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Uncertainty Analysis of Tensile Strength of Scarf Adhesive Joints using Numerical Method and Validation through Experimentation

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Abstract - Adhesive joints represent a significant advancement in material bonding technology, offering benefits such as reduced weight and uniform stress distribution, which distinguish them from conventional joining methods. Among the various adhesive joints, the scarf adhesive joint stands out due to its mechanical advantages and potential for high-strength applications. This research investigates the impact of key parameters on the strength of scarf adhesive joints, including scarf angle, surface roughness, adhesive type, and adhesive layer thickness. By systematically varying these parameters and employing a design of experimentation (DOE) methodology, we aim to identify the optimal conditions that maximize joint strength. A series of scarf adhesive joint specimens with diverse parameter combinations will be fabricated and tested to evaluate the resultant joint strength. Statistical analysis of the experimental data will facilitate the understanding of how each parameter influences joint performance and contribute to the development of optimized adhesive joint designs. The findings of this study are expected to advance the application of scarf adhesive joints in various high-performance engineering fields, providing insights into the critical factors that govern their strength and reliability.

***Key Words*:** Scarf Adhesive Joint, Adherend Material, SS 304 Stainless Steel, Finite Element Analysis (FEA), Tensile Strength, Max von Mises Stress, Scarf Angle, Design of Experiments (DOE), Adhesive Properties, Surface Roughness.

1. INTRODUCTION

Material joining is an extremely important and ancient process in engineering applications. Nearly every industrial product has individual parts that need to be fixed together. Most frequently, mechanical joining techniques like soldering, welding, riveting, and bolting are used. There are several types of adhesive joints that can be used to increase the strength of the joints, such as stepped lap adhesive joints, butt adhesive joints, double lap adhesive joints, and single lap adhesive joints are made up. One of them is the scarf adhesive joint, where the scarf angle is a crucial component. The strength of the scarf adhesive joint is significantly influenced by several other crucial factors, including surface roughness, bond length, adhesive thickness, surface area (function of scarf angle), and adhesive properties. To ascertain the strength of the scarf adhesive joint, it is crucial to investigate these parameters.

1.1 Types of Adhesive Joints

An adhesive joint is prepared by placing an adhesive layer in between two parts to be joined and allowing it to cure. The parts to be joined are called as adherents. Based on joint geometry they can be classified as:

1. Lap Adhesive Joint
2. Cover Plate Adhesive Joint
3. Stepped Adhesive Joint
4. Butt Adhesive Joint
5. Scarf Adhesive Joint

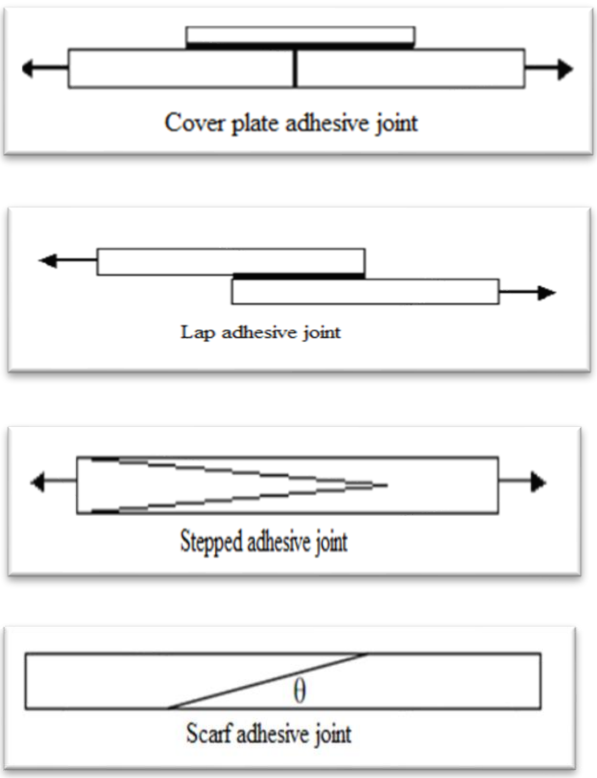


Fig. No. 1 Types of Adhesive Joints

1.1 Types of Adhesive

A. Natural Adhesives

B. Elastomer Adhesives

C. Modern adhesives

a) Anaerobic

b) Cyanoacrylates

c) Acrylics

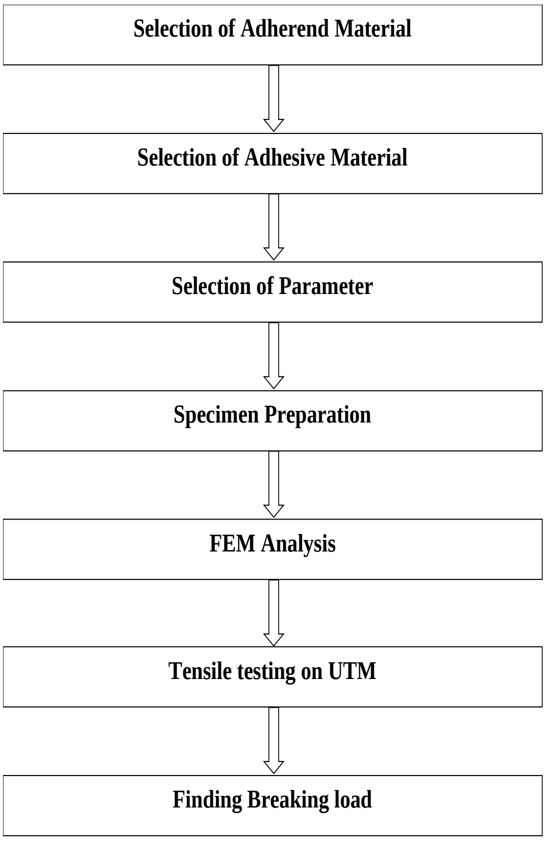
d) Epoxide Resins

e) Phenoxy

f) Elastomers

2. METHODOLOGY

To carry out experimental work following methodology is adopted.



2.1 Selection of Material for Adherend

Selection of the material for joint formation i.e. adherend material is the first step of the experimentation. After reviewing the literature, it is seen that stainless steel i.e. SS-400, SS-304, st60 tool steel, Aluminum, and its alloys like YH75 are some materials used commonly as an adherend.[2] Among these many materials Stainless steel SS 304 is selected as an adherend material which is satisfying the requirements given bellow:

•It must have high strength.

•It should resist the corrosion

•It should be durable.

•It should be available easily with reliable cost.

•Composition of SS 304 [26]

Constituent (by weight in percentage)	
Carbon	0.08
Manganese	2.00
Phosphorus	0.045
Sulphur	0.030
Silicon	0.75
Chromium	18.00 - 20.00
Nickel	8.00 -12.00
Nitrogen	0.10

2.2 Selection of Material for Adhesive

For a material to perform as a good adhesive it must have following main requirements:

•It must "wet" the surfaces - that is it must flow out over the surfaces that are being bonded, displacing all air and other contaminates that are present.

•It must adhere to the surfaces - That is after flowing over the whole surface area it must start to adhere.

•It must develop strength - The material now should change its structure to become strong and still adherend.

•It must remain stable - The material must remain unaffected by environmental conditions and other factors as long as the bond is required.[2]

2.3 Selection of Parameters

1.Scarf Angle

2.Surface Roughness

3.Adhesive Layer Thickness

4.Mixture Ratio of Adhesive (Resin to hardener)

2.4 FEM ANALYSIS

FEM Analysis is one of the important tasks.[3]

3. DESIGN OF EXPERIMENT

One extremely accurate data analysis technique for determining which factors influence which feature is experiment design. These methods are highly helpful in raising the product's quality through a statistical approach in the face of growing competition in the product quality market. The DOE technique uses science to establish the cause-and-effect relationships already present in the system, and the system is then adopted as a result.[1]

3.1 Control Factors with their Levels

Control Factors \ Level	1	2	3
Scarf angle (degree)	30	45	60
Surface roughness (µm)	1	2	3
Adhesive layer thickness (mm)	0.5	1	1.5
Mixture ratio	1:1	1.5:1	2:1

Table No. 1 Control Factors with their Levels

3.2 Selection of Orthogonal Array

One of the crucial duties in experiment design is choosing an orthogonal array. When using Mini-tab software to design an orthogonal array, two orthogonal arrays L9 and L27 were displayed for the design of experimentation, where a total of 27 experiments were needed. L27 array is chosen as a result because it only takes 27 experiments to produce effective results.

4. RESULT AND DISCUSSION

4.1 Tensile Test Graphs for Scarf Joint (30 Degree)

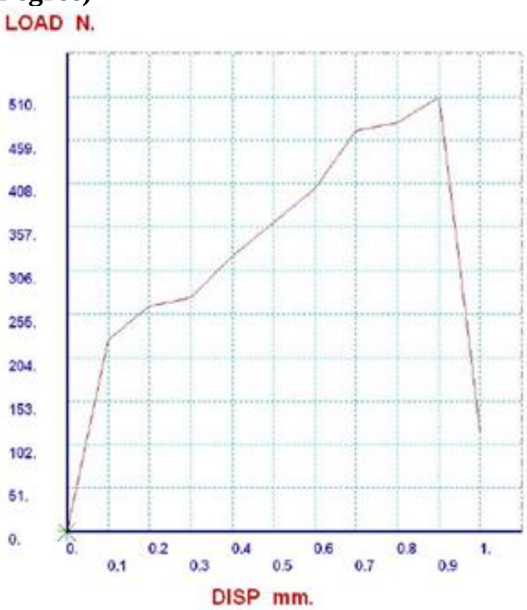


Fig. No. 2 Tensile Test Graphs for Scarf Joint 30 Degree

4.2 Tensile Test Graphs for Scarf Joint (45 Degree)

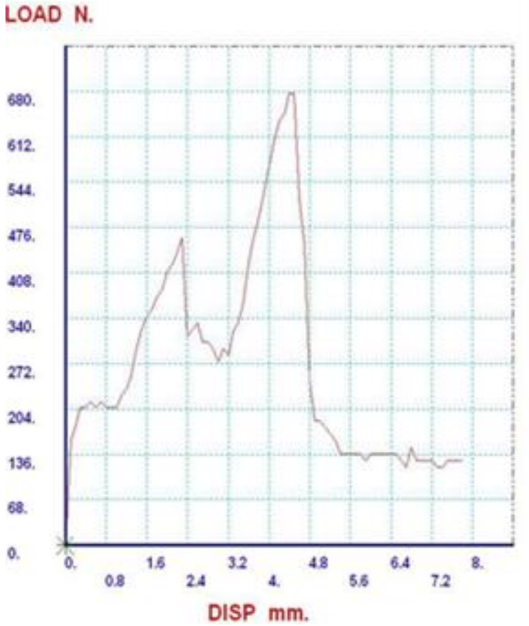


Fig. No. 3 Tensile Test Graphs for Scarf Joint 45 Degree

4.3 Tensile Test Graphs for Scarf Joint (60 degree)

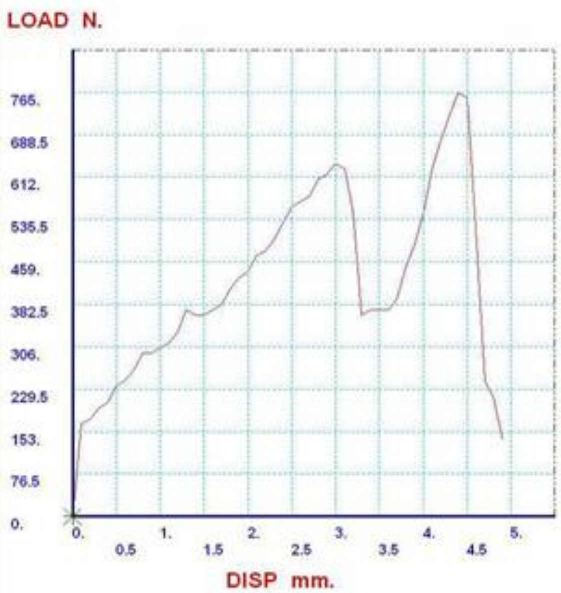


Fig. No. 4 Tensile Test Graphs for Scarf Joint 60 Degree

4.4 Displacement Plot for Scarf Joint (30 Degree)

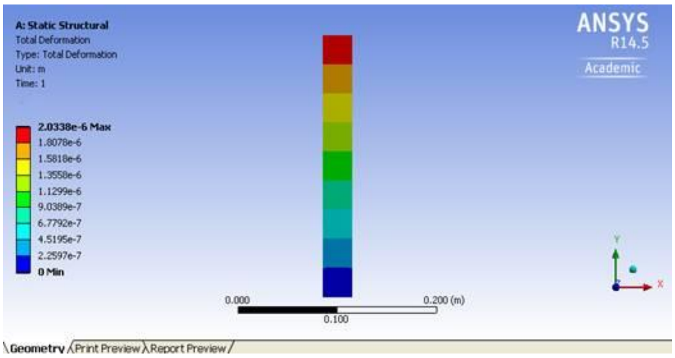


Fig. No. 5 Displacement Plot for Scarf Joint 30 Degree

4.5 Aa Displacement Plot for Scarf Joint (45 Degree)

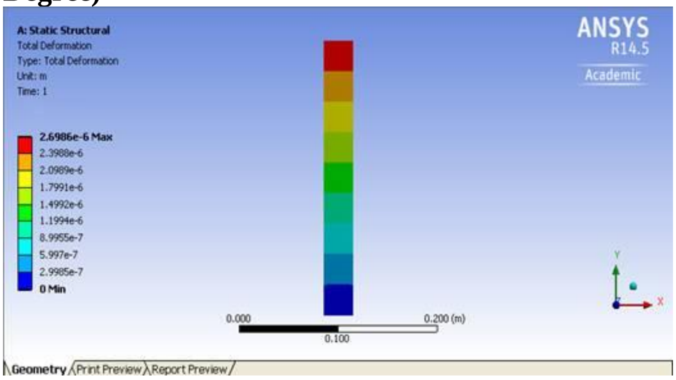


Fig. No. 6 Displacement Plot for Scarf Joint 45 Degree

4.6 Displacement Plot for Scarf Joint (60 Degree)

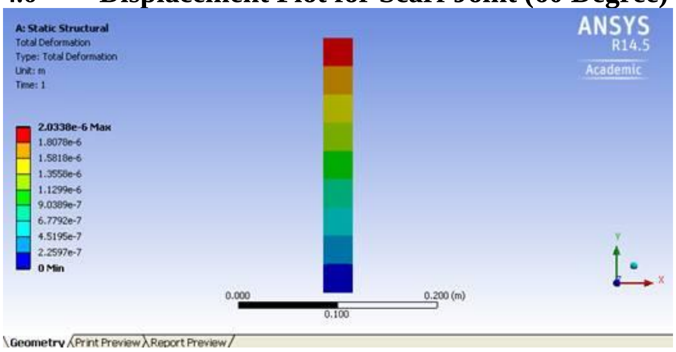


Fig. No. 7 Displacement Plot for Scarf Joint 60 Degree

4.7 Results Summary of Tensile Strength of Scarf Joint

Results Summary Table for Universal Testing Machine of the Scarf Joint			
Design	Force Applied (N)	Angle for the Scarf Joint	Tensile Strength in the Scarf Adhesive joint (Mpa)
Design 1	509.6	30 Degrees	1.699
Design 2	676.2	45 Degrees	2.254
Design 3	764.4	60 Degrees	2.548

Table No.2 Results Summary of Tensile Strength of Scarf Joint

4.8 Results Summary for FEA of the Scarf Joint

Results Summary Table for FEA of the Scarf Joint			
Design	Force Applied (N)	Angle for the Scarf Joint	Max von Mises Stress in the joint Adhesive Layer (Mpa)
Design 1	509.6	30 Degrees	1.698
Design 2	676.2	45 Degrees	2.253
Design 3	764.4	60 Degrees	2.547

Table No. 3 Results Summary for FEA of the Scarf Joint

Therefore, based on the results above, it can be concluded that there is a similarity between the values of stresses obtained from finite element analysis and tensile strength obtained from universal testing experiments.[7]

A conclusion that can be drawn from the above plotted result is that when the scarf angle increases, so does the Max von Mises Stress in the adhesive joint and the material's tensile strength. The testing point where crack initiation began was the maximum stress in the adhesive joint's stress distribution.

5 CONCLUSION

The current study has provided significant insights into the performance and optimization of scarf adhesive joints under tensile stress conditions, utilizing both experimental and finite element analysis (FEA) methods. The key findings are summarized as follows:

Validation of Methodology:

The finite element method (FEM) simulations conducted in ANSYS 14 demonstrated results consistent with those obtained from physical tests using a Universal Testing Machine, affirming the reliability of the FEM approach for analyzing the breaking strength of scarf adhesive joints.

Critical Influence of Scarf Angle:

Among the various control factors examined, the scarf angle emerged as the most critical determinant of joint strength. Specifically, a scarf angle of 60° was identified as optimal for achieving maximum tensile strength, while a scarf angle of 45° was optimal for withstanding maximum shear stresses.

Optimization of Control Factors:

The study revealed that for each response variable (tensile and shear strength), the optimal levels of other control factors remained consistent. The optimal settings were identified as a mixture ratio of 1:2, a layer thickness of 1.5 mm, and a surface roughness of 2 µm.

Impact of Surface Roughness:

Surface roughness was found to have the least impact on joint strength compared to other factors. However, it was noted that low surface roughness occasionally led to adhesive failure, contrasting with the predominantly cohesive failure observed in most cases.

Experimental Confirmation:

The maximum joint strength recorded was 2.6 kN, achieved with a configuration of a 60° scarf angle, 3 µm surface roughness, and a layer thickness of 0.5 mm.

In conclusion, the optimization of scarf adhesive joints is highly dependent on precise control of key factors, with the scarf angle being the most significant. The results provide a robust foundation for designing high-strength adhesive joints in engineering applications, validated through both experimental and simulation methods.

6 REFERENCES

1. Midori Y. Pitanga, Maria Odila H. Cioffi, Herman J.C. Voorwald, Chun H. Wang ‘Reducing repair dimension with variable scarf angles’, international journal of adhesion and adhesive 104 (2021) 102752

2. Seshadri Matta, Ramji M. ‘Prediction of mechanical behaviour of adhesively bonded CFRP scarf jointed specimen under tensile loading using localised DIC and CZM’, International journal of adhesion and adhesive 89 (2019) 88–108

3. Ligang Sun, Ying Tie, Yuliang Hou, Xingxue Lu, Cheng Li ‘Prediction of failure behavior of adhesively bonded CFRP scarf joints using a cohesive zone model’, Engineering Fracture Mechanics 228 (2020) 106897

4. Jairaja Ra, and G Narayana Naik, ‘Numerical studies on weak bond effects in single and dual adhesive bonded single lap joint between CFRP and aluminium’, Materials Today: Proceedings 21 (2020) 1064–1068

5. J.E.S.M. Silva, R.D.S.G. Campilho, I.J. Sánchez-Arce, R.D.F. Moreira ‘Numerical evaluation of tensile-loaded tubular scarf adhesive joints’ Procedia Structural Integrity 41 (2022) 36–47

6. R.D.F. Moreira, M.F.S.F. de Moura, F.G.A. Silva, J.P. Reis, ‘High-cycle fatigue analysis of adhesively bonded composite scarf repairs’ Composites Part B 190 (2020) 107900

7. Francesco Marchione, Placido Munaf, ‘Experimental strength evaluation of glass/aluminum double-lap adhesive joints’ Journal of Building Engineering 30 (2020) 101284

8. Ligang Sun, Cheng Li, Ying Tie, Yuliang Hou, Yuechen DuanMarchione, Placido Munaf, ‘Experimental and numerical investigations of adhesively bonded CFRP single-lap joints subjected to tensile loads’ International Journal of Adhesion and Adhesives 95 (2019) 102402

9. R.J.C. Carbas, M.A. Dantas, E.A.S. Marques, L.F.M. da Silva, ‘Effect of the adhesive thickness on butt adhesive joints under torsional loads’ Journal of Advanced Joining Processes 3 (2021) 100061

10. D.L. Alves, R.D.S.G. Campilho, R.D.F. Moreira, F.J.G. Silva, M.G. Cardoso ‘Effect of material hybridization on the strength of scarf adhesive joints’ Procedia Manufacturing 38 (2019) 1244–1251

11. Myong-Ho Kim, Un-Il Ri, Hyon-Sik Hong, Yong-Chol Kim ‘Comparative study of failure models for prediction of mixed-mode failure characteristics in composite adhesively bonded joint with brittle/ Quai-brittle adhesive using finite element analysis’ International Journal of Adhesion & Adhesives 109 (2021) 102911

12. M. Jurca, J. Vilcakov, M. Goralík, M. Masar, P. Ponízil, N. Kazantseva, S.H. Foulger, P. Saha ‘Reduced percolation threshold of conductive adhesive through nonuniform filler localization: Monte Carlo simulation and experimental study’ Composites Science and Technology 214 (2021) 108964