Influence of Surface Roughness of Adherend on Strength of Adhesive Joint

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Abstract— The requirements for lightweight equipment in automotive, aerospace and construction industries have led to a trend of replacing commonly used steel by aluminum alloy, fiber reinforced plastic and other types of alloy in auto- mobile parts, such as roofs, doors and engine covers. However, some traditional joining methods, such as riveting, bolting and threading and welding are not suitable to be applied in joining dissimilar materials and may bring problems in inevitable stress concentration. Epoxy-based adhesive has a wide range of applications in bonding similar & dissimilar materials for better lightweight effect. Here, experimental investigations were carried out to study the effect of surface roughness of adherend and adhesive layer thickness on joint strength. Effect has been compared by using four samples.

Index Terms— adhesive bonding, aluminum alloy, roughness, shear strength, single lap joint

I. INTRODUCTION

Adhesives have been widely used in the automotive, aerospace and construction industries to replace the conventional joining techniques. The lack of accurate strength prediction of adhesively bonded joints exposed to long-term hot-humid environment inhibits making more wide-spread application of adhesive bonding. Reliable strength prediction model is essential to reduce the amount of expensive and time consuming durability testing at the design stage with the increasing use and importance of adhesive bonds in structural engineering a high demand for the optimization of adhesive joint designs has developed. Understanding of the mechanical behavior is required. In particular, this includes the knowledge about the load transfer and the resulting stresses in adhesive joints. The different parameters that will have effect on the joint strength and durability like as

- Surface preparation methods
- Bond line thickness
- Types of adhesive
- Types of adherend

Surface preparation is one of the important parameter which is directly related to the quality of the bonded joint.

II. LITERATURE REVIEW

The work of different researchers in the area of strength analysis of single lap adhesive joint is presented below. Xiacong (2010) reviewed the recent work relating to finite element analysis of adhesively bonded joints, in terms of static loading analysis, environmental behaviors, fatigue loading analysis and dynamic characteristics of the adhesively bonded joints. It is observed that the finite element analysis of adhesive bonded joints will help future applications of adhesive bonding by allowing system parameters to be selected to give as large a process window as possible for successful joint manufacturing. This will allow many different designs to be simulated in order to perform a selection of different designs before testing, which would currently take too long to perform or be prohibitively expensive in practice. [1] Yasmine Bouter (2015) investigated the performance of recessed single-lap joints with similar and dissimilar adherend through the finite element method. The influence of material and geometric nonlinearity of the adhesive as well as the impact of the recess length was examined in terms of maximum principal stresses. The strength of the joint is obtained as the load to initiate the crack propagation. Results suggested that either adding a spew fillet or considering the adhesive plasticity led to reduced peak stresses at the edge of the adhesive layer. Large stresses occurred at the interfaces rather than the middle plane of the adhesive layer, which implied a limitation of analytical solutions. [2]

A Problem Statement;

Influence of adherend surface roughness on strength of an adhesive bond with the change in adhesive layer thickness.

B Objectives;

1. The main objective of this study is to investigate the effect of different surface roughness for aluminum adherend on the strength of an adhesive bond.
2. These include the ability to bind different materials together, to distribute stress more efficiently across the joint, the cost effectiveness of an easily mechanized process, an improvement in aesthetic design, and increased design flexibility.
3. Adhesive joints have good behavior under fatigue loads, allow the joining of different materials, and result in less stress concentrations compared to alternative joining techniques.

4. In order to increase the confidence of designers, it is necessary to accurately predict their strengths.
5. Structural adhesives are more frequently used in manufacturing processes as they provide numerous advantages when compared with the traditional joint systems, such as corrosion resistance weight reduction, and elimination of stress concentration due to the fastener mounting hole. Other benefits include improved stiffness, rigidity, impact behavior and energy absorption, less vibration and sound deadening.

III. EXPERIMENTAL SET UP

A. Materials

Aluminum AA6061 is used as adherend in this study. Aluminum alloy cut by hand shearing machine at required dimension of "200 mm x 25 mm x 2 mm". A bicomponent structural epoxy adhesive Araldite® 2015, supplied by Huntsman International (India) Private Limited, and was selected for this study. Mechanical properties of Araldite® 2015 and aluminum AA 6061 are summarized in table 1 and 2.

Table 1 Epoxy Adhesive Araldite® 2015

Sr No	Property	Value
1	Young's modulus, E (GPa)	1.85±0.21
2	Shear Yield strength (MPa)	14.6±1.3
3	Shear Modulus G (GPa)	0.56 ± 0.21
4	Poisson ratio	0.33

Table 2 Epoxy Aluminum 6061

Sr No	Property	Value
1	Tensile strength (MPa)	110-152
2	Yield strength (MPa)	65-110
3	Elongation of Failure %	14 to 16
4	Shear Modulus G GPa)	20-25
5	Young's modulus, E (GPa)	70-80
6	Poisson ratio	0.33

B. Surface Preparation of sample

Two kinds of adhered surface were used, abraded surface are prepared by using a different grade of emery paper. Three different grades of emery paper, P50, P80 and P120 are used for the making the different surface roughness values and the flat plate without abraded surface were measured with the help of digital surface roughness tester. The surface roughness pattern applied to the adherend was 0°, 90° and ±45° orientations (relative to loading direction).

Fig. 1 Surface preparation

Table 3 shows the surface roughness pattern used for all aluminum adherend. Two roughness parameters the average surface roughness value (R_a) and the maximum surface roughness value maximum height of profile, (R_z) were used to evaluate the surface quality of the specimens. Surface roughness values, R_a and R_z were measured using a digital surface roughness tester made by (Mitutoyo-3100, Japan) for both abraded and non-abraded four samples. The surface roughness measurements were performed in different areas, along two different directions. The measured surface roughness values, R_a and R_z of aluminum adherend are given in Table 3.

Table 3 Surface roughness value

Sample no	R_a µm	R_z µm
1	0.06	0.19
2	0.41	0.61
3	2.46	7.79
4	3.61	8.58

C. Contact Angle Measurement

The wetting characteristic of all types of the adherend surface (different surface roughness) was determined using a contact angle Digidrop Machine (DSA25E) equipment was used to measure the contact angle shown in figure 2. In order to measure the contact angle, a 01 ml drop of epoxy resin Araldite® 2015 was deposited on the adherend surface with a disposable micro-syringe. A minimum of three contact angle tests was recorded in different surface area to obtain an average result and also cross verification of surface uniformity. The complete instrument set-up for contact angle measurement is shown in figure 2.

Fig. 2 Contact angle measurements Digidrop Machine

Table 4 Average roughness and Contact Angle

Sample No	Roughness Value(Ra **µm)**	**Contact Angle (Degree)**
1	0.06	82.8
2	0.41	90.1
3	2.46	105.7
4	3.61	115.2

D. Testing on UTM

Four different samples were prepared of given material with the size "200 mm x 25 mm x 2 mm" with the different layer thickness value of 0.5, 0.7, 1.0, 1.5 mm. The overlap (gauge) length of every joint has 40 mm[13]. The specimens were tested in a Universal Testing Machine (Made by Blue Star, Model UTE 20) at a crosshead rate of 5 mm/min. The UTM was connected with a computer for automatic data acquisition and storage. Single strap shear tests were carried out in tensile testing mode. Four specimens were tested for each condition. The gripping length was kept at 30 mm at both ends, while the gripping width was covering the whole width of the specimen. The tensile test set-up is as shown in figure 3. The load and displacement values were recorded during the tests.

Fig. 3 Experimental set up of SLJ

D Analysis by FEA

In numerical analysis, the commercial FEA ANSYS 14.5 software has been used. The same geometry and different roughness of single lap bonded specimens was tested experimentally and numerically modelled by using two-dimensional 8-node isoperimetric finite element. Simulations of axial stretching of the bonded joints have been carried out under the same boundary conditions as in experimental work.

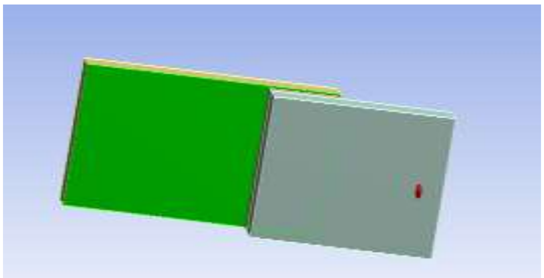


Fig.4 3D model of SLJ

First a 3D model in Catia V5 was made in defined dimensions. Width of joint is 25 mm, length of first and second plate is 100 mm, 140 mm, and thickness of plate is 2 mm. After cleaning up the geometry, both plates were meshed one by one. Then following values were entered. Element Size: 2, Mesh Type: quads. After Clicking on mesh button, a uniform mesh was generated. The meshed component is shown in figure 5.

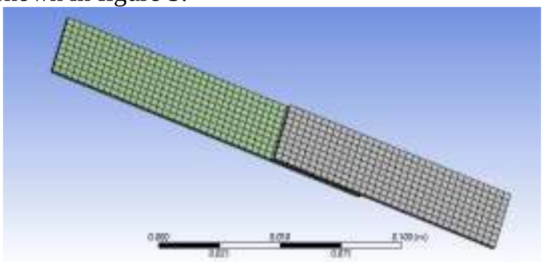


Fig. 5 Meshing of SLJ

For creating adhesive connection between two plates was created by hiding one meshed plate, then selecting some of the elements on bottom plate. Then after clicking on element and selecting select required row of elements to join. For components, Al Plate 01 and Al Plate 02 were selected. Adhesive connector is shown in figure 6.

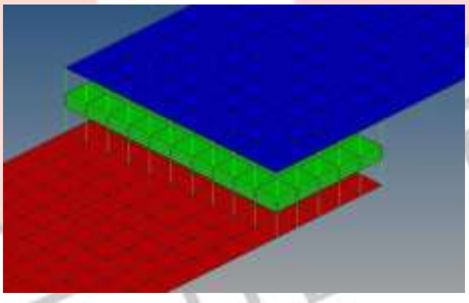


Fig. 6 Adhesive Connector

After the addition of adhesive connecter, boundary conditions were applied similar to the experimental conditions and different results were obtained. One sample result is shown in figure 7.

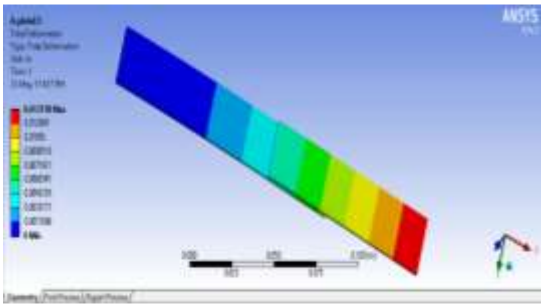


Fig. 7 Maximum Shear stress

IV. RESULT AND DISCUSSION

Different parameters of single lap joint with the help of experimental as well as FEA procedure are tested for different loads at adhesive thickness of 0.5mm, 0.7mm, 1.0mm and 1.5mm and respective stresses were determined. The values obtained by analysis and experimentation are presented into tabular form in table 5. Further, the graph showing relation between load applied and stresses are presented.

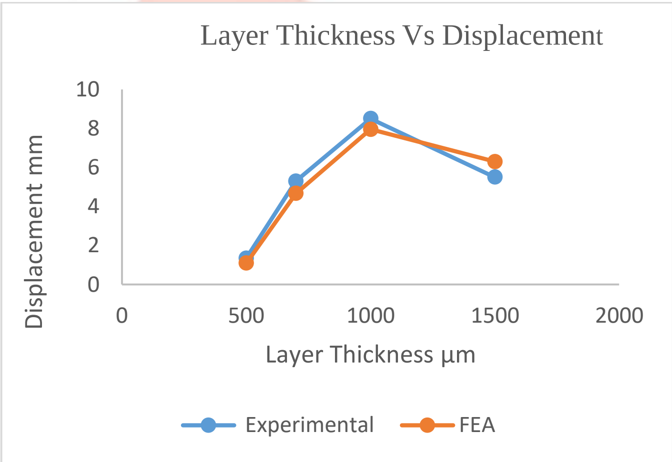
Table 5 Load and samples

	Sample 1	Sample 2	Sample 3	Sample 4
Load KN	0.1	0.2	0.5	0.5
	0.2	0.7	1	0.9
	0.3	1	1.5	1.8
	0.4	1.5	2	2.1
	0.45	1.76	2.84	2.14

In this work four different sample of a layer thickness are used which are given in table 6. At the time of loading, displacements for each sample was observed with the help of strain gauge. Roughness is one of the important parameter that affects the strength of adhesive joint. Roughness of every specimen was measured by digital surface roughness tester and an average roughness value (R_a+R_z) was taken. The observed result is tabulated in table 6.

Table 6 Thickness and Displacement

Layer Thickness µm	Displacement (mm)	
	Experimental	FEA
500	1.35	1.1
700	5.3	4.67
1000	8.5	7.95
1500	5.5	6.3



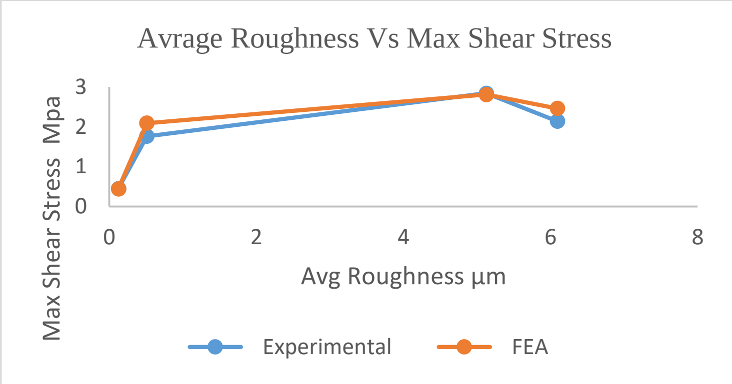
Fig; 8 Layer Thicknesses vs. Displacement

Experimentally calculated load was applied with the help of Ansys 14.5 and the principal and equivalent stresses were found which are given in table 7.

Table 7 Average roughness and Max Shear stress

Avg. Roughness(µm)	Max Shear Stress (MPa)	
	Experimental	FEA
0.125	0.45	0.44
0.51	1.76	2.09
5.125	2.84	2.81
6.095	2.14	2.46

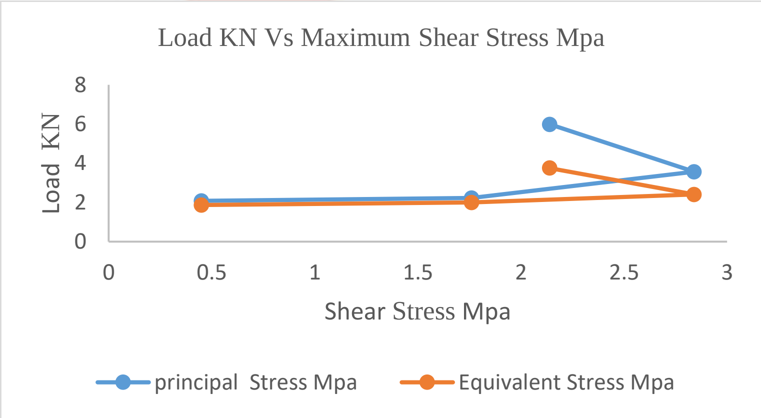
We can simply observe that as roughness value is increasing the stress is increasing until an average of 5.125 µm and then it suddenly decreases.



Fig; 9 Average roughness value Vs Max Shear Stresses

Table 7 Load Applied and Elemental Stress

Sample No	Load Applied in KN	Elemental Stress in MPa: Principal Stress (MPa)	Elemental Stress in MPa: Equivalent Stress (MPa)
1	0.45	2.072	1.86
2	1.76	2.22	1.99
3	2.84	3.56	2.4
4	2.14	5.98	3.75



Fig; 10 Load Vs Element stress in MPa

V. CONCLUSION

In this work, the effect surface roughness of aluminium adherend on Epoxy adhesive bond strength was investigated. Single lap joints with different adherent roughness and layer thickness (i.e.0.5, 0.7, 1.0, 1.5mm) were tested. Contact angle also plays an important role in strength of joint when surface roughness is changed. The following are some conclusions obtained:

1. The strength variations with respect to the surface roughness follow the same trend i.e. initially increases and then decreases with roughness.
2. The surface roughness parameter must be considered during the design stage of adhesively bonded joints, as the bond strength varied significantly by 30–35 %, between the different surface roughness values.
3. The equal amount of stress distribution of single lap adhesive joint is only possible with the help of adhesive joint.
4. An optimum surface roughness for maximum strength in aluminium adhered joints is obtained experimentally and analytically.
5. Adhesive joint is satisfying the characteristics like corrosion resistance, leak proof and sound deadening.

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