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Effect of Surface Roughness on Shear Strength of Bonded Joints of Aluminum AL 6061 T6 substrate

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Abstract: In this study, effect of surface roughness on adhesive bonding of aluminum (AL 6061 T6) substrates is investigated to determine the required bond strength between the adhesive and adherends interface. Quality of AL 6061 T6 lap shear joints (adherend surface preparation) is achieved by mechanical abrasion using diverse grades of silicon carbide sheets (P 320C, P 220C and P 180C). Lab grade acetone is utilized for the removal of impurities from the substrate surface while Loctite 4090 is served as adhesive to bond lap shear joints. Surface roughness of the substrates is measured by using profilometer (SURFTEST SJ-210). Experimental testing of adhesively bonded specimens with diverse surface roughness is conducted on Universal Testing Machine (UTM) to measure the shear strength. The results show that, aluminum adherends pretreated with P220 C achieve maximum adhesion bond strength up to 34.45 MPa at surface roughness of Ra=1.55 µm, but further increase in surface roughness from Ra=1.55 µm to Ra=2.4 µm causes 13.7% decrease in shear bond strength. Furthermore, the specimens without pretreatment achieve minimum shear bond strength up to15.23 MPa at surface roughness of Ra=0.03 µm. It was concluded that with the increase in surface roughness of the adherends up to certain limit, bond strength also increases, and locus of failure shifted from adhesive - adherend interface to within the adhesive.

Keywords: Surface roughness, Adhesive bonding, shear strength, Metals

1. Introduction

Adhesive bonding is considered as an important technique for joining dissimilar or similar structural components in various applications including microelectronics, biomedical, aerospace and automotive industries [1-4]. Researchers are trying to get optimum adhesion between adhesive and the adherends to achieve the required adhesion bond strength [5]. Adhesion phenomena have been greatly dependent on the surface morphology of the adherends, adhesive thickness of bond, testing conditions, surface pretreatment [6]. Nowadays, the usage of adhesively bonded joints in many structures or systems has become very usual. Load distribution, impact behavior and service life of the material can be increased with the enhancement of quality adhesive bonded joints. It also minimizes the vibrations, machining cost and production complexity [7-9]. However, adhesive bonded joints are often susceptible to a certain number of limitations due to early failure possibilities. Failures of adhesively bonded joints often subjected to more than one mode of failure and are defined as a percentage to adhesive failure or cohesive failure. This percentage can be easily calculated on the basis of fraction of surface contact area that subjected to cohesive or adhesive failure [10, 11].

The inherent adhesion between adherend and the adhesive can be studied from the fact that all materials exhibit attractive forces present among the atoms and molecules. Understanding of these atomic/molecular forces for adhesion could be extremely useful in creating or selecting the suitable materials to achieve the required adhesion strength. Materials exhibiting good surface wetting properties can ensure better adhesion [12, 13]. In order to accomplish a better joint strength, it is necessary for selected adhesive to manage enough close contact with adherend for attaining strong physical and chemical bonds. It was reported that bond strength of an adhesive bonded joint depends on bonded area, operating environment, service temperature, surface treatment of adherents and type of utilized adhesive [14-16]. Furthermore, to improve adherend surface properties of the materials, various surface treatment methods are developed. The surface treatment methods enhance the surface properties by changing surface chemistry and by improving the surface roughness of adherend. Typical surface treatment methods include handrails, spraying, sanding, etching and atmospheric plasma pressure treatment are well studied [17].

Mechanical surface treatment of adherend greatly effects the strength of joints, surface roughness of adherend, adhesive strength and properties of adhesive [18]. Surface roughness is an important factor which greatly affects the mechanical properties of adhesive joints. Different surface pretreatment methods are available such as grit blasting, grinding, mechanical etching and chemical etching etc. [3, 9, 19-29].

Based on above comprehension, it is not very simple and easily to define the phenomenon of surface roughness and the adhesion strength. Joint strength also varies with the surface roughness, surface morphology and used adhesive. In this study, Aluminum 6061 T6 specimens with varying degrees of surface roughness will be fabricated using mechanical abrasion and tested using UTM to get the optimum surface roughness for achieving required bond strength between the adhesive and adherends interface.

2. Experimental

Materials include Aluminum 6061 T6 base metal, LOCTITE 4090 as adhesive and lab grade acetone for the removal of foreign particles from the substrate surface.

LOCTITE 4090 is a two part/component epoxy with mixing ratio 1:1 and is applied using mixing gun to insure the optimum mixing ratio. Technical data sheet of LOCTITE 4090 shows that rate of cure depends upon temperature and time. Considering the mentioned parameters and technical data sheet to achieve full strength, 24 hours of cure time for adhesive at room temperature is adapted for all samples. The thixotropic nature of adhesive also makes it suitable for applications where good gap filling properties on rough and poorly fitting surfaces are required.

For the preparation of samples, according to FEPAP (Europe) standard different grades of silicon carbide paper (Grade P320 C, P220 C and P180 C) were used for achieving surface roughness of the adherends. Aluminum Specimens were prepared according to ASTM D1002 standard (standard for Lap shear joint test of metals) as shown in figure 1(a) and figure 1(b) shows the prepared surface of sample before joining.

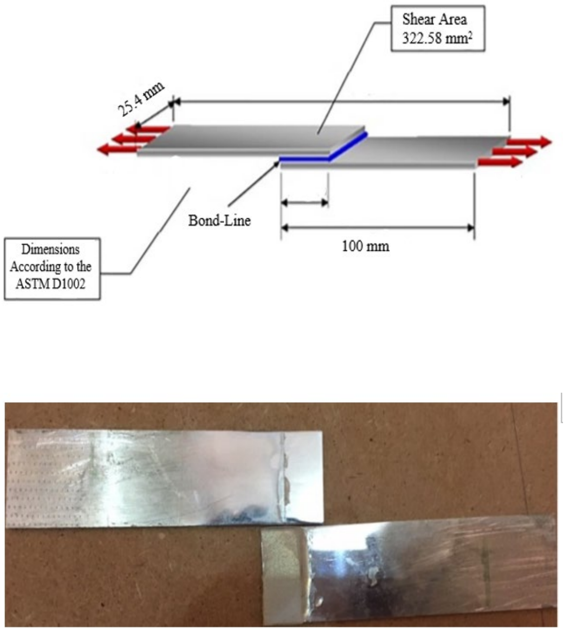

Figure 1: (a) dimensions of test Specimen; and (b) prepared Al specimens according to ASTM D1002

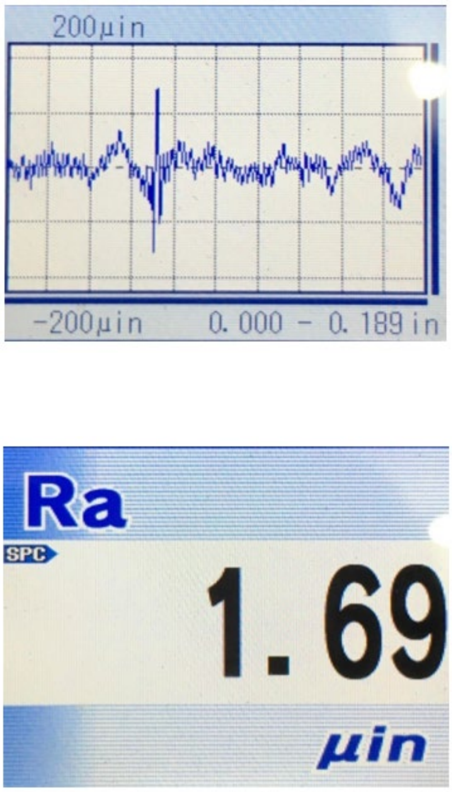

Figure 2: Al 6061 T6 Specimen Profilogram without Mechanical Treatment

SURFTEST SJ-210 is used for surface roughness measurement of all samples. Universal testing machine is device which was used in this study to conduct tensile test of samples. 100KN screwed AG-X (100KN) working on Trapezium X Testing interface software. According to ASTM standards three samples of each concentration were prepared and test at feed rate of stroke is 1 mm/min smoothly.

3. Results and Discussions

3.1 Results of Surface Roughness of AL 6061 T6

Firstly, three specimens of aluminum alloy ware tested without mechanical treatment. The results of these tests were used as reference in later research work. The profilogram of one specimen from these specimens is presented in figure 2. Furthermore, the profilogram and Ra value of aluminum specimens after different surface treatment with different grades of silicon carbide sheets (P320 C, P220 C and P180 C) are presented in the Figure 3, respectively. It is evident that surface roughness if increased from 1.69 μin to 30.89, 61.01 and 94.43 μin by treating the surface with P320 C, P220 C and P180 C, respectively.

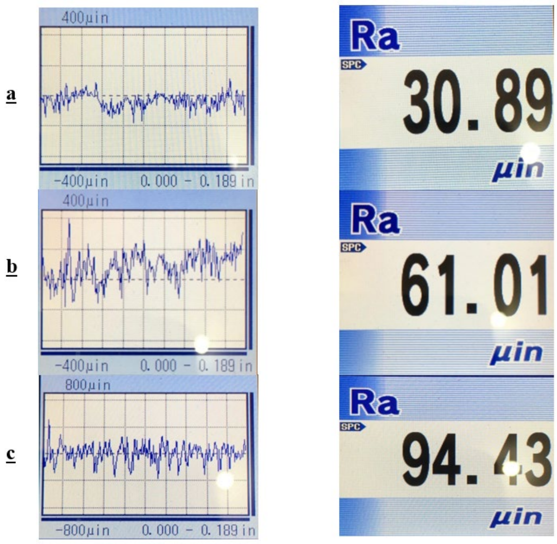

Figure 3: Al 6061 T6 Specimens Profilogram treated with (a) 320 C paper, (b) 220 C paper and (c) 180 C paper

3.2 Comparison of Surface Roughness after Mechanical Abrasion

Table 1 presents the average surface roughness of all three aluminum specimen, tested after treatment with different grades of silicon carbide sheets and without any pretreatment. Values are converted in μm for SI system of units. The profilogram of different specimens illustrates surface roughness of specimens after surface pretreatment increases with decreasing the silicon carbide paper grade. Maximum increase of 5640.47% in surface roughness is calculated by preparing the surface with P180 C silicon carbide sheet as compared to no treated surface.

Table 1: Ra Values of Aluminum Specimens without and with Mechanical Abrasion

Sr. No.	Abrasive Paper Number	Surface Roughness "Ra" µinch	Surface Roughness "Ra" µmeter
1	Specimens Without Mechanical Treatment	1.69 µinch	0.042 µmeter
2	Specimens Abraded with P320C Sheet	30.89 µinch	0.784 µmeter
3	Specimens Abraded with P220C Sheet	61.01 µinch	1.546 µmeter
4	Specimens Abraded with P180C Sheet	94.43 µinch	2.411 µmeter

3.3 Lap-Shear Strength of Adhesively Bonded Aluminum 6061 T6 Specimens

A relationship between lap shear strength and different abrasive sheets is presented in figure 5. Surface roughness varies with changing the grade of abrasive silicon sheets. It is also evident that shear strength is direct function of surface roughness. Increasing the surface roughness, bond strength also increases and vice versa.

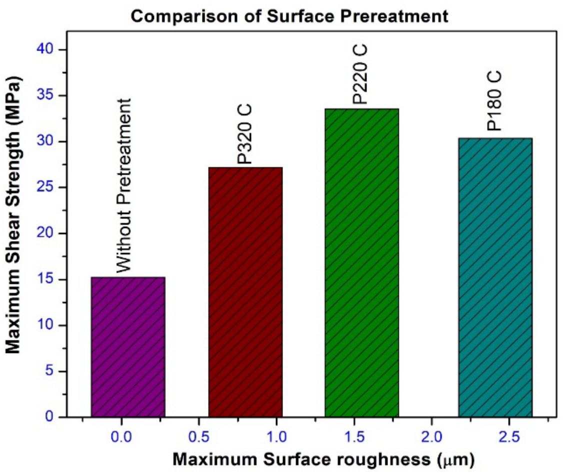

Figure 5: Comparison of shear strength with surface pretreatments

It is also observed that adhesively bonded joints obtained using P220 C silicon carbide sheet exhibits maximum joint strength and the treatment method adopted to achieve this strength also shows repeatability of results. The specimens treated with P180 C to achieve more surface roughness shows less shear bond strength than the specimens subjected to P220 C silicon carbide sheet.

Using this mechanical surface modification treatment technique, the increasing trend in joint strength is shown in Figure 8. The lowest joint strength of adhesively bonded specimens using the mentioned surface treatment technique was seen when adhesively bonded specimens without any surface pretreatment were subjected to lap shear joint strength test.

Furthermore, there are two types of failure occur at adhesive adherend interface. First one is adhesive failure of adhesively bonded joints and it occurs up to 0.042 µm avg. surface roughness as presented in figure 6. Adhesive failure occurs because adhesive did not completely fill into the pours/cavities of aluminum adherend. Second one is Adhesive-cohesive failure which is presented in figure 7. Adhesive-Cohesive failure occurred at 0.78 µm and 1.55 µm avg. surface roughness and it is because at this surface roughness, adhesive completely wet the adherend and filled into the cavities of adherend.

Figure 6: Adhesive Failure

Figure 7: Adhesive-Cohesive failure

Figure 8 clearly depicts that after a certain point (critical surface roughness), further increase in roughness causes to decrease in shear strength (it can also be seen in figure 5 at P180 C). Basic reason behind this, In the first phase, the increase in bond strength with increase in surface roughness was due to the factors like, removal of impurities, irregularities and increase in surface area. In the second phase, the decrease in the lap shear bond strength after certain limit called as critical surface tension, the surface treatment has started penetrating in to the internal layers of the material and ultimately leads to weakening of material which leads to decrease in lap shear bond strength as presented in figure 8. Furthermore avg. Surface roughness and avg. shear strength of specimens are used to show the increasing and decreasing trend in joint strength of adhesively bonded aluminum 6061T6 specimens and the results agree with published literature [29].

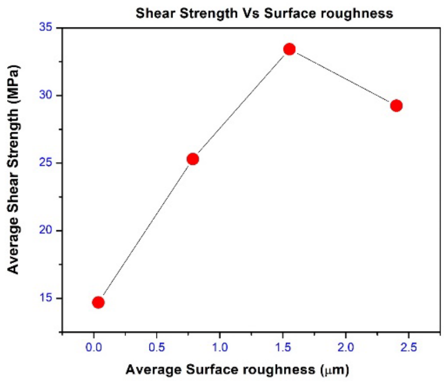

Figure 8: Graph between Avg. Ra and Avg. Shear Strength of specimens

4. Conclusion

Effect of surface roughness on adhesive bonding of AL 6061 T6 specimen using diverse grades of silicon carbide sheets is investigated to determine the required bond strength. Maximum adhesion was obtained when the aluminum 6061 T6 specimens were mechanically pretreated with P220 C silicon carbide sheets and 34.45 MPa average shear strength is measured. Minimum strength was achieved when specimens without any surface treatment were utilized and the obtained shear strength for these specimens was up to 15.23 MPa. Based on experimental results, it was observed that increase in surface roughness of substrate increases the shear bond strength while after critical surface roughness further increase in roughness causes to decrease in shear strength. It was concluded that the increase in bond strength with increase in surface roughness was due to removal of impurities, irregularities and increase in surface area while after critical surface tension, the surface treatment has started penetrating in to the internal layers of the material and ultimately leads to weakening of material which leads to decrease in lap shear bond strength.

Authorship contribution statement

Jawad Abid: Data curation, Formal analysis, Methodology, Writing-Original Draft

Hassan Raza: Conceptualization, Methodology, Formal analysis, Writing - original draft.

Awais Akhtar: Formal analysis, Review-Editing
Ghulam Abbas Gohar: Formal analysis, Review-Editing
Sana Ullah: Formal analysis, Review-Editing
Muhammad Akram: Formal analysis, Investigation
Yasir Raza: Formal analysis, Review-Editing
Muhammad Dawood Bukhari: Formal analysis, Review-Editing

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