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DESIGN AND ANALYSIS OF ALUMINIUM ADHESIVE JOINTS

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ABSTRACT:

Adhesive bonding is widely used for sheet metal joining. Majority of automobile, aerospace parts, mainly their body components are joined together by different types of adhesives. So their growing demand needs the detailed study of strength analysis of adhesive joints. Investigation on single lap adhesive joint is to be done for various applications.

Overlap length, load and Adhesive layer thickness has to be varied in the defined range & analysis is done by to see the nature of changes in the joint. FE analysis is done by using Ansys to observe the nature of changes in the joint. Validation by Mechanical testing is done by using Universal Testing Machine up to ultimate limit. Overall joint strength is related to maximum force that can be sustained by joint. The overlap at which the maximum force is required to break the joint is the length which can considered as optimum adhesive overlap length

KEYWORDS: Adhesive bonded lap joint, UTM Testing, Ansys.

1. INTRODUCTION:

Fastening between the plates such as structural work, ship building, bridges, tanks and boiler shell are done by riveting, welding, bolting as well as adhesive joint.

Adhesive bonding as an alternative method of joining materials together has many advantages over the more conventional joining methods such as fusion and spot welding, bolting and riveting. Demand for adhesive bonding is increasing day by day due to joining similar or dissimilar structural components and optimize its use in light weight structures. In adhesive bonding, the load is transmitted from one adherent to another adherent smoothly through the adhesive layer in the overlap region, i.e. the adhesive serves as a medium for load transmission.

Adhesive bonding is a material joining process in which an adhesive, placed between the adhered surfaces, solidifies to produce a joint. When we bond components together the adhesive first thoroughly wets the surface and fills the gap between, then it solidifies. When solidification is completed the bond can withstand the loads for their respective application. Adhesives come in several forms thin liquids, thick pastes, films, powders, pre applied on tapes, or solids that must be melted. Adhesive can be designed with a wide range from holding surfaces temporary to high strength application in aircraft and cars

Yi Huaet al.[1] thispaper investigated recessed single-lap joints with dissimilar adherendsi.e composite-titanium adherends through the finite element method. Recessed adhesive joints, is a gap in the center portion of the adhesive within the overlap which is one of the bonding techniques. The results suggested that there is mitigation of stress concentration for that recess length should be less than 50% of overlap length. Addition of recess in between reduces the peak stress at the edge, because the peak stress always occurred at the edges in this case the overlap length is considered as 12.5 mm so it occurs (x=0 and x=12.5) under tension, In addition to this stress at mid layer were less as compared to top and bottom interface between adhesive and adherends those may cause due out of plane bending or dissimilar adhrends As compared to continuous adhesive joint there is 0.6% to 3.6% increase in maximum principle stress for the case of 1.25 to 3.75 mm recess length respectively.

Lucas F et al.[2] investigate the effect of adhesive type and thickness on lap strength where they used three types of adhesive (brittle, intermediate and ductile) are selected and thickness taken for each adhesive is from 0.2,0.5,1 mm where they found that failure occurs cohesively close to the adherend-adhesive interfaces. Results predicted that thinner the bond line stronger the joint even for brittle adhesive. Depending upon toughness of adhesive its strength varies also with decrease in adhesive thickness lap shear strength increases

F.A. stuparu et al. [3]analyzed failures of dissimilar lap joint where overlap length and adhesive thickness is kept constant but the adherend thickness is varied. Alumimum and carbon fiberlap together to form a single lap joint. Al-Al joint with 3 and 5 mm thickness shows that stiffness is increased for thicker aluminiumadherends. As stiffness decreases (3mm) the peeling effect is greater and the joint fails at a smaller rate where it is same for carbon carbonadherends; however, the aluminium -carbon lap joint is stiffer but fails sooner. Dissimilar joints (aluminium-carbon) with smaller thickness adherends succeed to maintain the stiffness of the assembly as compared to the aluminium joints, but their strength is diminished by the pull-out and delamination of carbon fibers.

Lijuan Liao et al. [6]he investigated Three different adhesives AV 138 (brittle), Hysol EA 9321 (Intermediate),Hysol EA 9361 (Ductile) with scarf angles θ=30˚,45˚,60˚ are used where they found loading drops slow for the joint with intermediate and ductile adhesive that the complete separation occur at quite large displacements comparing with the joint with the brittle adhesive.Energy required for the failure of the DSJ with the brittle adhesive is smaller than that of the DSJ with the intermediate and ductile ones. Furthermore, it can be concluded that the adhesive joint performance is controlled both by the ultimate loading and by the ultimate displacement until complete failure.It can be found that the load-bearing capacity of the DSJ decreases as the scarf angle θ increases.

Kahraman et al. [12],studied the influence of adhesive thickness and aluminium filler contenton the mechanical performance of single lap jointbonded by aluminium powder filled with epoxy adhesive. This investigation shows that decrease in adhesion strength with increase in adhesive thickness. The failure mode in the joint is cohesive mode due to high stress level generated in the adhesive, which indicates adhesion to metal surface is stronger than the strength of adhesive itself.

Borsellino et al. [13]used thin aluminiumsheet, both non treated and mechanically treated aluminium sheet with abrasives surface, in a study of single lap joint. They conclude that joint strength is significantly higher with mechanical abrasion

Zadpoor et al.[14], Investigated the mechanical behavior of adhesively bonded blanks of similar and dissimilar metals. For similar materials, it is found that the straining is mainly parallel with transition line, where the formability is restricted by ductility of applied adhesive. If the straining is normal to transition line then the formality is controlled by fracture energy of adhesive.For dissimilar material combination due to low ductility of base sheet in comparison with upper sheet there is competition between failure mechanism like delamination and metal failure.Localization of strain imperfections of base material is prominent reasons for base metal failure occurring before delamination.

1.1 FACTORS AFFECTING:

A lot of factors affect the load carrying capacity of an adhesive joint. The geometrical configuration of bonded parts is essential to obtain enough structural strength. Even joints having same geometrical configuration may have different strength depending upon type of bond and its bonding characteristics. The adhering conditions are also important get the joint strength (e.g. the surface roughness surface of plates to be join, an adhesive layer thickness, the pressure applied to adhesive and its holding time, and curing conditions of adhesive are substantial factors affecting the joint strength).Adhesive strength is affected by the many physical and chemical factors. Here geometrical configuration of the joint has been varied which is overlap length.

In the view of gap between recent literature this study focus onan analysis of strength of single lap adhesive joint by varying overlap length from 15 mm to 60 mm , where such joint use in aluminum frame by comparing adhesive joint strength with riveted and welded joint under universal testing machine.

2. EXPERIMENTATION:

Two aluminum plate of size (130 x 30 x 2) mm are bonded over each other with Epoxy E 30 Cl by varying overlap length.

2.1 SPECIMEN PREPARATION:

The samples are cut to length with the help of shearing machine. Then the samples surface is cleaned after cleaning roughen the surface of overlap with emery paper then again cleaning is carried out. The resin and hardener mix in the ratio of 2:1; then the paste is applied over the lap region by placing weights on joint as shown in fig (1) and the adhesive layer thickness is 0.1 mm.The curing time for the joint is 56 hours at room temperature (25-26˚C)

For riveted joint same size plates are riveted with the help of tucker pop rivet of diameter 2.5 mm, the numbers of rivets are varied as the overlap length increases as shown in fig. (2)

TIG aluminum welding is done by wire diameter 2.4 for the samples by varying overlap as shown in figure (3)


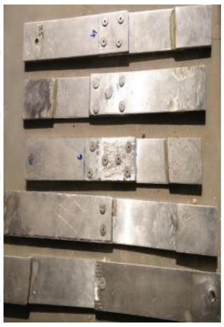


Fig.1:Adhesive Fig 2: RivetedFig. 3: welded joint

2.2TESTING ON UTM:

Gauge length is mark on specimen =50mm.Specimen is held between in clamps then it is loaded in tension using a 10 ton universal testing machine (UTM) with the cross-head speed of 1 mm/min

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Fig.4:The photograph of specimen loaded on the 10 ton load cell UTM.

2.3TEST RESULT:

For Adhesive, riveted, welded joint by varying overlap length, following are the maximum force sustained by joint.

Table 1: Maximum force carried by joints at different lap length

Lap joint overlap length (mm)	Adhesive joint Max force(N)	Riveted joint Max force (N)	Welded joint Max force (N)
15	3705.79	1738.52	7111.9
20	4605.37	3000	11828.4
35	5167.56	4786.16	11194.4
45	6886.24	7801.96	11573.9
60	10681.8	8745.3	11344.2

3. FEA BY USING ANSYS:

Bonded joints are needed to be simulated for the aluminum plate specimens; cohesive zone method is used while performing FEA on the component. Cohesive zone properties for the given join between adhesive and aluminum are unknown;so different set of properties are guessed for the initial first case analysis. After getting the results for the maximum force taken by the joint within the error zone below 15 %; the cohesive zone properties are finalized. Once the properties are finalized the same are used to perform different bonded joint simulations with varied conditions and same cohesive zone properties. Results form them are compared with the testing results and error between FEA and practical testing is calculated. Thus we get to establish the method to perform FEA on the joint between a given set of adhesive and parent material joint. Also we get to validate the testing data for different overlap settings with FEA. Maximum acceptable error in the forces experienced is 15 %.

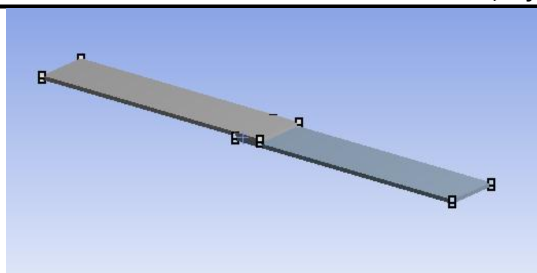

Fig. 5: Geometryof lap joint for FEA

Two specimens according to standard dimensions are created and 15 mm overlap is maintained between the two plates to create lap joint. Adhesive E30 CI is applied on the both faces and both components are help together with force during the curing period of the joint in order to give joint time to gain its adhesive bonding strength. Similarly in ANSYS material properties of the aluminum sample are used which are as follows:

Table 2: Material properties for Specimen

Properties	Al 99.5
Young's Modulus, E	70 Gpa
Poisson's Ration , ν	0.3
Density , ρ	2700 kg/m^3

Bonded contact is created between the two overlapping surfaces and augmented LaGrange formulation is used for contact. 530 Element are used to mesh the module with 4200 nodes.

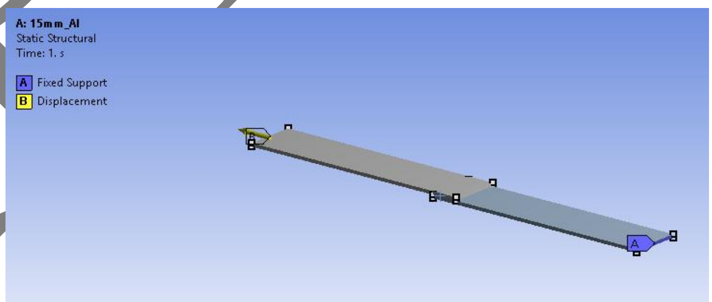

Fig. 6: Boundary conditions for the Bonded joint analysis

A fixed boundary condition is applied on the one end of the specimen while the other end is applied with single directional displacement with 0 displacements on other two planes. These boundary conditions simulate the UTM fixed and moving jaw behavior. Forces taken by the joint before failure are noted.

Same contact is applied with the cohesive zone material properties. Different cohesive zone material properties are applied to the contact with certain guesswork to simulate the joint created by the adhesive correctly. Results for the different properties are tried and at 4th trial load taken by the joint is 3662.7 N which is within the 1 % error zone of 3705 N and acceptable.

Most common type of debonding method used in FEA is separation distance-based debonding model which is applied to model this bonded joint with 15mm overlap.

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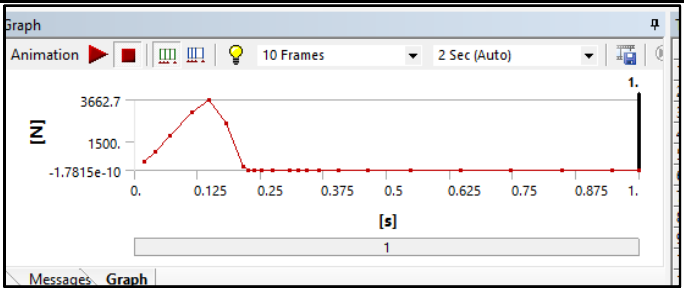

Fig.7: Load taken by the join in trial 4 with 15 mm overlap

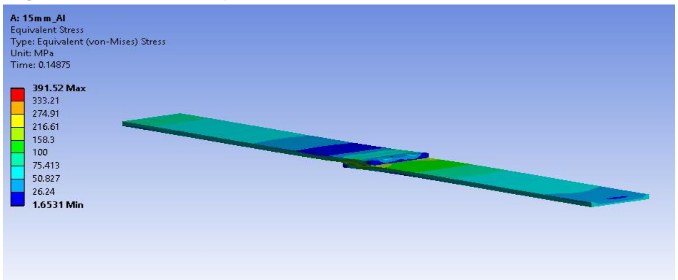

Fig.8: Vonmises stress plot at 15 mm overlap

Maximum point stress in the bonded joint area at the time of delamination goes much higher than the acceptable limit. It is shown in the von mises stress plot which is 391.5 MPa.

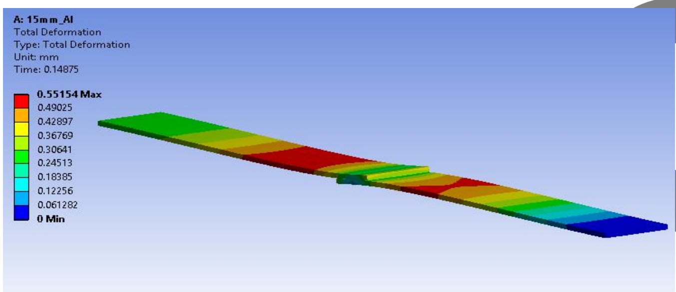

Fig.9:Deformation plot just before bonded joint breaks at 15 mm overlap

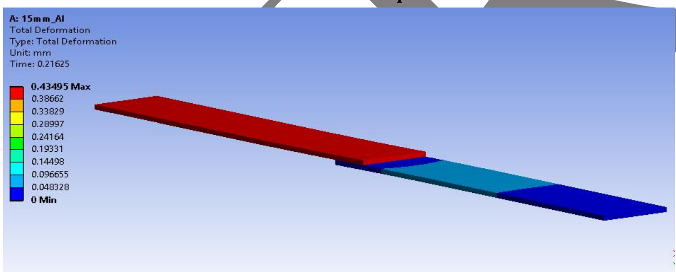

Fig.10: After delamination deformation plot at 15 mm overlap

As shown in the fig. after delamination the plate applied with motion slides away from the fixed plate. So contact between the two plates is broken. With same cohesive joint properties of 15 mm overlap we use for other lap joints.

4. RESULTS AND DISSCUSSION:

FEA and experimental analysis is done for Adhesive joint, the error found is below permissible limit which is acceptable; which means that czm properties in ansys are derived from experimental results on trial basis provides a countable result.

Table 3: Percentage deviation in maximum force values

Lap joint overlap length (mm)	Experimental max. force(N)	ANSYS max. force(N)	% Deviation
15	3705.79	3662.7	1.2%
20	4605.37	4369.3	5.1%
35	5167.56	5101.6	1.3%
45	6886.24	6420.5	6.8%
60	10681.8	9350	12%

A regression analysis is performed to forecast the values of load sustained by joint at any lap length depending upon values obtained from experimentation:

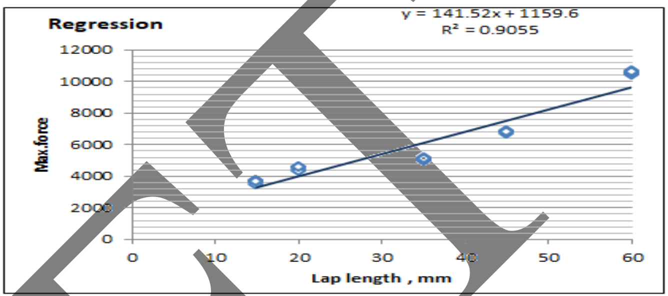

Chart 1: Regression plot for adhesive joint

Forecast(Yp)	
Input X	25
forecast Y	4697.516
95% prediction interval	3173.1963< Yp < 6221.835

Chart 2: Forecast at any adhesive lap length say 25 mm

Forecast(Yp)	
Input X	25
forecast Y	3402.754
95% prediction interval	2365.3932< Yp < 4440.1147

Chart 3: Forecast at any riveted lap length say 25 mm

Adhesive joint strength is compared with aluminum welded and riveted joint the results are as follows:

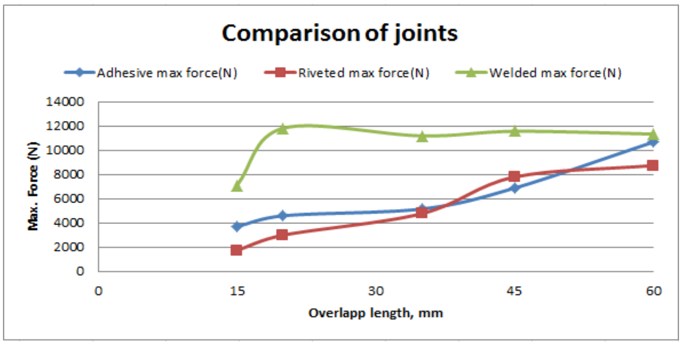

Chart 4: Comparison of adhesive, riveted, welded joints

From graph it shows the strength of adhesive joint increase with increase in overlap as well as for riveting with increase in number of rivets but increase in number of rivets causes a stress concentration because of holes drilled in the plates. The riveted joint does not provide a leak proof joint while riveting the plate may bend due to hammering effect. For the same overlap of 60 mm the adhesive joint withstand a force 10681 N at displacement of 72 mm while it is 8745.3 N for riveting at displacement at 3 mm, it means riveted joint shear much earlier than adhesive joint .As the crack in bonded structure propagate slowly as compared with the riveted structure because adhesive forms a continuous joint bond and this bond line acts as crack stopper. For welded joint which has higher strength but sometimes because of material impurities or stresses developed due to welding may cause a parent material to fail, which happens with 15 mm overlap length.

5. CONCLUSION:

The effect of single joint lap length on welded, riveted and adhesive joint was investigated in this study. The adhesive layer thickness is 0.1 mm and adherend were 2 mm thick aluminium. The experimental as well as finite element analysis incorporating interface properties were analyzed for adhesive joint. The following are the conclusions can be drawn:

1. The lap joint strength increase with increase in overlap length, but there is certain bound on increase in lap length as beyond 60 mm lap length the results are almost same when we compare 3 joints as shown in chart 4.
2. The strength of welded joint is almost same for all overlap length, because the fillet weld area is constant.
3. The strength of weld joint is more than adhesive, but welding also distort the material (light weight material as aluminum , magnesium) because of localized heating, so the in such a case adhesive joint can be incorporated
4. With the finite element analysis, it shows deviations are within limit for adhesive joint, so we can used different adhesive by applying interface properties and analyzed the load sustain capacity which results into overlap length should be maximum to have maximum bond area at constant adhesive layer thickness.

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