

STRENGTH OF ADHESIVE BONDED JOINTS: BENDING TEST

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ABSTRACT

An experimental investigation of "Strength of Adhesive Bonded Joints: Bending Tests" was presented. In this investigation, the Flexural Strength of Parent Aluminum specimen, Aluminum - Aluminum Laminate specimen and Aluminum- Steel Laminate specimen were determined experimentally. The Adhesive used for gluing the Aluminum (Aluminum Laminate and the Aluminum - Steel Laminate) was Araldite (an Epoxy Adhesive). The specimens were rigged up horizontally as simply supported beams and loaded vertically at their geometric centre. The beam loading versus deflection relationship for each specimen was developed and analyzed. Consequent on the above, the flexural strengths for the Parent Aluminum specimen, Aluminum - Aluminum Laminate and Aluminum - Steel Laminates were determined. The results revealed among others that the Aluminum - Aluminum Laminate's Flexural Strength was higher than that of the Parent Aluminum Plate. Therefore, it is more economical where there is the constraint of space to use Aluminum - Steel Laminate because higher strength is obtained even though the total laminate depth is less compared to that of Aluminum - Aluminum Laminate.

Keywords: *Adhesive Joints, Flexural Strength, Laminated Beams.*

INTRODUCTION

The purpose, need, function and justification for Joints in engineering design, manufacturing and production industries have been discussed in Okpighe (2009) where emphasis has been on the existence of joints as a consequence of inexistence of materials (metal bar, sheet metals and many others) of infinite length. For joints to be of use, they must perform the functions they have been chosen to perform satisfactorily. Various types of joints and various bonding methods exist and these have been discussed in Okpighe (2010). Some of these joint types include butt, lap (single and double), tee and laminate among others. In the same vein bonding methods for joints include welding, riveting, bolting and use of adhesives among others. A lot of work has been done in the area of adhesive bonding of joints. Wu, Yuan and Niu (2002) investigated stress transfer and fracture propagation in different kinds of adhesive joints with the view of determining the distribution of shear and normal stresses in a variety of adhesive joints subjected to bending. Also ASTM (1996-2010) established Standard Test Methods for end joints in structural wood products. According to ASTM (1996-2010), these test methods can be used to: (a) standardize the determination of strength properties for the material and joints being tested; (b) investigate the effect of parameters that may influence the structural capacity of the joint, such as joint profile, adhesive type, moisture content, temperature and strength reducing characteristics in the assembly. In the same vein, a laminated composite single lap joint without a spew

fillet subjected to tensile loading was investigated experimentally and numerically by Tsai and Morton (1995).

Experimental and numerical results of their work indicate that the adhesive shear and peel strain (stress) concentrations can be reduced greatly by introducing a fillet at the end of the overlap, and these concentrations are affected by the geometrically non-linear deformation of the single-lap joint. Similarly, Demir, Ozel and Temiz (2004) analyzed the mechanical behaviour of the Single-Lap Joints (SLJ) bonded with two different adhesives (FM73 SBT 9244) under a bending moment, both experimentally and numerically. The stress analyses and experimental results show that the failure in the SLJs subjected to a bending moment probably initiates from the overlap region on the adhesive upper adherend interface in tension and propagates towards the centre of the overlap.

Other related scholarly research papers include those of Cheng and Taheri (2005), Olia and Rossettos (1996), Kim and Keward(2001), and Liniecki, Hsu and Li (1995) among others. From the foregoing, it is indicative that most of the tests conducted were lap and butt joints oriented. Where laminate joints were considered, such joints were mere laminate representative/descriptive of lap joints, so full laminates were not actually subjected to bending tests. Consequent on the above, this research is undertaken to investigate the flexural strength for specific full laminates which include; (a) Aluminum Parent Plate, (b) Aluminum - Aluminum Laminate, and (c) Aluminum-Steel (Galvanized) Laminate. Flexural strength is defined by Shields (1970) and Skeist (1977) as the force in Newtons required to bend a specimen such that elongation of the outermost face of the arc is 5%. Ryder (1975) and Redford (1975) demonstrated that the strain energy for a simply supported beam with a single point load W at the centre is =

$$W^2L^3/(96EI) \quad \text{----(1)}$$

But if δ is the deflection under the load, the strain energy must be equal to the work done by the load (gradually applied), that is to say,

$$(W\delta)/2 = W^2L^3/(96EI)$$

Therefore: $\delta = WL^3/(48EI) \quad \text{----(2)}$

Where the product EI is called the flexural **rigidity** of the beam.

But E, the Young's Modulus of Elasticity is = Stress/Strain = σ/ϵ

$$\sigma = My/I$$

Therefore: $E = My/(I\epsilon)$ and $M = WL/2$.

Hence, $E = (WL/2)y/(I\epsilon)$. Substituting for E in equation (2), we get

$$\delta = WL^3/(48(WL/2)yI/(I\epsilon)) = (L^2 \epsilon)/(24y) \quad \text{----(3)}$$

y = vertical distance from the neutral axis to the outermost surface of beam (or specimen).

MATERIALS AND METHODS

Materials used for these tests are: test specimens (Fig.1), adhesive (araldite), deflection gauge, set of loads and load hanger. Setup for the experiment is shown in Fig. 2. The materials for the design of the Test specimens consist of aluminum and mild steel

sheets. These test pieces were cut to size and shaped in the workshop in line with ASTM D1184-55 Standards pertaining to reduction of stress concentration at corners and edges and removal of undue notches. The surfaces of the test specimen were thoroughly cleaned using acetone and clean piece of cotton cloth in order to rid the surfaces of dirt and grease (which are detrimental to healthy bond strength). Aluminum- aluminum laminates and aluminum - steel laminates specimens were formed using araldite (an epoxy adhesive) as bonding agent. Care was taken to ensure that spews of adhesive were not formed on the periphery of the bond joints of the specimen.

The materials for the experiment were rigged up as in Fig. 2. The first set of tests was carried out using the aluminum parent plate. The deflection gauge was set to zero position. Calibrated loads were slotted into the weight hanger (which is positioned at the centre of the span of the specimen), and the corresponding deflection value was read off each time. The experiment was repeated using Aluminum- Aluminum Laminate specimen and the results obtained are computed on Table. In the same vein, the experiment was carried out using Aluminum-Steel (Galvanized) Laminate specimen and the results obtained are presented on tables.

RESULTS AND DISCUSSION

Table 1: Parent Aluminum Plate treatment of (12.5mm x 2mm section)

Load(kg)	Deflection x 10 ⁻² mm
0.1	5
0.3	16
0.8	38
1.3	68.5
1.8	99
2.3	130
2.8	159
3.8	227.5

Source: Experimental Flexural Test on Parent Aluminum Plate

Strain (from given elongation i.e. definition of flexural strength) = 0.05

Y = 1mm. Effective length L = 122mm

Hence from equation (3),

$$\delta = (L^2 \epsilon)/(24y) = ((122\text{mm})^2 \times 0.05)/(24 \times 1\text{mm}) = 31\text{mm}$$

From Fig.3, Gradient of plot = AB/OB = 3.2Kg/(180 x 10⁻²mm) = 1.778Kg/mm.

i.e. Load P = 1.778δ

For δ = 31mm, therefore P = 1.778Kg/mm x 31mm = 55.118Kg

Hence, W = 55.118Kg x 9.81m/s² = 540.7N.

Therefore Flexural Strength of Aluminum Plate = 540.7N

Table 2: Aluminum – Aluminum Laminate

Experiment was carried out twice and the mean values obtained are as tabulated below.

Load(kg)	Deflection x 10 ⁻² mm
0.1	0.5
0.35	1.0
0.6	3.5
1.1	4.2
1.6	6.5
3.1	19.5
4.1	23.0

Thickness of section (t) =4.65mm

Source: Experimental Flexural test on Aluminum – Aluminum Laminate

Implying an adhesive layer thickness of 0.65mm.

Neglecting the effect of the Adhesive thickness and assuming homogeneity of material, and by symmetry $y = 4.65\text{mm}/2 = 2.325\text{mm}$ i.e. distance from neutral axis to the outermost surface of laminate

Hence, equation (3) gives:

$$\delta = ((122\text{mm})^2 \times 0.05) / (24 \times 2.325\text{mm}) = 13.34\text{mm}$$

$$\text{From Fig.4, Gradient} = AB/OB = 4.6\text{Kg} / (21 \times 10^{-2}\text{mm}) = 21.9\text{Kg/mm}$$

$$\text{But } P = 21.9\text{Kg/mm} \times \delta$$

$$\text{Therefore } P = 21.9\text{Kg/mm} \times 13.34\text{mm} = 292.15\text{Kg}$$

Hence, Flexural Strength of Aluminum – Aluminum Laminate

$$= 292.15\text{Kg} \times 9.81\text{m/s}^2 = 2865.95\text{N}$$

The flexural strength for a solid plate of thickness 4.65mm is equal to the flexural strength of 2mm solid plate x $(4.65)^3/2$, that is flexural strength for a solid plate of dept 4.65mm = $540.7 \times (4.65)^3/2 = 6795.56\text{N}$.

Table 3: Aluminum – Steel (Galvanized) Laminate

Experiment was carried out twice and mean values are as tabulated below.

Load (KG)	Deflection x 10 ⁻² mm
0.1	0.8
0.2	1.6
0.4	2.5
0.6	4.0
0.8	4.8
1.05	5.5
1.1	7.5
1.35	8.8
1.6	9.8
2.1	13.5
3.1	21
4.1	28
5.1	31.2
6.1	41.6
7.1	56

Thickness of laminate = 3.35mm.

Source: Experimental flexural test on Aluminum – Steel Laminate

$$\begin{aligned} \sigma_A/\sigma_B &= E_{AY_A}/E_{SY_S} & y_A = 1\text{mm} \text{ and } y_S = 0.5\text{mm} \\ &= (70 \times 10^9\text{N/m}^2 \times 1\text{mm})/(207 \times 10^9\text{N/m}^2 \times 0.5\text{mm}) = 0.676 \\ &= (70 \times 10^9\text{N/m}^2 \times 1\text{mm})/(207 \times 10^9\text{N/m}^2 \times 0.5\text{mm}) = 0.676 \end{aligned}$$

Subscript A and S stand for Aluminum and Steel respectively. Hence, Fig. 2c is the equivalent section as all of steel, and since all the parts are rigidly fixed together along their lengths, they will bend about a common neutral axis *xx*. The dimension of the Aluminum parallel to the neutral axis has been reduced in the modular ratio of 0.676. The position of *xx* is found in the usual way, that is,

$$y = [(8.45 \times 2)2.35 + (12.5 \times 1) \times (-0.5)]/[(8.45 \times 2) + (12.5 \times 1)] = 1.56\text{mm}.$$

From Fig. 5, Gradient = $AB/OB = 5.7\text{kg}/(37 \times 10^{-2}\text{mm}) = 15.41\text{kg/mm}$.

But $P = 15.41\text{kg/mm} \times$

Therefore, $P = 15.41\text{kg/mm} \times 19.88 = 306.35\text{kg}$.

Hence, Flexural Strength = $306.35\text{kg} \times 9.81\text{m/s}^2 = 3005.3\text{N}$.

Table 4: Summary

Material	Flexural Strength (N)	Depth (mm)
Aluminum (Parent)	540.7	2mm
Aluminum - Aluminum Laminate	2865.95	4.65
Aluminum - Steel Laminate	3005.3	3.35

Source: values from Tables 1, 2 and 3 above

Data on Table 1 and Fig.3 show the load and deflection curve for the Parent Aluminum Plate. The curve appears to be linear within the limits of the elastic range of the Aluminum Plate. Also, the data on Table 2 and Fig.4 show the load and deflection curve for the Aluminum - Aluminum Laminate. The curve appears to be linear within the limits of the elastic range of the Aluminum Laminate. In similar vein, data on Table 3 and Fig.5 show the load and deflection curve for the Aluminum - Steel Laminate. The curve also appears to be linear within the limits of the elastic range. Table 4 displays the Flexural Strength and Depth of the various Test specimens. These values of Flexural Strength and Depths of specimens are the summary results obtained from data on Tables 1, 2 and 3. Results obtained are quite satisfactory because the basic relation of equation 2 is satisfied. From equation 2, it is clear that when the thickness of a plate is doubled, the flexural rigidity is increased eight times. However, the deflection decreases linearly. This is portrayed in results on Table 4. It is more economical (space) to use Aluminum - Steel laminate because higher strength is obtained even though the total depth was less compared to that of Aluminum - Aluminum laminate.

CONCLUSION

The purpose of this study was to determine the flexural strength for (a) aluminum Parent Plate, (b) Aluminum - Aluminum Laminate, and (c) Aluminum-Steel (Galvanized) Laminate. Results of the Bending Tests revealed that when Aluminum plate is bonded to itself by a film of araldite adhesive (0.65mm film thickness), the flexural strength becomes 5.3 times of the parent Aluminum plate. Therefore, it is more

economical (space) to use Aluminum - Steel laminate because higher strength is obtained even though the total depth was less compared to that of Aluminum - Aluminum laminate.

Acknowledgements

My thanks go to the Department of Mechanical Engineering, University of Benin, Benin-City, Nigeria, for the approval of its Workshop, equipment and materials for this research. The comments and suggestions of Dr. C. L. Mehrotra (Formerly Senior Lecturer, Department of Mechanical Engineering, University of Benin, Nigeria), is acknowledged. I wish to make due acknowledgement to Professor R. O. Onyeonwu, former Head, Department of Mechanical Engineering, University of Benin, Benin-City, Nigeria, who took the necessary steps to ensure availability of research materials.

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APPENDIX

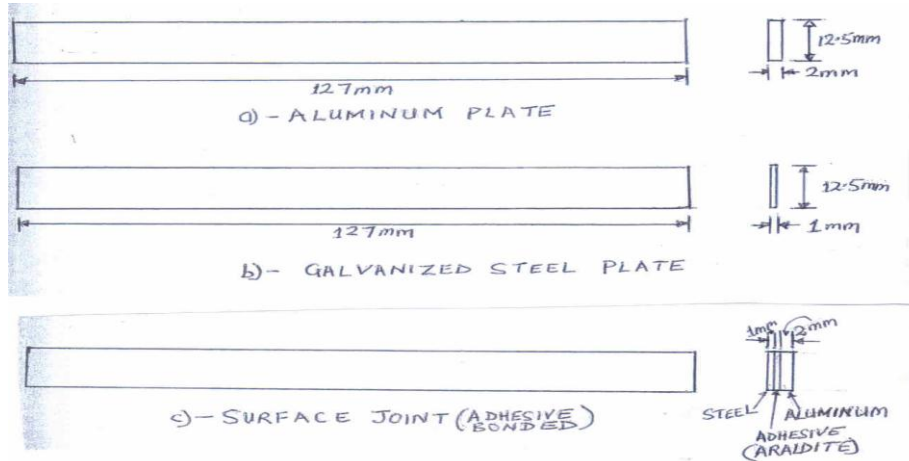


FIG. 1-BENDING TEST SPECIMENS

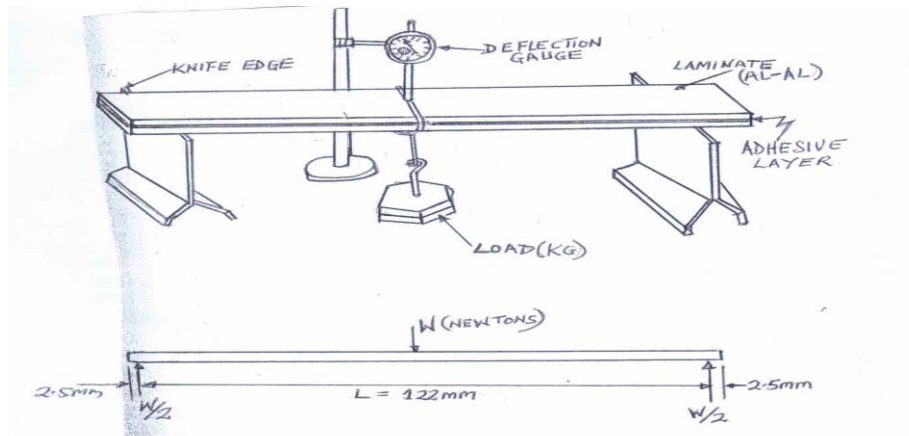


FIG.2-BENDING TEST SET-UP

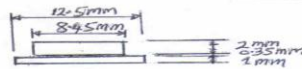


FIG.2C-EQUIVALENT SECTION AS ALL OF STEEL

