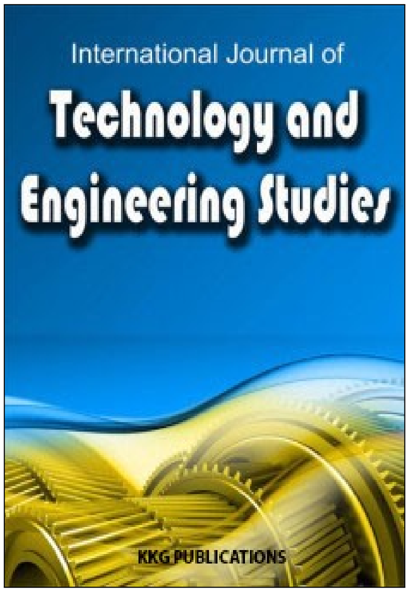

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THE DESIGN AND MECHANICAL ANALYSIS OF DOUBLE ZIGZAG TYPE OF ADHESIVE JOINTS

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Abstract. In this article, the mechanical analysis of the double zigzag type of adhesive joints was investigated. Glass-fiber prepregs adherends are examined on several overlap angles under axial tensile loading. Overlap angle, 30^o, 45^o, 60^o, and 75^o were employed. The ductile-type epoxy adhesive was employed for the bonding area. The effect of overlap angles on zigzag type of joints was studied as numerical and experimental separately. For numerical process, three-dimensional finite element analysis was exercised to understand the stress distributions in the bonding area by ANSYS® 14.5 version. Failure criteria Von Mises equivalent stress can be acceptably determined close by experimental results for joint strength. The failure load of overlap angle joints is directly proportional as it increases as the overlap angle increases. Furthermore, the available experimental results perfectly match with numerical results.

INTRODUCTION

Adhesive-bonded joint is a combination method used as an alternative to mechanical joining methods such as bolt, rivet, welding, and soldering. Adhesives do not cause any changes in crystal structure and result in melting on the contrary of welding, rivets, soldering, and other similar connection. They have found a suitable development area because of not creating stress concentration. Composite materials of high strength/weight and rigidity/weight ratio were facilitated by the development of lighter structure instead of conventional metal materials. They are more advantageous in terms of maintenance and repair as the composite materials are also lighter in terms of long life and to be fast are preferred [1]. The strength of adhesive-bonded joints is subject to the adherend's size and thickness, elastic modulus, elastic modulus of adhesive, the overlap length, the pretreatment of the bonding surface in addition to the conditions of exposure of the connection process, which must combine the adhesion and adhesive [2], [3]. These conditions have led researchers, who are interested in adhesion and adhesive, focus on determining the mechanical behavior [4].

In the literature, commonly, the effect of stress distribution on the adhesive joint of the various variables has been examined [5]. In this article, a model zigzag-type geometry has been studied. Thus, this type of bonding is intended to provide important data in the literature on the mechanical properties.

LITERATURE REVIEW

[6] evaluated stress distribution in a composition of adhesive joints. The concentration of stress affects the adhesive-adherend interface, to the plane of adhesive, the end overlap. This indicates that the start of the damage is likely to occur at this interface, which may explain a little adhesive failure that is usually explained by inadequate surface preparation. The glass-glass joints show maximum stress value at the end of the top cover. This is justified by the more significant effects of rotation relative to the lower stiffness [6], [7]. Similarly, [8] analyzed stress distribution of scarf adhesive bonds with similar adherend under static tensile load. Two cases of length and width of the adhesive-adherend remained constant. Young modulus adhesive effect was examined at the angle of scarf and coat of adhesive on stress distribution interface. Joint force was predicted by the stress distribution-based interface Von Mises' stress tests. Maximum strength bond was observed when the angle of the scarf was 60^o [8], [9]. [10] examined that the flat joggle flat bonding glass fiber epoxy laminates are designed to prevent the existence of eccentricity joggle so that the load is in the plane of bending, and the effect is prevented and bonding strength increases. Experiments conducted on FJF-related items showed an increase of 90% of the failure load on the coupling surface [10].[11] found that plates of different angles are used to obtain corresponding different combinations of the shear strain. 0^o tensile butt joints, circular cross-section

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have been ground to create a scarf angle of 30°, 30°, 60°, and 75°. Single lap joint shear strength was used to represent the load 90°. SLS relationship between 1.6 mm thick aluminum sheet 2024 class T3 and overlapping length of 12.7 mm. As the thickness of the adhesive is reduced, nominal power performance decreases, the amount of inter facial defects increases due to higher bending deformation, which calls for the failure of the joint. The rise in bond angle from 0° to 30° results in lower bond strength reduction. Smaller angular joints 30° have responded in a cohesive mode, while the rest of the larger angular joints from 60° onwards showed mixed mode fracture [11]. [12] studied strength epoxy adhesive sheets of different adherends in several scarf angles and different thicknesses under custom supervision uniaxial tensile load. Angles of scarf 45°, 60°, and 75° are employed. The thickness of the bond between different adherend '*t*' is controlled to be between 0.1 mm and 1.2 mm. The measured stress multi axiality of joints increases with increasing scarf angle [12]. [13] found that shear stresses between adherend and adhesive are present perpendicular to the applied load direction and that in the adhesive materials, the ratio of poisson to these stresses is the reason [13].

METHOD AND MATERIALS

In this study, double zigzag type of adhesively bonding joint configurations by using the different overlap angles (30°, 45°, 60°, 75°) were designed and manufactured with glass fibre-re inforced epoxy samples under axial tensile load (Figure 1 and Table 2). Ductile-type adhesive (Dp460) has been used for this bonding joint. Three specimens of the same type of joint were carried out again for the accuracy of test results [14]. Afterwards, the experimental and numerical analysis results were compared (Figure 2).

The mechanical properties of the composite material were determined by Dokuz Eylul University Composite Research and Testing Laboratory with Shimadzu AG-X models tensile test machine (Table 1). The machine has a capacity of 100 kN equipped with integrated video extenso meter for more accurate results (Figure 3).

Two-part paste epoxy (DP 460, prd. by 3M Comp.) was used as adhesive. Material properties of the adhesive were used in the study [15]. Adhesive thickness was held constant to be 0.20 mm. Adherend thickness was average (*t*) 3 mm too [16].

TABLE 1
MATERIAL PROPERTIES OF THE ADHEREND AND ADHESIVE [13]

	Composite Material	DP 460
(E) (Mpa)	28250	2077,10
(υ) (-)	0,13	0,38
(σ_t) (Mpa)	379,232	44,615

E: Young's modulus; υ: Poisso's ratio; σ_t: Ultimate tensile strength

TABLE 2
GEOMETRIC PARAMETERS FOR ADHESIVELY-BONDED JOINTS

Overlap Angle (°)	Width(w) (mm^2)	Bonding Area(A) (mm)	Overlap Length (a), (b) (mm)	L1 (mm)	L2 (mm)
30	27,46	180	20	118,68	131,32
45	35,12	180	20	122,27	127,73
60	40,64	180	20	126,73	123,27
75	43,66	180	20	131,75	118,25

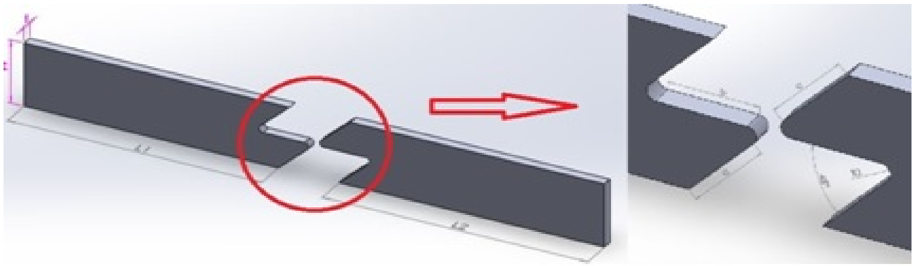

Fig. 1. Geometric size of bonded specimen

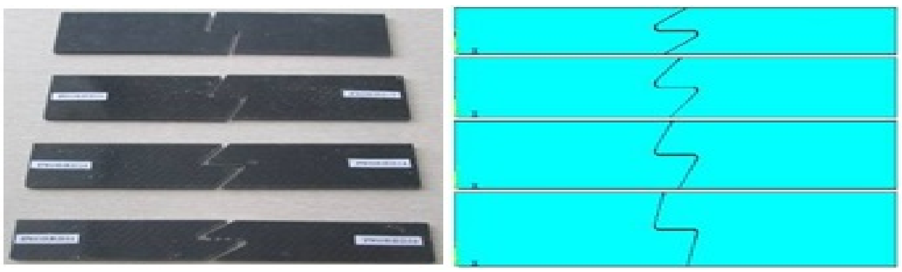

Fig. 2. (30^o,45^o,60^o,75^o) Overlap angle samples and ansys drawings

Fig. 3. Applying tensile test to joint sample

Experiments were operated totally using a Zwick/Roell Z 100 test equipment with a 100 kN load. The lower jaw is fixed and the upper jaw is moved. Also, 0.10 MPa load was given for pre-loading (Figure 3). The calibration of the test machine was made. The relative humidity of the environment was considered not to affect the material properties. Tensile loading speed is also 1 mm/min [17].

$$\sigma_{eqv} = \sqrt{\sigma_x^2 + \sigma_y^2 - \sigma_x.\sigma_y + 3\tau_{xy}^2} \quad (Mpa) \qquad (1)$$

Prediction of failure criteria and three-dimensional effects on stress distributions in zigzag-type joint, numerical analysis was accomplished in version 14.5 ANSYS®. In the 3D analysis by using three degrees of freedom, eight-node layered solid element Solid 185 was selected for composite laminates. In the 3D analysis by using three degrees of freedom, eight-node structural solid element Solid 65 was selected for adhesive layer. Moreover, the tiny meshes were applied in bonding regions due to stress distribution being important (Figure 4).

The load and boundary conditions of samples sizes (Table 2, Figure 4) used in experimental study are the same as those used in the finite element. In ANSYS®, the Von Mises yield criterion was preferred to evaluate the equivalent stress σ_{eqv} (eq. 1). Boundary conditions for left side are Ux = 0, Uy = 0 also Uz = 0; for right side when applied force are Ux $\neq$ 0, Uy = 0 also Uz = 0 (Figure 4). Critical stress distributions were examined by σ_x, σ_y, σ_z, τ_{xy}, and σ_{eqv}.

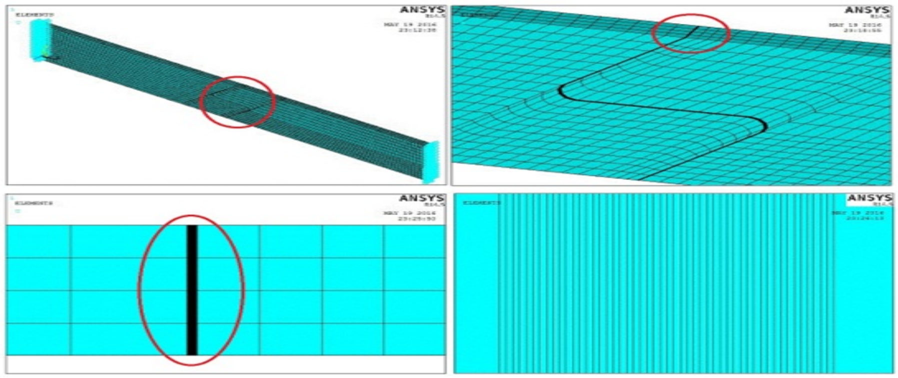

Fig. 4. Details of mesh size and boundary conditions for the joint

RESULTS

Four specimens were dependent upon tensile load to failure. In this way, the obtained value of the maximum load and failure to apply for any type of joint, as shown in Figure 5. In addition, the regime has been identified in the failures on each connection type. Testing the maximum failure load indicated in Figure 5 for four different overlap angles was acquired by using adhesive which has ductile performance with the same bonding area 180 mm^2. Figure 5 shows that when angle of overlapping develops, failure load increases except 45° as well. Just only 5% decrease occurs in this type of joint. The maximum failure load is 14.900 N on overlap angle 75° in Table 3. For understanding this rising numerically, a critical path is determined by examining the stress distribution in a detailed way (Figure 7).

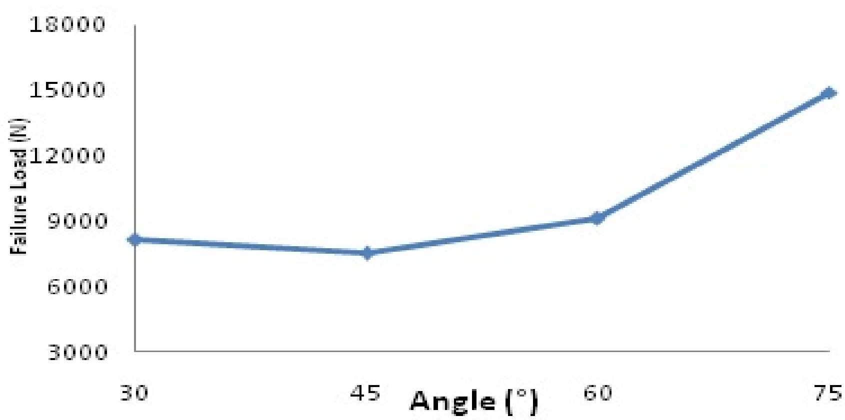

Fig. 5. Failure loads of bonded joints against angles in experimental study

TABLE 3
EXPERIMENTAL AND FINITE ELEMENT FAILURE LOADS OF JOINTS

Overlap Angle (°)	Exp. Failure Load F_{exp} (N)	FEA Failure Load F_{FEA} (N)	F_{exp} / F_{FEA}
30	8.136	8.460	0,96
45	7.531	7.920	0,95
60	9.091	9.360	0,97
75	14.900	15.300	0,97

F_{exp}(N): Experimental failure load; F_{FEA}(N): Finite element analysis failure load

In adhesively-bonded joint, critical line on adhesive surface from point A to point B (AB) was identified and critical stress distribution graphs were generated based on this line (Figure 6).

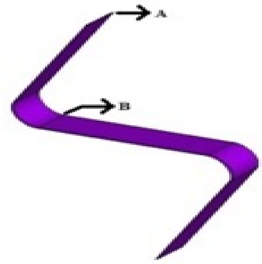

Fig. 6. Critical line (AB) on adhesive layer

Based on the Von Misses criteria, equivalent stress (σ_{eqv}) was estimated. It was accepted that when the joint failure took place, the equivalent stress (σ_{eqv}) in region of adhesive layer reached the ultimate tensile strength (σ^* = 44.615 MPa) of the adhesive. The experimental results and finite element analysis for double zigzag type of adhesive joints are in good agreement with a piece in Table 3. In Figure 7, it is shown that stress concentrations occur in the overlap area particularly bonding edges with a maximum value at point B. Tensile stress character exists at bonding edges. However, they reduce towards the center. Shear stress character exists at bonding center virtually zero for big angle. The equivalent stress character is maximum at (x = 0) adhesive layer. Besides, equivalent stress develops with decreasing overlap angle.

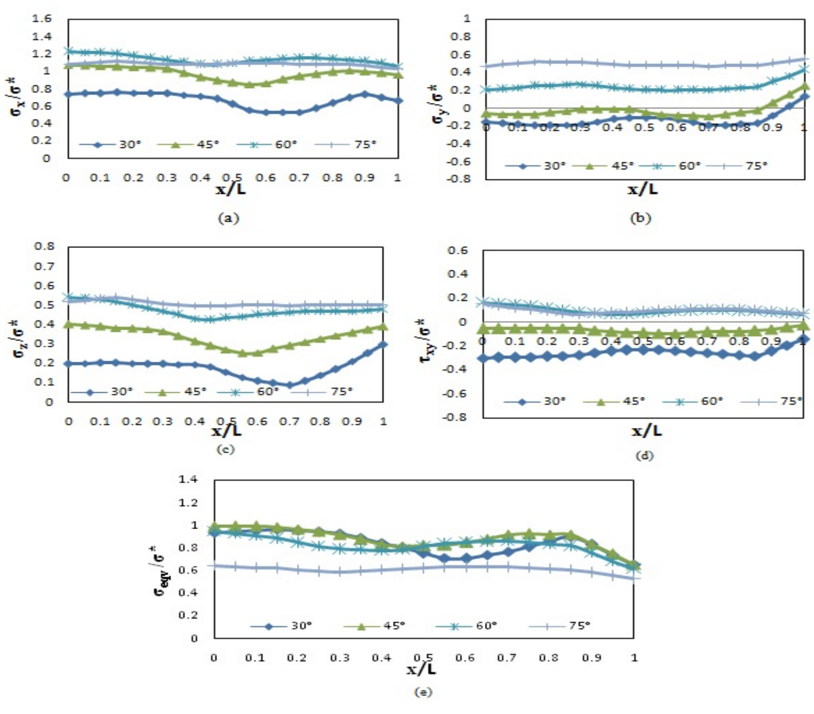

Fig. 7. Stress distributions taken from the adhesive layer throughout x/L: [18], [19]. (a), (b), (c) normalized σ_x, σ_y, σ_z stress distributions, (d) normalized τ_{xy}, stress distributions (e) normalized σ_{eqv}, Von-Misses stress distributions.

DISCUSSION

In this work, the mechanical behaviors of overlap angles $(30°, 45°, 60°, 75°)$ exposed to tensile loading were examined with two methods, both numerically and experimentally, respectively. Both sides of surface for zigzag-type joint were found to be adhesive layers. This indicates the start of the damage is likely to occur at this interface agree able to [6] study.

Von-Mises yield criterion is used for adhesive layer and adherends in the calculation of the equivalent stresses. Percentage value of experimental and finite element failure loads of joints is almost the same i.e., 96%. Therefore, the effect of two methods with respect to agreements is quite good. According to result of two methods, the adhesive is most critical in terms of failure showing the bonding surface of the material. Composite materials have not faced any failure because the tensile strength of the material is higher than the adhesive. While composite material has elastic modulus of 28.250 (MPa) and the adhesive material DP 460 has elastic modulus just 2077.10 (MPa).

CONCLUSION AND RECOMMENDATIONS

The results of experimental and numerical analyses of the double zigzag-type adhesive joint have shown that the variation of mechanical behaviors depends on the overlap angle. The overlap angles have been observed as the most important geometrical parameter for failure behavior. Failure load in overlap angle increases according to proportional increase in overlap angle in the same bonding area. That is the experimental results on this geometry are compatible with the results in the literature studies of [8], [12]. In this geometry, the overlap angle is 30° and the experimental failure load is 8.13 (kN). When overlap angle increases to 75°, the experimental failure load is also increased to 14.9 (kN). It means that with an increase in the value of the overlap angle, failure load increased nearly to 83%. So, overlap angle 75° joint has carried a maximum load.

The double zigzag-type joints increase in normalized maximum stresses generated at both end points of the line ($\frac{x}{L} = 0 \ \ ve \ \ \frac{x}{L} = 1$) of the overlap angle. Due to the absence of sharp corners in the design, it can be said that due to the reduction of stress concentrations for numerical analysis. This is caused by remarkable effects of rotation coherent with [6] study.

Declaration of Conflicting Interests

The authors declare that there are no conflicts of interest.

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REFERENCES

[1] A. J. Kinloch, "Adhesives in engineering," in *Proceedings of the Institution of Mechanical Engineers, Part G, Journal of Aerospace Engineering,* vol. 211, no. 5, pp. 307-335, 1997.

[2] A. J., Gunnion and I. Herszberg, "Parametric study of scarf joints in composite structures," *Composites Structures*, vol. 75, no. 1, pp. 364-376, 2006.

[3] T. Sawa, J. Lu, K. Nakano and J. Tanaka, "A two dimensional stress analysis of single lab adhesive joints of aissimilar adherents subjected to tensile loads," *Journal of Adhesion Science and Technology*, vol. 14, no. 1, pp. 43-66, 2000.

[4] T. Sawa, I. Hguch and H. Suga, "Three-dimensional finite element analysis of single-lap adhesive joints under mpact loads," *Journal of Adhesion Science and Technology,* vol. 16, no. 12, pp. 1585-1601, 2000.

[5] S. Kumar and P. C. Pandey, "Behavior of bi-adhesive Joints," *Journal of Adhesion Science and Technology,* vol. 24, no. 7, pp. 1251-1281, 2010.

[6] A. Magalhaes, M. de Moura and J. D. Gonalves, "Evaluation of stress concentration effects in single-lapbonded joints of laminate composite materials," *Journal of Adhesion Science and Technology*, vol. 25, no. 4, pp. 313-319, 2005.

[7] J. H. Lee, S. P. Kim and R. W. Jeon, "Optimal design for adiabatic pipes using vacuum at cryogenic temperatures," *Journal of Advances in Technology and Engineering Research*, vol. 2, no. 2, pp. 6-11, 2016.

[8] G. Li and P. Lee-Sullivan, "Finite element and experimental studies on single-lap balanced joints in tension," *Journal of Adhesion Science and Technology*, vol. 21, no. 3, pp. 211-220, 2001.

[9] N. Kishore and N. S. Prasad, "An experimental study of flat-joggle-flat bonded joints in composite laminates," *Journal of Adhesion Science and Technology,* vol. 35, pp. 55-58, 2012.

[10] M. Lee, C. H. Wang and E. Yeo, "Effects of adherend thickness and taper on adhesive bond strength measured by portable pull-off tests," *International Journal of Adhesion and Adhesives,* vol. 44, pp. 259-268, 2013.

[11] J. Lim, L. Yue, Y. Na and S. Kim, "Four cases of production-installation simulation for free-form concrete panels," *Journal of Advances in Technology and Engineering Research,* vol. 2, no. 1, pp. 22-27, 2016.

[12] M. Afendi, T. Teramoto and H. B. Bakri, "Strength prediction of epoxy adhesively bonded scarf joints of dissimilar adherends," *International Journal of Adhesion and Adhesives,* vol. 31, no. 6, pp. 402-411, 2011.

[13] R. D. Adams and N. A. Peppiatt, "Stress analysis of adhesive-bonded lap joints," *Journal of Strain Analysis*, vol. 9, no. 3, pp. 185-196, 1974.

[14] Huntsman Advanced Materials. (2007). *User's guide to adhesive* [Online]. Available: https://goo.gl/mZR

[15] S. Akpnar, M. D. Aydin and A. Ozel, "A study on 3-D stress distributions in the biadhesively bonded T-joints," *Applied Mathematical Modelling,* vol. 37, no. 24, pp. 10220-10230, 2013.

[16] P. Pfeiffer, A. E. Salam and M. Shakal, "Effect of bonded metal substrate area and its thickness on the strength and durability of adhesively bonded joints," *Journal of Adhesion Science and Technology,* vol. 12, no. 3, pp. 339-348, 1998.

[17] G. Romanos, "Strength evaluation of axisymetric bonded joints using anaerobic adhesives," *International Journal of Materials and Product Technology,* vol. 14, no. 5, pp. 430-443, 1999.

[18] H. Adin, "The investigation of the effect of angle on the failure load and strength of scarf lap joints", *International Journal of Mechanical Sciences,* vol. 61, no. 1, pp. 24-31, 2012.

[19] H. Adin, "The effect of angle on the strain of scarf lap joints subjected to tensile loads," *Applied Mathematical Modelling,* vol. 36, no. 7, pp. 2858-2867, 2012.

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