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# Strength Evaluation of Scarf Adhesive Joints with Different Adherends Subjected to Static Tensile Loading

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**ABSTRACT**: In this study, the tensile strength of scarf Adhesive joint is carried out at various angles by experimentally and numerically. Commercially available araldite epoxy is used as adhesive and glass epoxy and Bakelite is used as Adherends. Numerical analysis is done by a three dimensional finite element method. The FEM analysis is executed by an ANSYS. Tensile tests are carried on computerized universal testing machine. Experimental and FEM results are compared and found reasonable. From results it is noticed that when the angle of scarf adhesive joint is increases then the failure load values also decreases in all joints.

**KEYWORDS**: Adherends, Adhesive, ANSYS, Araldite epoxy, Bakelite, Glass epoxy, FEM, Scarf adhesive joint, Strength.

### I. INTRODUCTION

Adhesive joints are used in various industries such as mechanical structures, aerospace, automobiles, electronics devices, wood industry etc. In structural engineering and industrial applications the adhesive joint is very good substitute for conventional bonding methods like riveting, diffusion bonding, welding, etc. In light weight structures the weight can be reduced by using adhesive bonding. With this advantage of adhesive bond it is not used everywhere because the adhesive bonded joint lose their strength when exposed to high humidity aqueous environments and high temperatures.Composite materials are widely used in aerospace industries and they are quite expensive. Therefore it is very expensive to replace the damaged parts. We have some repair techniques to reduce cost without compromising structural integrity. These techniques are lap joints, butt joints and scarf joints from these techniques the scarf joints have been found to exhibit the highest structural efficiency because joint eccentricities are minimized in loading path and a more uniform stress distribution is obtained across the joint. To study the mechanical behaviour of scarf adhesive joint, the tensile test is carried out by experimentally and numerically. For performance analysis of adhesive with different adherends and different scarf angles the tensile testing is done. Results from experimentation and FEM are compared. A failure criterion for the scarf adhesive joint is predicted.

### II. LITERATURE REVIEW

Strength and stress analysis of scarf adhesive joint under static bending moments was analysed by Hirako Nakano, Yasuhisa Sekiguchi and Toshiyuki Sawa using FEM. In this research paper Mild steel (SS400 (JIS)) is selected as adherend and epoxy as adhesive, bending moments were calculated by using FEM code ANSYS. The results are obtained as the stress decreases first and then increases with increase in scarf angle of scarf adhesive joint and the minimum maximum principal stress value was observed at  $60^{\circ}$  scarf angle. [1] From this research paper, we can conclude that the strength of scarf adhesive joint is dependent on the scarf angle so we have to selected different scarf angle for experimentation and numerical analysis.MohdAfendi, TokuoTeramota and Hairul Bin Bakri [2] studied the effect of different scarf angle of the dissimilar Adherends scarf joints SUS304 stainless steel and YH75 aluminiumalloy was selected as adherend and epoxy as adhesive. The scarf angles were selected as 45, 60 and 75. They found the stress singularity is more between the 45 – 75 scarf angles. Tensile test was used for predication of strength of scarf adhesive joint. From this research paper, in this study tensile test was selected for evaluating the strength of scarf adhesive joint.



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The effect of various angles on the strength of scarf lap joints was predicted by Hamit Adin with composite material as adherend. Maximum strength of scarf adhesive joint was observed at scarf angle  $45^{\circ}$ . [3] From this research paper, we got our attention on the effect of different composite materials as adherends on scarf adhesive joint.

Under tensile testing the scarf angle decreased the failure energy is increased was investigate by Lijuan Liao, Chenguang Huang and Toshiyuki Sawa. [4] From this research paper we conclude that for different types of adhesives the results are different. He Dan, Toshiyuki Iwamoto and Yuya Hirayama was investigated the effect of scarf angle and thickness on the strength of scarf adhesive joint under static tensile loading with similar and dissimilar adherends as they found the strength of scarf adhesive joint was maximum when scarf angle 60° and strength of scarf adhesive joint with similar adherend was more than that of dissimilar adherend. [5][6]. with the help of this research paper we are going to study the effect of similar and dissimilar adherends as composite material on the strength of scarf adhesive joint. For metal adherends of single lap joints the strength was increased by minimizing the taper angle was done by ErolSancaktar& Prasad Nirantar [7]. The effect of various thicknesses on scarf adhesive joint with dissimilar adherend with tensile test and 3 PB test was studied by MohdAfendi and TokuoToramoto and found the stress singularity is more in tensile model than that of 3 PB model was. [8] From this we can say that the tensile test is efficient so, in this study we are selecting the tensile test is used for Experimental and Numerical analysis. Strength of scarf adhesive joint with dissimilaradherend under static bending moment was studied by He Dan, Toshiyuki Sawa and Atsushi Karami. [9]

#### **III. OBJECTIVES**

- 1. To study effect of scarf angles on the strength of scarf adhesive joints.
- 2. To determine the effect of Glass Epoxy and Bakelite as adherend on the strength of scarf adhesive joint.

#### IV. EXPERIMENTAL DETAILS

Experimentation is carried out to calculate strength of the scarf adhesive joint. Figure shows the geometric details of scarf adhesive joint.



Fig. 1: Geometric details of Scarf adhesive joint

The scarf angles  $\theta$  is chosen as 30°, 60° and 90°. The adhesive thickness of joint is set as 0.1 mm. The thickness of specimen is chosen as 10 mm. The material of adherend is chosen as glass epoxy and bakelite. The material of adhesive is araldite and its young's modulus and Poisson's ratio are 3340 Mpa and 0.38 respectively. The experiments were carried out after bonding and solidifying a joint for 8 hours with an araldite at room temperature. Tensile test is carried out for evaluating the strength of scarf adhesive joint by using Computerized Universal Testing Machine. Figure 2 shows the experimental setup for measuring joint strengths under tensile loading.



Fig. 2: Experimental Set up.



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### A. Evaluation of stresses in scarf joints

The scarf adhesive joints are subjected to the axial tensile load stresses inside the adhesive layer of scarf adhesive joints are relatively uniform except for the small region at the interface corner. Theoretically, for scarf adhesive joints loaded axially with average stress,  $\sigma_{av}$ , normal and shear stresses are given by [2]

$\therefore \sigma_n = \sigma_{av} \times \sin^2 \theta(1)$
And
$\therefore \tau_{sn} = \sigma_{av} \times sin\theta \times cos\theta(2)$
Stresses acting in the s- and z- directions are similar and given as,
$\therefore \sigma_{\rm s} = \sigma_{\rm z} = \frac{\mu_a \times \sigma_n}{2}.$ (3)
Maximum and minimum principal stresses derived as,
$:: \sigma_{1,3} = \frac{\sigma_{s} + \sigma_{n} \pm \sqrt{(\sigma_{s} - \sigma_{n})^{2} + 4\tau^{2} s_{n}}}{2}.$ (4)
Median principal stress is calculated as,
$\therefore \sigma_2 = \sigma_s = \sigma_z = \frac{\mu_a \times \sigma_n}{1 - \mu_a}.$ (5)
Equivalent Von-Mises stress is given by,
$\therefore \sigma_{eq} = \sqrt{(\sigma_1 + \sigma_3) \times (\mu^2 - \mu + 1) - (3\sigma_1, \sigma_3)}.$ (6)
Hydrostatic stress is given by,
$\therefore \sigma_{hyd} = \frac{\sigma_1 + \sigma_2 + \sigma_3}{3}.$ (7)
Figure 3shows the coordinate system that is typically used to evaluate stresses in the central region of adhesive layer in

Figure 3shows the coordinate system that is typically used to evaluate stresses in the central region of adhesive layer in scarf adhesive joints.



Fig.3: Coordinate system of scarf adhesive joint.

### V. FEA CALCULATION

In this part FEM is carried out to analyse the behaviour of the scarf adhesive joints. The geometrical parameter and material properties of adhesive and adherends are used in FEM calculation are tabulated in table 1 and table 2.

TABLE I GEOMETRICAL PARAMETERS USED IN EXPERIMENTAL AND NUMERICAL STUDIES.

INICAL FARAMETERS USED IN EXFERIMENTAL AND NUMERICAL S				
Adherend	Scarf Angle	Adherend	Adhesive	
Thickness	(Deg.)	Breadth	Thickness	
(mm)		(mm)	(mm)	
10	30	30	0.1	
10	60	30	0.1	
10	90	30	0.1	



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TABLE II MATERIAL PROPERTIES OF ADHERENDS AND ADHESIVES						
Material	Young's	Poisson's	Density p			
	Modulus E	Ratio (µ)	$(Kg/m^3)$			
	(Gpa)					
Glass Epoxy	3.4	0.396	1250			
Bakelite	1.1	0.118	1450			
Adhesive	3.34	0.38	1200			

FEM calculations are performed using ANSYS software and the stress analysis of scarf adhesive joint is obtained according to von-mises yield criteria. By von-Mises criteria the equivalent stress distribution at interface are calculated. The effects of various scarf angles are examined.



Fig. 4:Boundary Condition of scarf adhesive joint.

In the analysis, stress strain behaviours of adhesives are considered as linear. The boundary conditions applied are shown in figure 4.



Fig.5: Meshing of Scarf adhesive joint of scarf adhesive joint.

The upper adherend is fixed in y-direction and the tensile loading is applied to the end of the lower adherend. Vonmises stresses calculated from FEA for scarf adhesive joint is shown in figure 6.



Fig.6:Equivalent Von-Mises Stress of scarf adhesive joint.



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The upper and lower adherend are chosen as same materials and they are subjected to static tensile loadings. Figure 5 shows an example of mesh divisions of scarf adhesives joint in FEM calculations. The deformation plot of scarf adhesive joint from FEA is shown in figure 7.



Fig.7: Deformation of scarf adhesive joint.

Similar analysis is done for remaining scarf adhesive joint of different angle with Glass epoxy and Bakelite adherend.

### VI. RESULT AND DISCUSSION

The experimental results of scarf adhesive joint at various scarf angles with different adherends are tabulated in table 3.

EXPERIMENTAL BREAKING LOADS OF SCARF ADHESIVE JOINTS				
Scarf Angle θ	Breaking Load	Breaking Load		
	when Glass	when Bakelite is		
	Epoxy is used as	used as adherend		
	adherend (KN)	(KN)		
30	4.25	3.50		
60	3.52	2.67		
90	3.42	2.45		

TABLE III

From experimental and FEA analysis we get the results for equivalent von-mises stresses at various scarf angle with different adherend are tabulated in table 4.

COMPARISON OF EXPERIMENTAL AND FEA VON-MISES STRESSES					
Scarf	Von-Mises	stresses	Von-Mises	stresses	
Angle $\theta$	when Glass	Epoxy is	when Bakelite is used		
	used as adherend		as adherend		
	Experimental	FEA	Experimental	FEA	
30	10.71	14.263	8.81	15.48	
60	11.028	11.927	7.14	9.479	
90	4.413	11.591	3.16	7.966	

TABLE IV

The comparison between maximum principal stress and Von-mises equivalent stress are obtained in experimental results is shown in figure 8(a) for glass epoxy adherend and figure 8(b) for bakeliteadherend.



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Fig.8:(a) Failure criteria for glass epoxy adherend (b) Failure criteria for Bakelite adherend

The accepted failure criteria for scarf adhesive joints are maximum principal stress and von-mises equivalent stress.

### VII. CONCLUSION

In the present work, we have investigated both experimentally and analytically the effects of scarf angles upon the strength of scarf adhesive joint of Glass epoxy and Bakelite adherends with araldite as adhesive. The following conclusion can be drawn:

- 1. The maximum strengthfor both adherends is at scarf angle 30 degree.
- 2. As the scarf angle  $\theta$  increase the strength of scarf adhesive joint decreases.
- 3. The maximum principal stress criteria is used when scarf angle is greater than 45 degree and equivalent vonmises stress criteria is used when scarf angle is smaller than 45 degree.
- 4. The Strength of scarf adhesive joint with glass epoxy adherend is more than scarf adhesive joint with Bakelite as adherend.

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