Stress analysis and Strength Evaluation of Composite Scarf Adhesive Joints

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Abstract—Nowadays, Composite materials usage in industrial sector as well as in Aerospace area has predominantly increased. The main reason for it has been its lightweight structure as well as high durability. The only problem which comes in its path has been tedious repair and replacement work. Many bonding techniques are used but effective strength and efficiency is not achieved. The reason for this is stress concentration over bonded area and non-uniform stress distribution. To counter this problem, scarf adhesive joining method can be brought into picture and utilized in the repairing and replacement process of composite material components and product. In our experimental study, scarf Adhesive joints tensile strength is carried out at various angles by experimentation and numerical analysis method. Araldite epoxy which is available commercially is used as adhesive and epoxy glass and Bakelite is used as Adherends. Bakelite and epoxy glass specimens are prepared at three different scarf angles with similar materials and dissimilar materials. Numerical analysis is done by a three dimensional finite element method.The stress distributions in scarf adhesive joints under static tensile loadings are analysed using three-dimensional finite-element calculations. The Finite Element Method (FEM) analysis is executed by ANSYS software. Tensile tests are carried on computerized universal testing machine. Calibrated Universal Testing machine provides breaking load values for different scarf angles specimen. Stress distribution is recorded during tensile testing to validate strength of Bakelite and epoxy glass specimens. For effective study, we have prepared 30°, 45°, and 60° scarf angle specimen for separate Bakelite, epoxy glass and then Bakelite with epoxy glass as dissimilar composite material. Experimental and FEM results are compared and found reasonable. Inference of our results shows that when the angle of scarf adhesive joint increases then the failure load values also decreases in all joints.

Keywords— Scarf Adhesive Joints, Adherends, Composite, Glass Epoxy, Bakelite, Design of Experiments, Tensile Strength, Strength to weight ratio, FEM,FEA, Adhesive.

I. Introduction

A scarf joint (also known as a scarph joint) is a method of joining two members end to end in joining work. The scarf joint is used when the material being joined is not available in the length required. It is an alternative to other joints such as the butt joint and the splice joint and is often favoured over these in joinery because it yields a barely visible glue line.

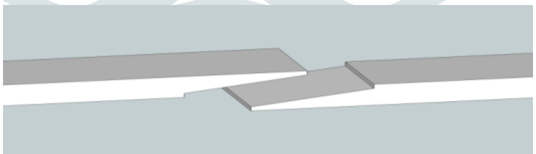

Fig.1.1 Scarf Adhesive Joint

In woodworking, there are two distinctly different categories of scarf, based on whether the joint has interlocking faces or not. A plain scarf is simply two flat planes meeting on an angle relative to the axis of the stock being joined, and depends entirely on adhesive and/or mechanical fastening (screws, bolts, etc.) for all strength. Hooked, keyed, and nibbed scarfs are some of the many example of interlocking scarfs, offering varying degrees of tensile and compressive strength, though most still depend on mechanical fastening to keep the joint closed.

The plain scarf is not preferred when strength is required, so it is often used in decorative situations, such as the application of trim or moulding. The use of modern high-strength adhesives can greatly increase the structural performance of a plain scarf.

The keyed hook scarf is common in ship and boat-building as well as timber framing and wooden bridge construction. In large timbers such as these the scarf is virtually always secured with through bolts, and is frequently reinforced externally with iron or steel fishplates, and/or strapping.

A scarf joint may also be used to fix problems caused when a board is cut too short for the application. The board can be cut in half with a tapered cut yielding a scarf joint. When the joint is glued together, the tapers are slid against each other so that the two sections are no longer in line with each other. This has the effect of making the board longer. Once the glue has set, the board can be planed down to an even thickness, resulting in a longer but thinner board.

II. Problem Definition

- Preparation of Scarf joint specimen with different scarf angle and similar and dissimilar adherends.
- Experimentation to be carried out to calculate strength of the scarf adhesive joint.
- Evaluation of stresses in scarf joint by numerical method.
- The comparison between maximum principal stress and Von-misses equivalent stress obtained in experiment for glass epoxy adherend and for Bakelite adherend.
- Stress VS Scarf Angle Graph for both adherend used in Scarf adhesive Joint.
- The accepted failure criteria for scarf adhesive joints between principal stress and von-misses equivalent stress.

III. Methodology

3.1 Material

An important and main phase of our project is that the Selection of material. As in market many composite materials species available such as ceramics, Bakelite, polyester, Aluminium, epoxy glass, carbon-fiber and much more. On market research basis we went through all materials specifications like cost, weight, physical properties, etc. As our project is based on high strength to low weight ratio, so we came on conclusion of selection of two materials as Bakelite and Epoxy Glass.

3.2 Properties of Bakelite

Table 3.1 Bakelite Properties

Chemical Formula	$(C_6H_6O{\cdot}CH_2O)_n$
Molar Mass	Variable
Appearance	1.45 g/cm^3
Density	0.2 W/(m.k)
Young's Modulus, E	1.1Gpa
Poisson Ratio, µ	0.118

3.3 Properties of Glass Epoxy

Table 3.2 Glass Epoxy Properties

Chemical Formula	FR-4
Molar Mass	Variable
Appearance	Yellowish
Density	1.25 g/cm^3
Young's Modulus, E	0.2 W/(m.k)
Poisson Ratio, µ	0.396

3.4 Geometry of Single Scarf Adhesive Joint Specimen

For evaluating the factors we need to fix certain parameters for e.g. Material Thickness, Length, Width, joint thickness etc.

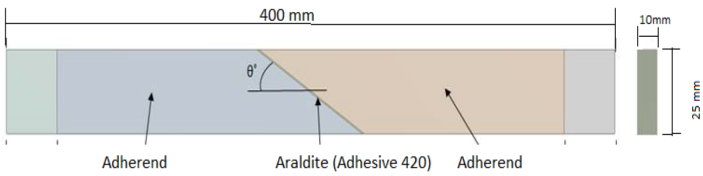

Figure 3.1 Scarf Adhesive Joint Specimen Terminologies

3.5 Preparation of Specimen

We needed to prepare total nine (9) specimen of required geometry with correct dimension using both materials. The specimen's preparation was divided into three sets. The first set consists of three specimens of similar adherend materials of glass epoxy. The material was cut using tooling material in required dimension and then grinded for smooth further joint preparation.

Set 1: Glass epoxy + Glass epoxy similar adherend specimen

Specimen 1: 30° scarf Angle Specimen
Specimen 2: 45° scarf Angle Specimen
Specimen 3: 60° scarf Angle Specimen

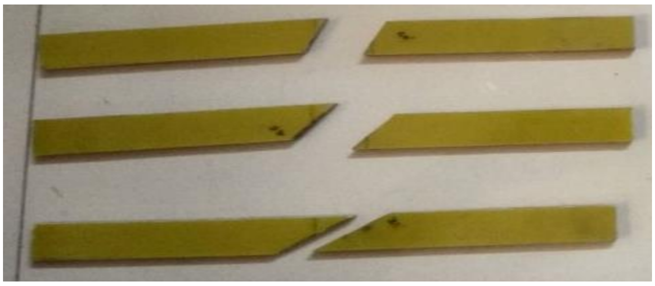

Figure 3.2 Glass Epoxy similar adherend specimens

Set 2: Bakelite + Bakelite similar adherend specimen
Specimen 4: 30° scarf Angle Specimen
Specimen 5: 45° scarf Angle Specimen
Specimen 6: 60° scarf Angle Specimen

Figure 3.3 Bakelite similar adherend specimen

Set 3: Glass Epoxy + Bakelite dissimilar adherend specimen
Specimen 7: 30° scarf Angle Specimen
Specimen 8: 45° scarf Angle Specimen
Specimen 9: 60° scarf Angle Specimen

Figure 3.4 Glass Epoxy & Bakelite dissimilar adherend specimen

3.6 Preparation of Scarf Adhesive Joint.

After specimen cutting from material block, it was now to prepare scarf joint for each specimen with respect to their scarf angle. At joint area the abrasiveness was obtain by degreasing and chemical treatment work. Using sandpaper the abrasive treatment was achieved and then etching was carried out for chemical treatment purpose. The adhesive bonding can be done at room temperature. Therefore we have selected adhesive bonding process. The bonding material used in the present work is, Araldite Standard Epoxy adhesive. Epoxy adhesives have two tubes resin and hardener which forms tough, rigid joints with high strength. The mixture of resin and hardener is 1:1 for better mixing and strength value.

Figure 3.5 Specimen No. 1, 2, 3

Figure 3.7 Specimen No. 7, 8, 9

Figure 3.6 Specimen No. 4, 5, 6

3.7 Analysis

a) By Experimentation (UTM)

Experimental analysis of specimen was done through UTM machine. The breaking load and ultimate tensile strength were evaluated of each scarf joint to know their strength and then compare the values to know which material specimen is the strongest among all. At the end, we get know which scarf angle joint possess the maximum strength. Also the strength of both composite materials is obtained to know which is tougher and better to use in industrial work.

b) By Numerical Method (FEM)

Finite element method (FEM) analysis was also done to validate the experimental analysis and put more effective objective and result regarding the project goal.ANSYS software was used to prepare the CAD model and mesh analysis was carried out. Boundary conditions were applied and stress and strength evaluation was done.

IV. Experimentation

4.1 Experimental Procedure

The scarf angles θ 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 24 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 4.1 shows the experimental setup for measuring joint strengths under tensile loading.

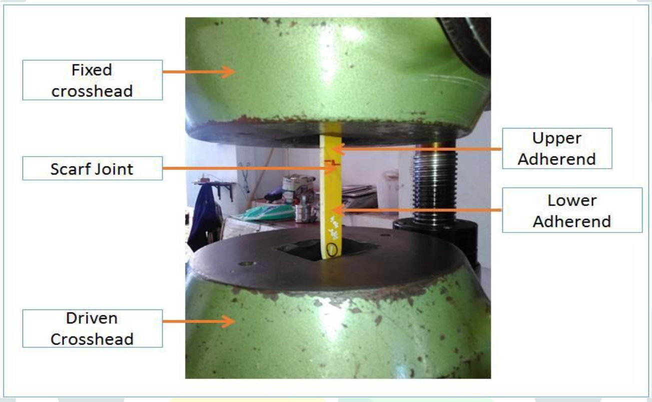

Fig. 4.1: Experimental Set up.

4.2 Experimental Calculation

Set 1: Glass Epoxy + Glass Epoxy Similar Adherend Specimens

Specimen 1: 30° Scarf Angle Specimen.

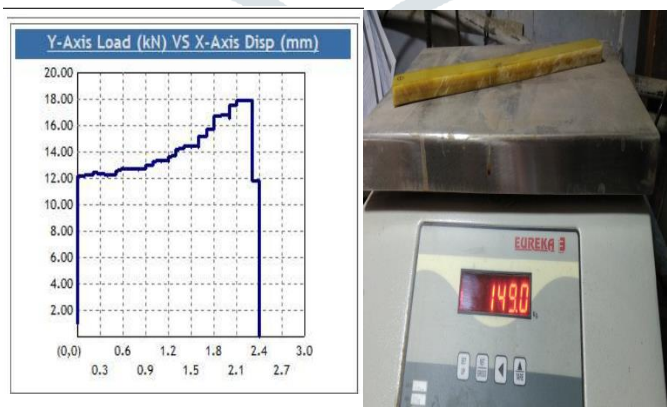

Figure 4.2 Graph and Weight for Specimen No. 1

Breaking Load=17.9KN
Ultimate Tensile Strength=71.6 N/mm²
Specimen Weight=0.149Kg
Strength to weight ratio = Breaking Load / Weight
= 17.9 / 0.149
= 120.134 KN / Kg

Specimen 2: 45° Scarf Angle Specimen.

Breaking Load=17.1KN
Ultimate Tensile Strength=68.2 N/mm²
Specimen Weight=0.150Kg
Strength to weight ratio = Breaking Load / Weight
= 17.1 / 0.150
= 114 KN / Kg
Specimen 3: 60° Scarf Angle Specimen.

Breaking Load=16.2 KN
Ultimate Tensile Strength=68.4 N/mm²
Specimen Weight=0.151Kg
Strength to weight ratio = Breaking Load / Weight
= 16.2 / 0.151
= 107.28 KN / Kg

Set 2: Bakelite + Bakelite Similar Adherend Specimen

Specimen 4: 30° Scarf Angle Specimen.

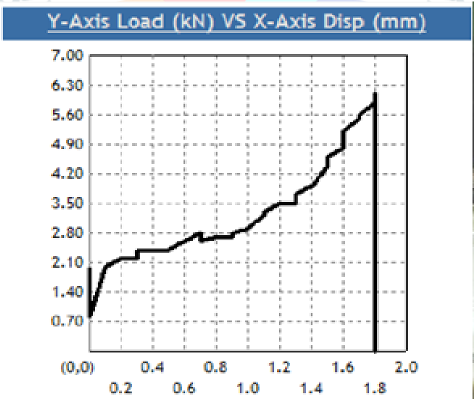

Figure 4.3 Graph for Specimen No. 4

Breaking Load=15.2 KN
Ultimate Tensile Strength=56.3N/mm²
Specimen Weight=0.1165Kg
Strength to weight ratio = Breaking Load / Weight
= 15.2 / 0.1165
= 130.47 KN / Kg

Specimen 5:45° Scarf Angle Specimen.

Breaking Load=13.1 KN
Ultimate Tensile Strength=50.4N/mm²
Specimen Weight=0.118Kg
Strength to weight ratio = Breaking Load / Weight
= 13.1 / 0.118
= 111.01 KN / Kg

Specimen 6:60° Scarf Angle Specimen.

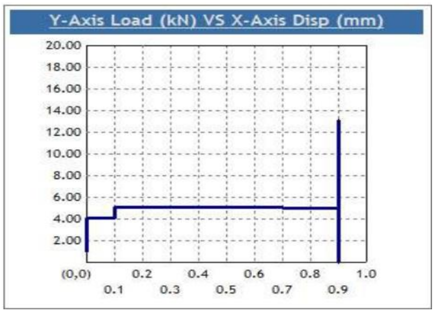

Figure 4.4 Graph for Specimen No. 6

Breaking Load=13.1 KN
Ultimate Tensile Strength=52.4N/mm²
Specimen Weight=0.1165Kg
Strength to weight ratio = Breaking Load / Weight
= 13.1 / 0.1165
= 112.44 KN / Kg

Set 3: Glass Epoxy + Bakelite Dissimilar Adherend Specimens

Specimen 7: 30°Scarf Angle Specimen

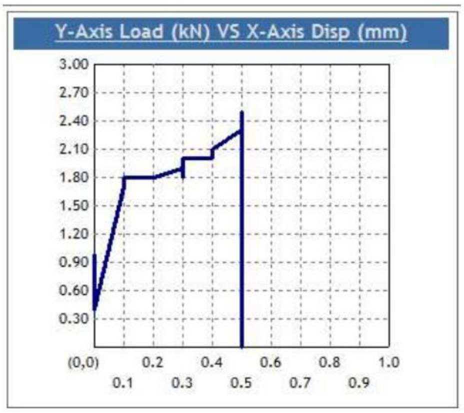

Figure 4.5 Graph for Specimen No.7

Breaking Load=11.6 KN
Ultimate Tensile Strength=46.4N/mm²
Specimen Weight=0.131 Kg
Strength to weight ratio = Breaking Load / Weight
= 11.6 / 0.131
= 88.55 KN / Kg

Specimen 8:45° Scarf Angle Specimen

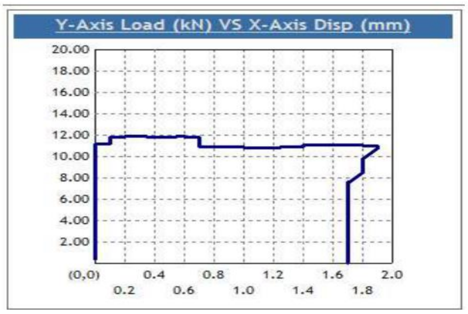

Figure 4.6 Graph for Specimen No. 8

Breaking Load=11.3 KN
Ultimate Tensile Strength=47.6N/mm²
Specimen Weight=0.133 Kg
Strength to weight ratio = Breaking Load / Weight
= 11.3 / 0.133

= 84.96 KN / Kg

Specimen 9: 60° Scarf Angle Specimen

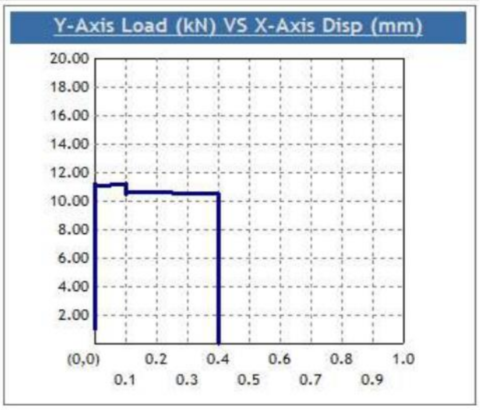

Figure 4.7 Graph of Specimen No. 9

Breaking Load=11.3 KN
Ultimate Tensile Strength=45.2 N/mm²
Specimen Weight=0.133 Kg
Strength to weight ratio = Breaking Load / Weight
= 11.3 / 0.133
= 84.96 KN / Kg

4.3 FEM Calculation

In this part FEM is carried out to analyse the behaviour of the scarf adhesive joints.Material properties of adhesive and adherends used in FEM calculation are tabulatedin table given below.

Table 4.1 Material Properties

Material	Young's Modulus E (Gpa)	Poisson's Ratio (μ)	Density ρ (Kg/m^3)
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-misses yield criteria. By von-Misses criteria the equivalent stress distribution at interface are calculated. The effects of various scarf angles are examined.

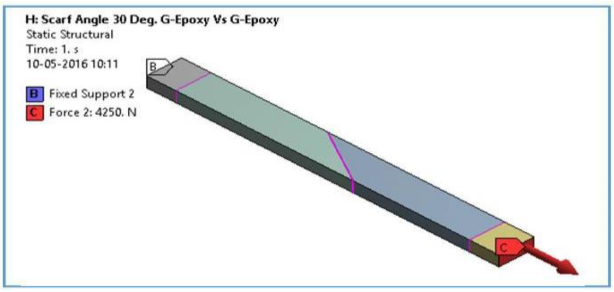

Fig. 4.8 Boundary Condition of scarf adhesive joint.

Stress strain behaviours of adhesives are considered as linear. The boundary conditions applied are shown in figure 4.8.

Fig.4.9: Meshing of Scarf adhesive joint of scarf adhesive joint

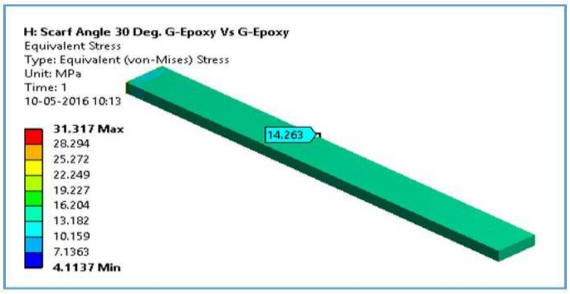

Fig.4.10: Equivalent Von-Misses Stress of scarf adhesive joint

V. RESULT

Table No.5.1 Results of Experiments

Expts.	Type of Adherend and Scarf Angle Joint	Breaking Load (KN)	Weight (Kg)	Strength to Weight Ratio (KN/Kg)	Ultimate Tensile Strength (N/mm²)
1	Epoxy Glass + Epoxy Glass (30°)	17.9	0.147	120.134	71.6
2	Epoxy Glass + Epoxy Glass (45°)	17.1	0.150	114	68.2
3	Epoxy Glass + Epoxy Glass (60°)	16.2	0.151	107.28	68.4
4	Bakelite + Bakelite (30°)	15.2	0.1165	130.47	56.3
5	Bakelite + Bakelite (45°)	13.1	0.118	111.01	50.4
6	Bakelite + Bakelite (60°)	13.1	0.1165	112.44	52.4
7	Epoxy Glass + Bakelite (30°)	11.6	0.131	88.55	46.4
8	Epoxy Glass + Bakelite (45°)	11.3	0.133	84.96	47.6
9	Epoxy Glass + Bakelite (60°)	11.3	0.133	84.95	45.2

The FEM results of scarf adhesive joint at various scarf angles with different adherends are tabulated In table 5.2.

Table No.5.2 Fem Breaking Loads of Scarf Adhesive Joint

Scarf Angle θ°	Breaking Load when Glass Epoxy is used as adherend (KN)	Breaking Load when Bakelite is used as adherend (KN)
30	15.2	13.1
45	15.1	12.55
60	14.26	11.6

From experimental and FEA analysis we get the results for equivalent von-misses stresses at various scarf angle with different adherend are tabulated in table 5.3

Table No. 5.3
Comparison of Experimental & FEA Von-Misses Stresses

Scarf Angle θ°	Von Misses stress of Epoxy Glass		Von Misses Stress of Bakelite	
	Experimental	FEA	Experimental	FEA
30	10.71	14.263	8.81	15.48
45	11.028	11.927	7.14	9.479
60	4.413	11.591	3.16	7.966

VI. 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 for similar adherends as well as dissimilar adherends.The following conclusion can be drawn:

1. The maximum strength for both adherends is at scarf angle 30° degree.
2. As the scarf angle θ increases 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 von- misses 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 since strength to weight ratio of glass epoxy is higher than Bakelite adherend joint.

It is beneficial to prepare and use similar material adherend scarf adhesive joint for better efficiency and strength than dissimilar adherend joint.

VII. Future Scope

1. Time-Frequency based Analysis for Damage Discrimination is one of the important future scopes of study pertaining to the topic. Many factors come under picture in frequency analysis which is not seen in parametric Study of Scarf Adhesive Joint. Fibre tear Failure and Fibre Damage Cycle is two main Characteristics of Frequency Based Analysis of Scarf Joint.
2. The compressibility factor and flexure strength of Scarf Adhesive Joint using Composite Material is under parameter which can be checked and get better strength evaluation of Joint.
3. In Aerospace industry ,while turbulence effect takes place, Joint are Subjected to non-uniform stress field which behaves differently and does not obey ideal case characteristics, hence turbulence effect on Scarf adhesive Joint can be studied

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