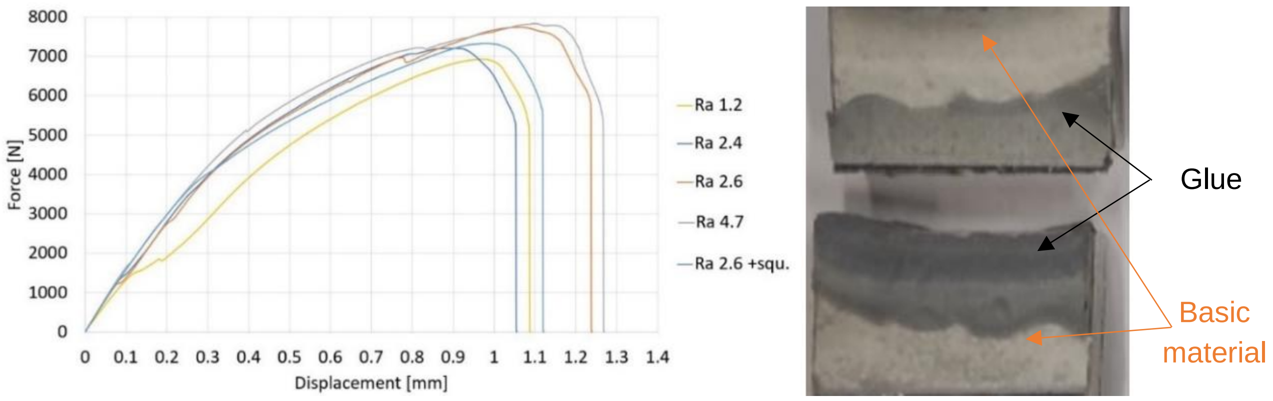

Figure 2 Graph comparing tested roughnesses (Left side). Specimen after measurement (Ra 2.6) – right side.

A comparison of tensile tests of all roughnesses is shown in **Figure 3.** Differences can be observed in the curves of each roughness in elongation and in the curve itself, which is not regular for all of them. The minor variations in the tensile test waveforms are attributed to the adhesive overflows, as the wiped overflows had a smoother waveform. There is very little variation in the highest forces achieved.

The following graph in **Figure 3**, converts the measured values from the tensile tests from force to bond strength in [MPa], by recalculating the bonded area. The standard deviations for the individual measurements are also included for clarity. As can be seen from the graph, higher roughness materials achieve higher strengths.

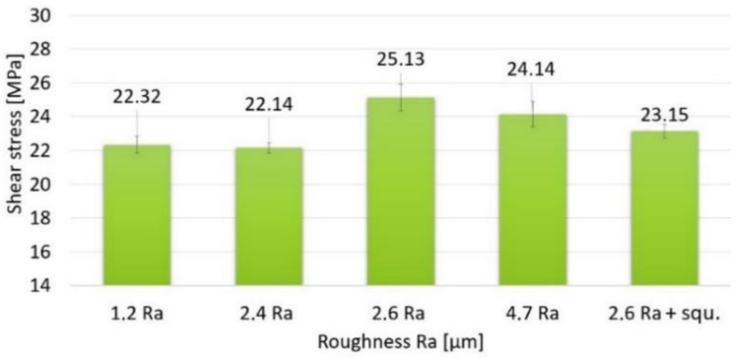

Figure 3 Dependence of shear stress on surface roughness

MATERIALOGRAPHIC ANALYSIS OF JOINTS AND IMAGES OF SURFACES

For a more detailed analysis of the bonded joint in the tested samples, materialographic analysis was used. Thanks to this analysis, it was possible to determine, where were the pores in the adhesive occur. The analysis images also showed the surface irregularities of the samples, caused by the surface treatment. The samples were cut in the middle of the glued joint, then sanded and polished. The grey area shows the glue area, and the outermost white area represents the aluminium sample.

Figure 4 shows an image of the bonded sample with a surface roughness of R_a 1.2 µm. The surface roughness of the samples can be observed minimal and shallow. There were pores in the adhesive, which can be seen as dark circular patterns. The size of the pattern depends on the location of the cut. The approximate size was around 50 µm. The roughness R_a of 2.4 µm, in this case, the irregularities are deeper than in the case of R_a 1.2 µm and the porosity is approximately the same. A snapshot of a joint with a surface roughness of

R_a 2.6 µm. Here was the surface roughness is greater than in the previous two cases. The pores size does not differ. In the adhesive, there is an impression (grey circular solid spot in the image) from the spacer bead (0.3 mm diameter), which is sized according to the location of the glass ball (balotina balls) in the cut and brush area. Surface roughness R_a 4.7 µm. Due to the combination of laser cleaning with sandblasting, the indentations (irregularities) in the surface are more rugged and deep than in previous cases. The porosity of the adhesive is similar.

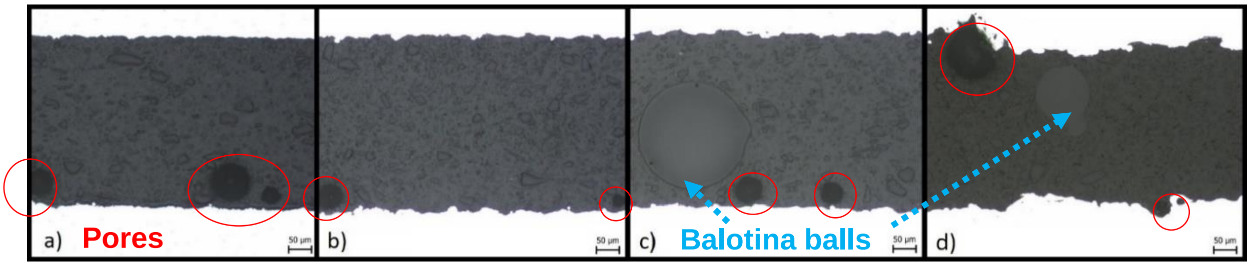

Figure 4 Metallographic image of roughness specimens a) R_a 1.2 µm, b) R_a 2.4 µm, c) R_a 2.6 µm, d) R_a 4.7 µm.

5. CONCLUSION

When the effect of surface roughness on the shear strength of the bonded joint was tested using a laser surface cleaner, surfaces with higher roughness showed positive results, due to the higher bond strength achieved. In our case, the highest bonded joint strength was around 25.1 MPa. Differences in strength were observed in units of MPa. The best results were achieved with a surface roughness of $R_a = 2.6$ µm, which we attributed to the uniformity of the surface wrinkling along with the coarsest observed surface wrinkling of the bonded material according to the microscope photos. Thus, the laser beam incident on the surface of the material produced a larger surface wrinkling, which supports the function of a better anchor profile for the type of adhesive. In addition, it was found that wiping off the excess adhesive resulted in more accurate measurement results and did not produce higher values of standard deviation from the measurement mean. Materialographic analysis and electron microscope images of the surface were taken to visualize the roughness. Here, parts of the glass balls (ballotina balls) with a diameter of 0.3 mm can be seen, which have the task of maintaining the thickness of the adhesive layer at this level. Laser surface cleaning is therefore suitable for the preparation of bonded joints of aluminium materials and can replace chemical methods of surface preparation. However, it would be advisable to test the effect of other laser settings on the strength of the bonded joint. We observed a partial effect of peeling on the tensile test due 3 mm thin wall of the aluminium sheet sample. For that reason, we think, that the adhesive on the detail of the glued joint after tensile test is half detached from the base materials in both halves of the sample.

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