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Adhesion Imrovement with Plasma Surface Activation Between Aluminum Alloy Plates

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Abstract

Aluminum alloys are advantageous light metals in many respects. In the use of these alloys in the ship, aviation and automotive industries, bonding applications rather than welded joints or mechanical connections are preferred. Improving adhesion properties with various surface treatments applied to aluminum alloys is an important issue. Adhesive type, front surface treatments and surface activation techniques control adhesion strength. In this study, the effect of plasma surface treatment technology on adhesion strength was examined in detail. The water drop wetting ability of the alloys were examined, and then adhesion properties were compared with adhesion tests. It has been determined that plasma technology significantly increases the adhesion strength.

Key words: Aluminum alloys, Adhesion, Surface Treatment, Plasma activation

1. Introduction

Aluminium-Magnesium alloys have excellent corrosion resistance especially to seawater and industrially polluted atmospheres. EN AW 5754 finds use in almost every field of the industry due to its combination of many features such as very good welding ability, excellent corrosion resistance, superior cold forming, and very good anodizing ability. To endure critical conditions in aeronautic or marine applications some chemical processes, such as, conversion coatings, anodizing and chromatization are often applied as pre-treatment for Al alloys to improve corrosion resistance and enhance adhesion properties [1]. The surface properties of aluminum alloys will be considered and the various processing methods are being used to modify the surface for effective adhesive bonding. To increase 5754 aluminium corrosion resistance, its surface is usually covered with protective coatings like paints. Certainly, performance of paint or each protective coating is greatly influenced by its proper adherence to the substrate material. Therefore, substrate preparation before the application of any coatings is considered as the essential first stage of paint procedure to improve coatings' durability and efficiency. According to the literature survey, there are several surface treatment methods for the surface preparation prior to the coating to enhance the adhesion. Almost many researches in this area try to out methods with best quality, low cost and applicable in the industrial level. Surface cleaning by solvents can promote the coating adhesion through removing hydrocarbons from the surface. Although these methods are typically used in the industrial applications, they are faced with the problems of solvents inflamma-bility and personal health risks. Physical treatment of the surface such as wire brushing, sand blasting, scraping and chipping, majorly manipulates the physical properties of the surface. In these methods, modification of surface roughness can improve mechanical interlocking between the coating and

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surface to achieve a stronger bond. However, these methods usually suffer from the waste production and serious damage to the treated surface. Plasma surface treatment is an alternative method. This high energy physical method is clean and environmental-friendly type of process that can be easily applied in in-line production, the capital cost is relatively low when compared to other methods [3-5]. Plasma is an ionized gas consists of electrons, ions and neutral particles such as atoms, molecules, radicals and excited and reactive species. Interaction of all these species with the surface can lead to the improvement in adhesion through plasma proccessing. Research results showed plasma treatment can increase the surface free energy, leading to a higher adhesion [2-6]. In this study, the effect of plasma surface treatment technology on adhesion strength was examined in detail. The water drop wetting ability of the alloy surafces were examined, and then adhesion properties were compared with adhesion tests.

2. Materials and Test Methods

5754 aluminum alloy plates in 180mmx25.4mmx2mm dimensions were used in this experimental study. The chemical composition and properties of the alloy are shown in Table 1.

Table 1. 5754 Alloy Composition and Properties

Element	**%**
Si	0.4
Fe	0.4
Mn	0.5
Mg	2.6-3.2
Al	Balance
Property	**Value**
Yield Stress	60-160 Min MPa
Tensile Strength	200- 300 MPa
Elongation A50 mm	6 Min %
Hardness Brinell	70-90 HB

Test plates were cleaned in an ultrasonic cleaning unit for 15 min., then air dried and moisture was removed. 2-component epoxybased adhesive is prepared and applied to the metal surfaces. It was left at room temperature for 1 day for curing. Different surface treatments (sand blasting, grinding, plasma treatment) and coatings (anodizing) have been applied to the aluminum alloy test plate surfaces. Contact angle measurements were made to measure the wetting ability of the treated surfaces (Fig.1). The surface activation process was carried out under vacuum (Fig.2). Both cleaning and activation of the surface under vacuum have been successfully achieved. Afterwards, adhesive was applied to the surfaces and they were subjected to an adhesion test comparatively. ASTM D1002 is commonly performed to measure the shear strength of adhesives that are used to bond metals (Fig. 3). This test method is primarily comparative. However, it does have application as a discriminator in determining variations in adherend surface preparation parameters and adhesive environmental durability. The test method has found applications in controlling surface preparations, primer, and adhesive systems for determining strength properties of tested systems [7].

Fig.1. Contact Angle Measurements on Test Samples

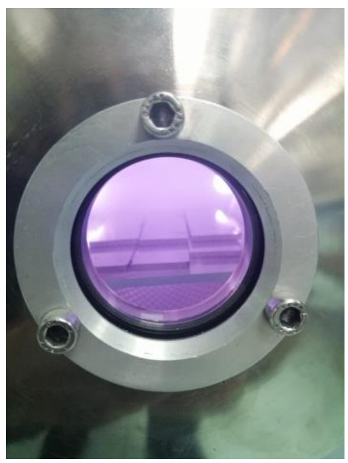


Fig. 2. Plasma Surface Treatment on Plates

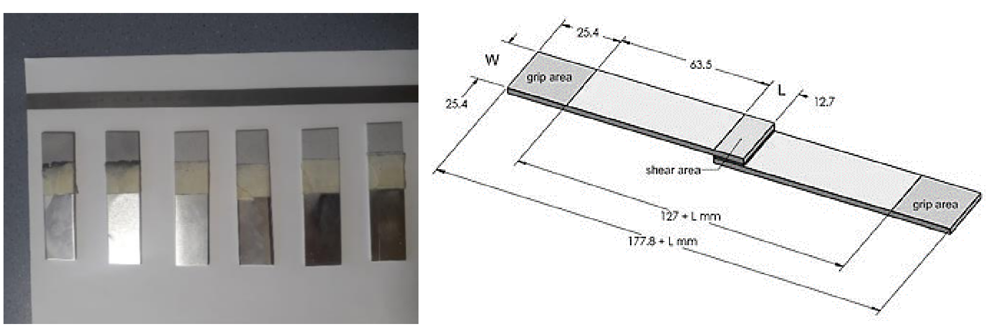
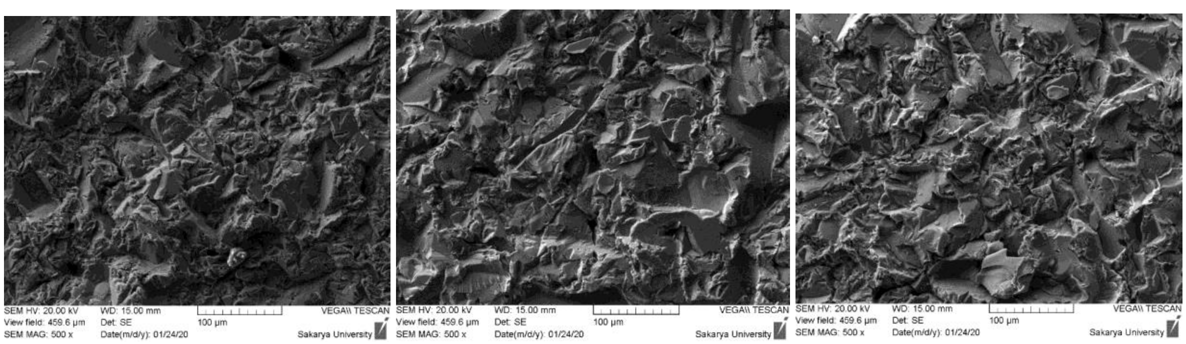


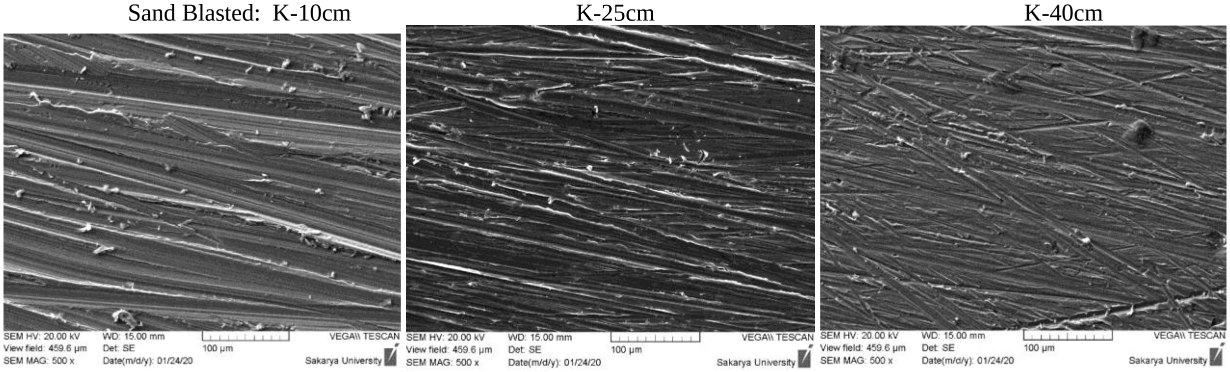
Fig. 3. Adhesive Lap Joint Shear Strength Test Specimens

3. Results and Discussion

In many industrial applications, surface pretreatment of Al alloy is a must to achieve strong and stable adhesion. Chemical and electro-chemical pretreatment of Al surfaces exhibit favorable adhesion. Disadvantages regarding those pretreatment methods are the disposal of chemicals involved, long pretreatment times and high operating costs. For these reasons, the application of mentioned or similar pretreatment methods is not recommended in many industries. On the other hand, mechanical pretreatments result often in unsatisfactory adhesion and long-term stability. The application of plasma pretreatment methods could be considered as an alternative technique. The Al sheets as received were contaminated and were covered with a layer of oil. Therefore the surfaces were cleaned and degreased with ultrasonic activated ethanol for 10 min and dried with oil-free compressed air. The two-component adhesives (Aradur 4311/ Araldite 480) were mixed manually. For keeping an even layer of 0.1 mm adhesive thickness, copper wires of 0.1 mm diameter were inserted. To keep a constant applied pressure, a device with constant weights was used. The adhesive joints were selfcured in a room condition. To determine adhesive strength, single overlapped tensile shear test specimens were used according to ASTM D1002. Sandblasting (10-40 cm), grinding (80-500) and plasma surface treatment (1-shortherm, 2-longtherm) applications on aluminum plate surfaces have been comparatively studied and tested (Table 2.). It was sand blasted with 80 mesh alumina based sand grit from 10 cm to 40 cm distances with 6 bar pressure and the surface was roughened. The surface texture was formed by grinding the surfaces with different (80-500mesh) sanding papers (Fig 4). Surface activation was carried out with air plasma under vacuum at 10^{-3} bar for 2 to 10 min.



Sand Blasted: K-10cm K-25cm K-40cm



Grinded: Z-80 Z-320 Z-500

Fig.4. Different Surface Treated Plates and SEM Micrographs of the Top Surfaces

When the surface roughness measurement results of the sandblasted surfaces are examined, it is observed that the surface roughness changes with the increase of the sandblasting distance. Ra and Rz values decrease with increasing sand blasting distance. Ra and Rz values according to increasing sanding distance, respectively: Ra:5.5µm, 4.6µm, 4.1µm., Rz:32µm, 28µm, 24µm. As a result of grinding, as the grinding number increases, the surface Ra roughness values decrease from 2µm to 0.5µm. As a result of the surface roughening processes performed mechanically, the change of the surface texture can be clearly observed. Generally, obtaining an optimum surface roughness in adhesion processes is critical for increasing the surface area and improving adhesion. Plasma treatment is a nanoscale surface activation process. It increases adhesion by activating the chemical structure of the top surface. The duration of action is critical depending on the plasma type, power and gas pressure used. With the effect of plasma treatment, the wetting ability of the surface increases and the adhesion properties improve with it (Fig. 5, 6). As can be seen in Figure 5, the wetting angle could be reduced from 95^o to 34^o by plasma treatment on a non-surface treated plate. It can be reduced from 34^o to 10^o with increasing plasma duration. Plasma is able to activate the surface very quickly in the nano layer just below the top surface. The plasma effect can maintain its effect for an average of 10 minutes. Therefore, the bonding process should be done immediately after the plasma treatment.

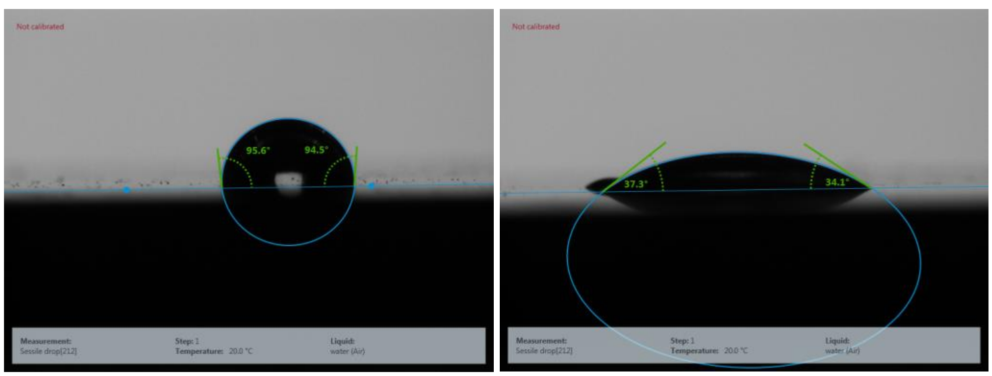


Fig.5. Results of Contact Angle Measurements Before And After Plasma Treatment on Untreated Aluminum Surface

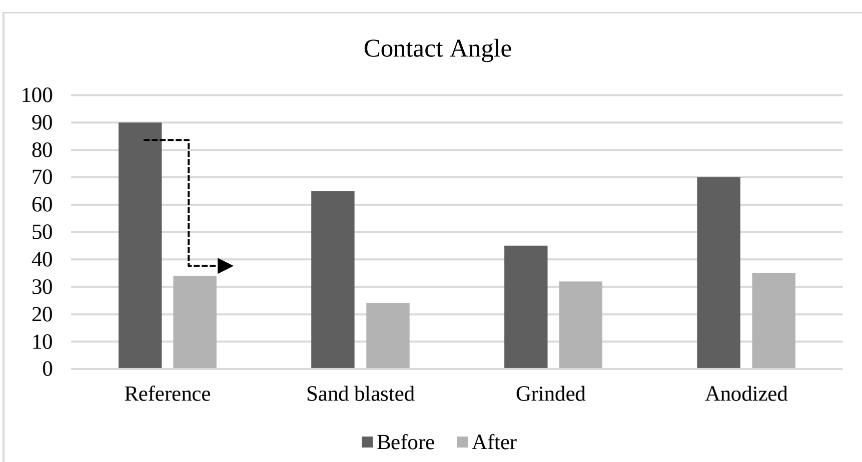


Fig.6. Results of Contact Angle Measurements Before And After Plasma Treatment on Treated Aluminum Surface

Table 2. Test Results of Adhesion Tests

Epoxy based adhesive	Treatment	F(max) N	Mpa	Acceptance
Al-Al (K10)	**K: Sand blasting**	2965	9,488	**OK**
		2982	9,542	**OK**
		3012	9,638	**OK**
Al-Al (K25)		2272	7,270	**OK**
		2350	7,52	**OK**
		2500	8	**OK**
Al-Al (K40)		2217	7,094	**OK**
		2450	7,84	**OK**
		2507	8,0224	**OK**
Al-Al (Z80)	**Z: Grinding**	1424	4,5568	**OK**
		1500	4,8	**OK**
		1450	4,64	**OK**
Al-Al (Z320)		1088	3,481	**OK**
		1120	3,584	**OK**
		1200	3,84	**OK**
Al-Al (Z500)		1061	3,395	**OK**
		1121	3,587	**OK**
		1010	3,232	**OK**
Al-Al (P1)	**P: Plasma Treatment**	3452	11,04	**OK**
		3400	10,88	**OK**
		3385	10.83	**OK**
Al-Al (P2)		4288	13,72	**OK**
		4300	13,76	**OK**
		4316	13,81	**OK**
Al-Al (Reference)	**No treatment**	461	1,4752	**NOK**
		470	1,504	**NOK**
		463	1,4816	**NOK**
Al-Al (Anodized)	**No Treatment**	458	1,452	**NOK**
		420	1,446	**NOK**
		478	1,514	**NOK**

Table 2 shows the adhesion test results. The desired adhesion strength could not be achieved in tests with reference plates. Since the adhesion is very poor, surface treatment is a mandatory requirement. With the increase of surface roughness after sandblasting, a sufficient adhesion strength can be obtained. Among the sandblasted samples, the highest bond strength could be obtained in the K10 coded samples. Adhesion strength varies between 9.5 and 7.2 MPa. Samples with grinded surface have 40% lower adhesion strength than sandblasted samples. Among the grinded samples, the highest adhesion was achieved with the sample coded Z40. Plasma surface treatment was applied in two different periods and as can be seen, the highest bond strength can be obtained after plasma treatment. Adhesion strength could be increased tenfold compared to untreated. Figure 7 shows the adhesion contact surfaces after lap shear test. We can clearly see that plasma treatment improves the adhesion properties compared to anodized surfaces. In addition to surface properties, adhesive type and bonding method, physical activation processes with high energy play an effective role in increasing the bond strength.

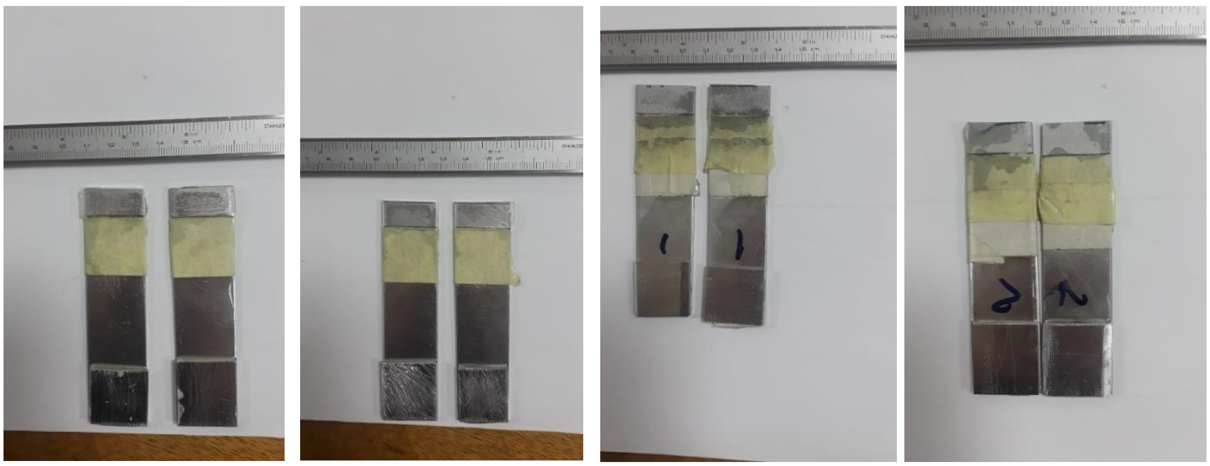


Fig.7. Test Samples After Adhesion Lap Shear Test

4. General Conclusions

The structural aluminum parts and their joint based design requirements (high strength-to-weight ratio, high damage tolerance, high durability, design flexibility, environment-friendly and low cost fabrication etc.) can be practically improved with plasma surface treatment technology. In this study; surface characteristics and durability of adhesive bonded 5754 aluminium alloy joints with different pre-treatments have been studied. The results indicate that plasma surface treatment is promising as a simple, very rapid and environmentally friendly pre-treatment for adhesive bonding. Plasma surface treatments represents an efficient, non-polluting and economical way to clean, activate, and thus to increase the adhesion properties of aluminum surfaces. Therefore, plasma eliminates the need for application of primer prior to adhesive bonding, thus making the process much simpler. In addition to the improvement of wettability and adhesion, various mechanical and material properties such as corrosion resistance, fatigue strength and surface resistance can be improved.

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References

[1] ASM Specialty Handbook: Aluminum and Aluminum Alloys, Editor J. R. Davis, 1993.

[2] A.Maroofi, N. Nava Safa, H. Ghomi, Atmospheric air plasma jet for improvement of paint adhesion to aluminium surface in industrial applications, Int. Journal of Adhesion and Adhesive 98, 2020,1-7.

[3] O. Lundera, B. Olsen, K. Nisancioglu, Pre-treatment of AA6060 aluminium alloy for adhesive bonding, International Journal of Adhesion and Adhesives 22(2):2002, 143-150.

[4] O.V. Penkov, M. Khadem, W.S. Lim, D.E. Kim, A review of recent applications of atmospheric pressure plasma jets for materials processing, J. Coat. Technol. Res., 12 2015, 225-235.

[5] B. Díaz-Benito, F. Velasco, Atmospheric plasma torch treatment of aluminium: improving wettability with silanes, Appl. Surf. Sci., 287, 2013, 263-269.

[6] T. S. M. Mui, L. L. G. Silva, V. Prysiazhnyi, K. G. Kostov, Surface modification of aluminium alloys by atmospheric pressure plasma treatments for enhancement of their adhesion properties, Surface and Coatings Technology, Vol.312, 2017, 32-36.

[7] ASTM D1002 (10), 2019 – Standard Test Method for Apparent Shear Strength of Single-Lap-Joint Adhesively Bonded Metal Specimens by Tension Loading (Metal-to-Metal).

[8] L. Bónová, A. Zahoranová, D. Kováčik, M. Zahoran, M. Mičušík, M. Černák, Atmospheric pressure plasma treatment of flat aluminum surface, Appl. Surf. Sci., 331, 2015, pp. 79-86

[9] V. Prysiazhnyi, V. Zaporojchenko, H. Kersten, M. Cernák, Influence of humidity on atmospheric pressure air plasma treatment of aluminium surfaces, Applied Surface Science, Volume 258, Issue 14, 2012, 5467-5471.

[10] K. Brunelli, L. Pezzato, E. Napolitani, S. Gross, M. Magrini & M. Dabalà, Effects of atmospheric pressure plasma JET treatment on aluminium alloys, Surface EngineeringVol 30 No 9, 2014, 636-642.