STRESS ANALYSIS AND STRENGTH EVALUATION OF SCARF ADHESIVE JOINTS

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ABSTRACT

Adhesive joints are used to join two materials by using adhesive. Light weight, uniform stress distribution is the important factors which differentiates adhesive joints from other conventional joints. Scarf adhesive joint is one of them. The strength of scarf adhesive joint depends on the parameters like scarf angle, bond length, surface roughness, adhesive thickness, type of adhesive etc. Effect of these parameters on adhesive joint strength is to be studied. For this purpose samples of scarf adhesive joints with different combinations of affecting parameters will be prepared. By varying the values of affecting parameters in certain levels, strength of joint is found out and variations in the strength to be studied. By applying design of experimentation technique optimum values of these parameters for maximum strength to be found out.

1. INTRODUCTION

In engineering applications material joining is very old but important process. Almost everything that is made by industry has component pieces and these have to be fixed together. Often mechanical joining methods like Bolting, riveting, welding, soldering is chosen. However, engineers now often choose to use adhesive bonding. Joining of two materials by placing adhesive between them and allow it to solidify is nothing but a adhesive bonding and that joint is called as an adhesive joint [1].

The conventional methods like bolting, riveting, welding causes stress concentration on a surface of a joining material which results in damage of material parts. While uniform stress distribution which avoids concentration of stresses is the main advantage of adhesive joint method. Hence adhesive joint rises as the alternative method to the conventional joining methods. Low structural weight, ability to join two dissimilar materials, reduced component and/or assembly costs, improved product performance and durability, greater design freedom, less finishing operations are the other advantages of adhesive joints.

In order to increase the strength of adhesive joints different types of adhesive joints like single lap adhesive joint, double lap adhesive joint, butt adhesive joint, stepped lap adhesive joint etc. are invented. Scarf adhesive joint is one of them in which scarf angle is a most critical parameter. Surface roughness, bond length, adhesive thickness, surface area (function of scarf angle), properties of adhesive to be used are the other important parameters to be considered which affects the strength of scarf adhesive joint greatly. So the study of these parameters is important to determine the strength of scarf adhesive joint.

2. ADVANTAGES OF ADHESIVE BONDING

Continuous bond: On loading, there is more uniform distribution of stresses over the bonded area. Bonded structures can consequently offer a longer life under load.

Less weight: Adhesive joint gives high strength to weight ratio.

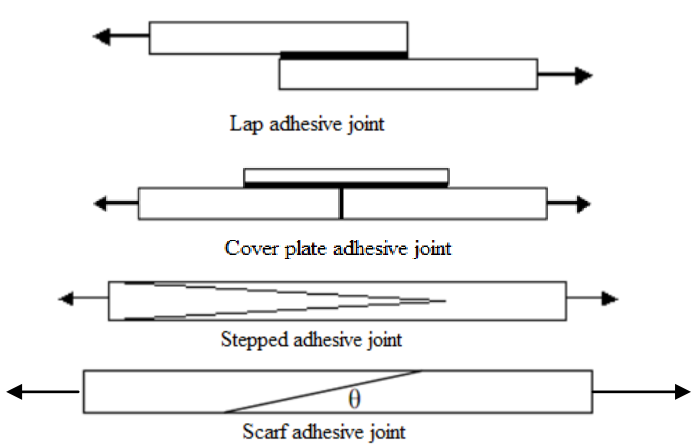

Fig. 1 Types of adhesive joints

Stiffer structures: The bonded joint being continuous produces a stiffer structure. Alternatively, if increased stiffness is not needed, the weight of the structure can be decreased while maintaining the required stiffness.

Improved appearance: Adhesive bonding gives a smooth appearance to designs.

Adhesives form a continuous bond between the joint surfaces: Rivets and spot welds pin the surfaces together only at localized points. While adhesive bonding gives continuous bonding.

Increased fatigue strength: Because of uniform stress distribution fatigue cracks are less likely to occur in adhesive bonding.. A fatigue crack in a bonded structure will propagate more slowly than in a riveted structure, because the bond-lines act as a crack stopper.

Less heat treatment: Adhesive bonding does not need high temperatures to cure.

Complex assemblies: Complex assemblies often joined with adhesive which cannot be joined together in any other feasible way than adhesive joint.

Dissimilar materials: Adhesives can join two dissimilar materials which are different in composition, modules, coefficients of expansion, or thickness etc.

Reduced corrosion

Electrically insulating

Vibration damping

Simplicity

3 EXPERIMENTATION

The next step is to conduct the experiments. Experiments should be carried out as per the combination given by Taguchi's orthogonal array and results should be recorded for desired response.

3.1 Analysis and determination of optimum parameters

After the experiments have been conducted, the next step is to determine optimal levels of the each control factor and to perform analysis of variance (ANOVA). To determine the optimum levels, S-N ratio approach is used. Hence S/N ratio of every response is to be found out. The ANOVA predicts the relative significance of the process parameters along with estimating the experimental errors [18]. It gives the percentage of contribution of each factor and gives the idea about the relative effect of the different factors on experimental responses.

3.2 Confirmation experiment:

The experimental confirmation test is the last step in a verifying results obtained based on Taguchi's methodology. In this step the experiments are performed for the combination of all parameters with their optimum levels and response is recorded. Then the results from the confirmation experiments are compared with the predicted results based on parameters and level tested. The confirmation experiment is a crucial step and is highly recommended by Taguchi to verify the experimental results [18]. It may be noted that if the optimal combination of parameters and their levels coincidently match with one of the experiments in the OA, then no confirmation test is required.

3.3 Analysis of Variance (ANOVA)

ANOVA is a statistically based, objective decision making tool for detecting any differences in the average performance of groups of items tested [18]. ANOVA helps in testing the significance of all main factors and their interactions by comparing the mean square of deviations of individual factor against the

Table 2 the standard ANOVA table

Sr. No.	Factor	SS	DOF	MSS	F	% contribution
1	Scarf angle					
2	Surface roughness					
3	Layer thickness					
4	Mixture ratio					
5	Error					
6	Total					

Experimental errors at specific confidence levels. The standard ANOVA table is shown in table .2.

The four factors are given in the second column along with error. Third column gives the sum of squares of deviations of each factor. By subtracting sum of squares of all individual factors from total sum of square we can get sum of square for error.

After calculating the sum of the squares degrees of freedom are assigned to each parameter. Statistically, there is a tool called an F test, named after Fisher [18], to see which design parameters have a significant effect on the quality characteristic. For performing the F test, the mean of square deviations, MSS due to the each process parameter needs to be calculated. The mean of square deviation MSS is equal to sum of square deviation divided by degrees of freedom associated with that parameter. Then the F value of a parameter is a ratio of mean square deviation of that parameter divided by mean square deviation of error. And by comparing F value with standard F value significance of a parameter can be determined. Percentage contribution can be found out by comparing sum of square of deviations.

3.4 Evaluation of stresses in scarf adhesive joint:

In order to ensure high reliability and significant strength performance of adhesive joint, strength and stresses induced in adhesive joint should be properly determined. If scarf adhesive joints are subjected to axial tensile load tensile as well as shear stresses gets induced in the joint. To derive these stresses geometry of the joint is important.

Consider the section according to fig.2, principle component of stress can be determined as,

$$P = \frac{F}{Q} \qquad (1)$$

Force F can be resolved into normal and tangential components, the individual force components are

$N = F \times \sin\alpha$ Normal component (2)

$T = F \times \cos\alpha$ Tangential component (3)

Bonded surface area S is

$S = Q / \sin\alpha$ (4)

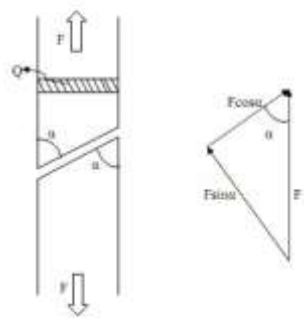

Fig. 2 Stresses in scarf adhesive joint

Introduce equation (3) and (4) in the basic equation of shear stress, relation between scarf angle and shear stress can be given as,

$$\text{Shear stress } \tau = \frac{T}{S} = \frac{F * \cos\alpha}{\frac{Q}{\sin\alpha}}$$

$$= \frac{F}{Q} * \cos\alpha * \sin\alpha$$

$$\tau = \frac{P}{2} * \sin 2\alpha \qquad (5)$$

Similarly tensile stresses at bonded surface can be found out by introducing equation (2) and (4) in the basic equation of tensile stress as,

$$\sigma = \frac{N}{S} = \frac{F * \sin\alpha}{\frac{Q}{\sin\alpha}}$$

$$= \frac{F}{Q} * \sin^2\alpha$$

$$\sigma = \frac{P}{2} * (1 - \cos 2\alpha) \qquad (6)$$

So by using the expression (5) and (6) it is possible to find out the tensile and shear stresses induced in the joint if force F and scarf angle α is known.

From the geometry shown in Fig.2 it can be predict that when scarf angle is minimum shear stress induced within the joint are maximum. So by rearranging eq. (5) we can write the expression for minimum scarf angle as

$$\tau_{max} = \frac{P}{2} * \sin 2\alpha_{min}$$

$$\text{i. e.} \quad \alpha_{min} = \frac{1}{2} [\sin^{-1} (2*\tau_{max} /P)] \qquad (7)$$

On similar line, when scarf angle is maximum, tensile strength is maximum, hence by rearranging eq. (6), expression for maximum scarf angle is given as,

$$\sigma_{max} = \frac{P}{2} * (1-\cos 2\alpha_{max.})$$

i. e.

$$\alpha_{max} = \frac{1}{2} [\cos^{-1} (1 - 2*\sigma_{max} /P)] \qquad (8)$$

3.5 Selection of orthogonal array:

Design of experimentation and Taguchi's method to find optimum levels of control factors were discussed in detail in chapter number 3. Selection of orthogonal array is one of the important tasks in Taguchi's method. After designing the orthogonal array in Mini-tab software, it had shown two orthogonal arrays namely L9 and L27 for Taguchi's method where number of experiments required performing is 9 and 27 respectively. Hence L9 array is selected due to the fact that only nine experiments required to be performed to obtain the efficient results. The L9 array given by Taguchi is as shown in Table 3

Table 3 L9 Orthogonal array

Expt. no.	Control factors			
	A	B	C	D
1	1	1	1	1
2	1	2	2	2
3	1	3	3	3
4	2	1	2	3
5	2	2	3	1
6	2	3	1	2
7	3	1	3	2
8	3	2	1	3
9	3	3	2	1

Where A, B, C, D are the four control factors with 1, 2, 3 as a three levels of each factor. This orthogonal array gives the combination of control factors with different specified levels for all nine experiments. Accordingly it is required to prepare the nine specimens of scarf adhesive joint with the given combination of control factors as given by L9 orthogonal array. The combinations of control factors for scarf adhesive joint for all nine experiments is given in table 4

Table 4 L9 orthogonal array with detailed values

Experiment number	Parameters			
	Scarf angle (degree)	Surface roughness (µm)	Layer thickness (mm)	Mixture ratio (Resin : Hardener)
1	30	1	0.5	1
2	30	2	1	1.5
3	30	3	1.5	2
4	45	1	1	2
5	45	2	1.5	1
6	45	3	0.5	1.5
7	60	1	1.5	1.5
8	60	2	0.5	2
9	60	3	1	1

3.5.1 Specimen preparation

Nine specimens of scarf adhesive joint are prepared as per the combinations of control factors given by L9 orthogonal array shown in Table 4. Following three steps are followed for specimen preparation:

3.5.2 Specimen geometry

Geometry of the specimens of scarf adhesive joint is decided by referring ISO standard. ISO 6922:1987(E) [25] gives the standard geometry of the specimen for tensile test of scarf adhesive joint as follows:

Specimen of rectangular cross section should have side of 10, 15, 25 or 50 mm with tolerance of 0.1mm. The minimum length should be 50mm or 3 × side length. Accordingly specimen is prepared as per the dimensions shown in fig. 3

All SS - 304 specimens for this test method were fabricated using the procedure described below. A bar with rectangular cross section is of SS-304 material was purchased and rough cut with a circular saw into a small bars of length 400mm each. By locating the centre, scarf angle is marked on the specimens and then bar is cutted in two parts with appropriate scarf angle.

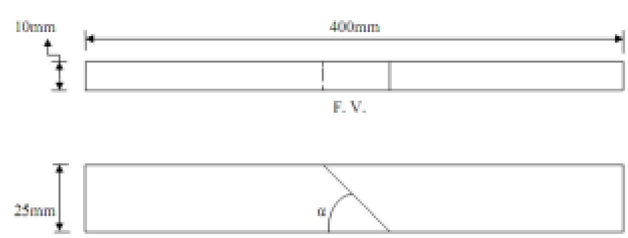

Fig 3 Dimensions of specimens of scarf adhesive joint as per ISO standard

Specimens ready for bonding are as shown in fig. 5

Fig 4 Specimens ready for bonding

3.5.3 Tensile test on Universal Testing Machine:

Tensile test of each specimen of scarf adhesive joint was conducted at room temperature using universal testing machine (INSTRON) manufactured by Fine spavy associates and engineers pvt. ltd. having 60 kN maximum load as shown in Fig. 5 Failure load is recorded for every specimen. Failure load is shown in Table 5

Fig 5 Testing of scarf adhesive joint on UTM

Table 5 Experimental values for Breaking Strength

Experiment number	Control factors				Breaking strength (KN)
	Scarf angle (degree)	surface roughness (µm)	Layer thickness (mm)	Mixture ratio (Resin : Hardener)	
1	30	1	0.5	1	1.6
2	30	2	1	1.5	1.4
3	30	3	1.5	2	1.4
4	45	1	1	2	1.5
5	45	2	1.5	1	2.3
6	45	3	0.5	1.5	2.1
7	60	1	1.5	1.5	1.7
8	60	2	0.5	2	2.1
9	60	3	1	1	2.4

4 RESULT ANALYSIS

4.1 Tensile and Shear stresses induced in the joint

From the observed values of breaking strength, induced tensile stresses and shear stresses within the joint can be calculated. Table 6 shows the tensile and shear stresses induced within each scarf adhesive joint.

Table 6 Stresses induced within the joints

Expt. No.	Breaking Strength (N/mm^2)	Shear Stress (N/mm^2)	Tensile Stress (N/mm^2)
1	1.6	2.771	1.6
2	1.4	2.424	1.4
3	1.4	2.424	1.4
4	1.5	3.000	3.0
5	2.3	4.600	4.6
6	2.1	4.200	4.2
7	1.7	2.944	5.1
8	2.1	3.637	6.3
9	2.4	4.156	7.2

4.2 Analysis of Breaking Strength

The breaking strength observed is entered as a response for this analysis. The results generated by the MINITAB 16 in terms of S/N ratio are used to draw the conclusions.

4.2.1 S/N ratio for Breaking Strength

The Table 7 indicates the S/N ratio for nine experimental runs with factor level set for each trial as per MINITAB software.

Table 7 S/N ratio given by MINITAB for Breaking Strength as a response

Sr. No.	Scarf angle (^{0})	Surface roughness (µm)	Layer thickness (mm)	Mixture ratio (Resin: Hardener)	Breaking Strength (KN)	S/N ratio
1	30	1	0.5	1	1.6	4.082
2	30	2	1	1.5	1.4	2.922
3	30	3	1.5	2	1.4	2.922
4	45	1	1	2	1.5	3.521
5	45	2	1.5	1	2.3	7.234
6	45	3	0.5	1.5	2.1	6.444
7	60	1	1.5	1.5	1.7	4.608
8	60	2	0.5	2	2.1	6.444
9	60	3	1	1	2.4	7.604

The response table for S/N ratio, main effects plot generated by MINITAB is as follows:

4.2.2 Response table for S/N ratio for breaking strength:

Response table for S/N ratio for breaking strength given by MINITAB software is shown below.

Response Table for Signal to Noise Ratios Larger is better

Level	Scarf angle	surface roughness	Layer thickness	Mixture ratio
1	3.309	4.071	5.657	6.307
2	5.734	5.534	4.683	4.659
3	6.219	5.657	4.922	4.296
Delta	2.910	1.586	0.974	2.011
Rank	1	3	4	2

Every value in the response table for S/N ratio gives average of S/N ratio for a parameter for each level. For example, the first value in a table is 3.309 which is an average of three values of S/N ratios for scarf angle for first level i. e. 30^0. Similarly all average values for S/N ratios are given in a table. Delta value given in the table gives the variations in S/N ratio within the levels, more the variation more is the delta value and hence more is the contribution of that factor in the response. The rank for each control factor given in a table gives the order in which every factor is contributing in a particular response and it is decided on the value of delta. From higher to lower value of delta ranks of all factors are decided.

It can be seen from the table that for a breaking strength delta value of scarf angle is maximum followed by mixture ratio, surface roughness and layer thickness. Hence in the same order rank is given to the control factors.

4.2.3 Main effects plot for Breaking Strength

The main effect plot obtained from MINITAB software is shown in Fig. 6 the main effects plot graphically represents the effect of factors on the response which helps to compare the effect of each level of the control factor on the response under study. The reference line drawn is showing the average S/N ratio for overall response. From the main effect plot it is clear that the breaking strength will maximum at level 3 for scarf angle and surface roughness while level 1 of layer thickness and mixture ratio will result in maximum response.

4.2.4 Percent contribution

The optimum levels of controlling parameters found out by using S/N ratio. The rank has given the order in which each factor is contributing to the response. Now in order to find out significant factors involved in the analysis determination of their percent contribution and F ratio is needed. Applying analysis of variance, ANOVA it can be done. The ANOVA for breaking strength is shown in Table 8. The percent contribution is a function of sum of squares of each control factor. It is shown in the Table 9. A problem with ANOVA is that, in L9 array which is chosen for analysis, total degrees of freedom available are 9-1= 8 [18],[19]. Three levels of each factors are considered, so all four factors are

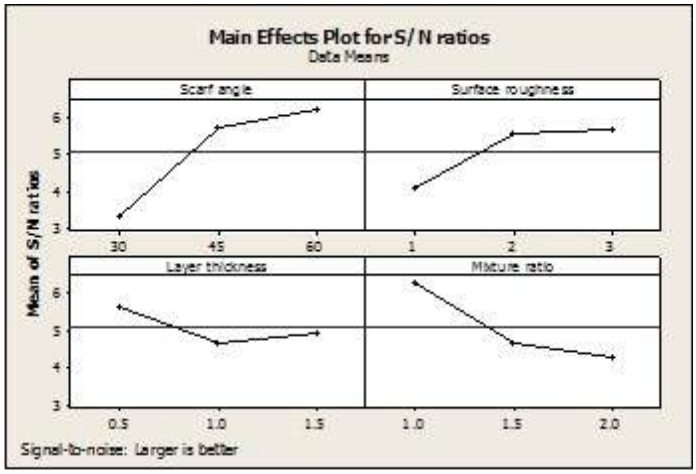

Fig 6 Main effects plot for S/N ratio of Breaking Strength

Assigned with 2 degrees of freedom each. Hence degrees of freedom can be assigned to the error is zero, because of which it was not possible to calculate the mean sum of square for error and hence the F ratio. To solve this problem the concept of pooling is used, in which one of the controlling parameter having least percentage contribution can be 'pooled' to the error that means its contribution is considered as an error and added into it. Which allowed assigning 2 degrees of freedom to the error from which mean sum of square is calculated and ultimately F ratio can be found out. The modified ANOVA table is shown in the Table 8. The percent contribution given by ANOVA is shown in Fig.7. For the breaking strength it is clear from Table 8 that percent contribution of layer thickness is minimum so it is pooled to error which is shown in Table 9

Table 8 ANOVA for Breaking Strength

Sr. No.	Factor	SS	DOF	MSS	F	Percent contribution
1	SA	0.62	2	0.31		50
2	SR	0.246	2	0.123		19.89
3	LT	0.046	2	0.023		3.76
4	MR	0.326	2	0.163		26.34
5	Error	0	0	-	-	-
6	Total	1.24	8			100

Table 9 Modified ANOVA table for Breaking Strength

Sr. No.	Factor	SS	DOF	MSS	F	Percent contribution
1	SA	0.62	2	0.31	13.285	50
2	SR	0.246	2	0.123	5.285	19.89
3	LT	Pooled				
4	MR	0.326	2	0.163	7	26.34
5	Error	0.046	2	0.023		3.76
6	Total	1.24	8			100

The percentage contribution of each factor is shown graphically in Fig. 7

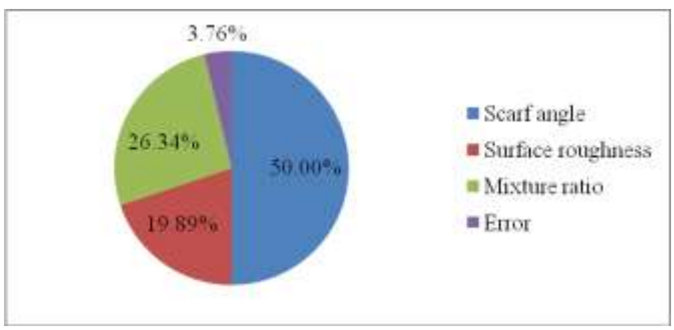

Fig 7 Percent contribution in Breaking Strength

4.3 Analysis of Shear Stresses:

The shear stresses obtained are entered as a response for this analysis. The results generated by the MINITAB 16 in terms of S/N ratio are used to draw the conclusions.

4.3.1 S/N ratio for Shear Stresses:

The Table 10 indicates the S/N ratio for nine experimental runs with factor level set for each trial as per MINITAB software.

Table 10 S/N ratio given by MINITAB for Shear Stress as a response

Sr. No.	Scarf angle (^{0})	Surface roughness (µm)	Layer thickness (mm)	Mixture ratio (Resin: Hardener)	Shear Stresses (N/mm^2)	S/N ratio
1	30	1	0.5	1	2.771	8.853
2	30	2	1	1.5	2.424	7.693
3	30	3	1.5	2	2.424	7.693
4	45	1	1	2	3	9.542
5	45	2	1.5	1	4.6	13.255
6	45	3	0.5	1.5	4.2	12.465
7	60	1	1.5	1.5	2.944	9.378
8	60	2	0.5	2	3.637	11.215
9	60	3	1	1	4.156	12.375

The response table for S/N ratio, main effects plot generated by MINITAB is as follows:

4.3.2 Response table for S/N ratio for shear stresses

As discussed earlier Average values of S/N ratios for each level of each factor are given in following response table for S/N ratio. As well as delta values and hence ranks are given in the table.

Response Table for Signal to Noise Ratios (Larger is better)

Level	Scarf angle	surface roughness	Layer thickness	Mixture ratio
1	8.080	9.258	10.845	11.495
2	11.754	10.721	9.870	9.846
	10.990	10.845	10.109	9.484
Delta	3.674	1.586	0.974	2.011
Rank	1	3	4	2

For shear stresses also scarf angle is the measure contributing factor followed by mixture ratio, surface roughness and layer thickness.

4.3.3 Main effects plot for shear stresses:

The main effect plot obtained from MINITAB software for shear stresses is shown in Fig. 8 From the main effect plot it is clear that the maximum shear stresses sustained by joint are at level 2 for scarf angle, level 3 for surface roughness whereas it will maximum at level 1 for layer thickness and mixture ratio.

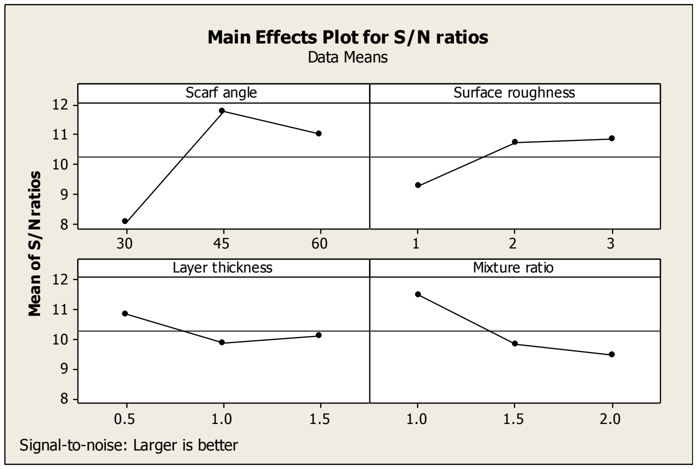

Fig 8 Main effect plot for S/N ratio of Shear Stresses

4.3.4 Percent contribution

Same problem was in the ANOVA for shear stress analysis. So again pooling method is used over here. The initial ANOVA table is given in Table 11 while modified one is given in Table 12. Layer thickness is having minimum contribution to the shear stresses hence it is pooled in Table 12. Percent contribution is shown graphically in Fig. 9

Table 11 ANOVA for Shear Stress

Sr. No.	Factor	SS	DOF	MSS	F	Percent contribution
1	SA	3.145	2	1.572	-	58.76
2	SR	0.897	2	0.448	-	16.76
3	LT	0.179	2	0.089	-	3.35
4	MR	1.13	2	0.565	-	21.12
5	Error	0	0	-	-	-
6	Total	5.352	8			100

Table 12 Modified ANOVA for Shear Stress

Sr. No.	Factor	SS	DOF	MSS	F	Percent contribution
1	SA	3.145	2	1.572	17.551	58.76
2	SR	0.897	2	0.448	5.005	16.76
3	LT	Pooled				
4	MR	1.13	2	0.565	6.309	21.12
5	Error	0.179	2	0.089		3.35
6	Total	5.352	8			100

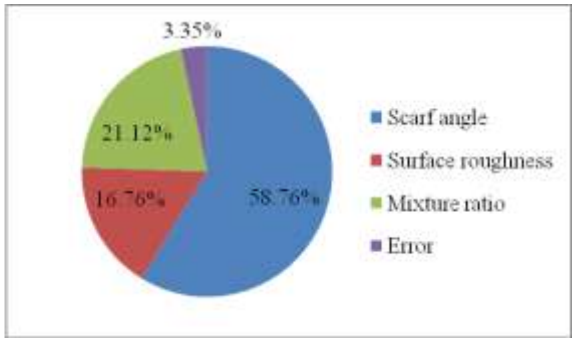

Fig 9 Percent contribution in Shear Stress

4.4 Analysis of Tensile Stress

The tensile stresses obtained are entered as a response for this analysis. The results generated by the MINITAB 16 in terms of S-N ratio are used to draw the conclusions.

Table 13 S/N ratio given by MINITAB for Tensile Stress as a response

Sr. No.	Scarf angle (^{0})	Surface roughness (µm)	Layer thickness (mm)	Mixture ratio (Resin: Hardener)	Tensile stresses (N/mm^2)	S/N ratio
1	30	1	0.5	1	1.6	4.082
2	30	2	1	1.5	1.4	2.922
3	30	3	1.5	2	1.4	2.922
4	45	1	1	2	3	9.542
5	45	2	1.5	1	4.6	13.255
6	45	3	0.5	1.5	4.2	12.465
7	60	1	1.5	1.5	5.1	14.151
8	60	2	0.5	2	6.3	15.986
9	60	3	1	1	7.2	17.146

4.4.1 S/N ratio for Tensile Stress

The Table 13 indicates the S/N ratio for nine experimental runs with factor level set for each trial as per MINITAB software.

The response table for S/N ratio, main effects plot generated by MINITAB is as follows:

4.4.2 Response table for S/N ratio for tensile stress:

As discussed earlier average values of S/N ratios for each level of each factor along with delta value and rank for each factor are given in following response table for S/N ratio given by MINITAB software.

Response Table for Signal to Noise Ratios

Larger is better

Level	Scarf angle	surface roughness	Layer thickness	Mixture ratio
1	0.309	9.259	10.845	11.495
2	11.754	10.722	9.871	9.846
3	15.762	10.845	10.110	9.484
Delta	12.452	1.586	0.974	2.011
Rank	1	3	4	2

Here also scarf angle is most significant factor followed by mixture ratio, surface roughness and layer thickness.

4.4.3 Main effects plot for Tensile Stress

The main effect plot for tensile stresses as a response obtained from MINITAB software is shown in Fig. 10. It gives comparison between effects of each level of the control factor on the response under study. The reference line drawn is showing the average S/N ratio for overall response. From the main effect plot it is clear that the maximum tensile stresses sustained by the joint is maximum at level 3 for scarf angle and surface roughness and at level 1 for layer thickness and mixture ratio.

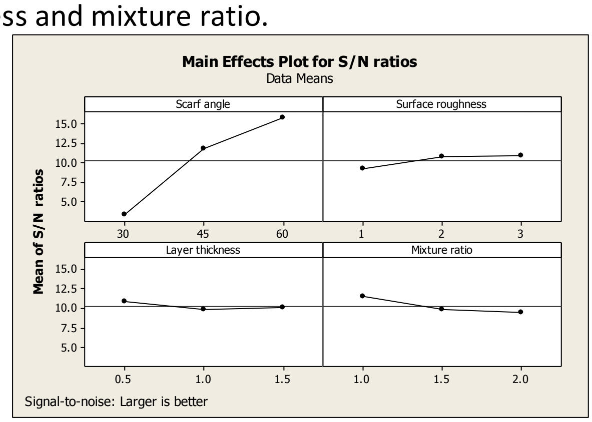

Fig 10 Main effect plot for S/N ratio of Tensile Stress

4.4.4 Percent contribution

Same problem was in the ANOVA for shear stress analysis. Thus pooling method is employed here also. The initial ANOVA table is given in Table 6.9 while modified one is given in Table 14. Here layer thickness is having minimum contribution which can be seen in Table 15; hence it is pooled in Table 15. Graphical representation for percent contribution is given in Fig. 11.

Table 14 ANOVA for Tensile Stress

Sr. no.	Factor	SS	DOF	MSS	F	Percent contribution
1	SA	33.626	2	16.813	-	90.25
2	SR	1.846	2	0.923	-	4.96
3	LT	0.166	2	0.083	-	0.45
4	MR	1.62	2	0.81	-	4.35
5	Error	0	0	-	-	-
6	Total	37.26	8			100

Table 15 Modified ANOVA for Tensile Stress

Sr. No.	Factor	SS	DOF	MSS	F	Percent contribution
1	SA	33.626	2	16.813	201.76	90.25
2	SR	1.846	2	0.923	11.08	4.96
3	LT	Pooled				
4	MR	1.62	2	0.81	9.72	4.35
5	Error	0.166	2	0.083		0.45
6	Total	37.26	8			100

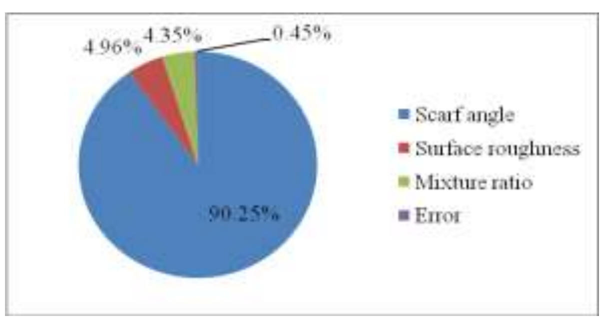

Fig 11 Percent contribution in Tensile Stress

4.5 Confirmation Experiment:

In order to verify the results obtained from Taguchi analysis, a confirmation experiment need to be perform. To perform a confirmation experiment, specimens of scarf adhesive joints are prepared

For three different responses with optimum levels of parameters obtained from the Taguchi analysis. The configuration of joints to be tested for different responses is as given in Table 6. These joints are tested on Universal testing machine by exerting tensile load and obtained results are shown in the same Table 6.

Table 16 Configuration of joints for confirmation experiment along with results

Response	Control factors				Observed results
	Scarf angle (^{0})	Surface roughness (µm)	Layer thickness (mm)	Mixture ratio (Resin :Hardener)	
Breaking Strength (KN)	60	3	0.5	1	2.6
Shear Stress (N/mm^2)	45	3	0.5	1	5
Tensile Stress (N/mm^2)	60	3	0.5	1	7.5

4.5.1 Result Prediction by Taguchi Method:

The results of confirmation experiments can be predicted by using Taguchi method. For this MINITAB software is used. After putting the specific optimum levels of control factors, software gives the result for respected response. The predicted results by Taguchi are shown in table 17

Table 17 Predicted results by Taguchi Method

Response	Control factors				Predicted Results
	Scarf angle (^{0})	Surface roughness (µm)	Layer thickness (mm)	Mixture ratio (Resin : Hardener)	
Breaking strength (KN)	60	3	0.5	1	2.683
Shear stresses (N/mm^2)	45	3	0.5	1	5.078
Tensile stresses (N/mm^2)	60	2	0.5	1	8.054

4.5.2 Confidence Interval

The predicted results are only a point estimate based on the averages of the results obtained from the experiments. While performing the confirmation experiment it is better to have a range of value than having a exact value of predicted results within which the observed values should fall with some confidence. This range is called as confidence interval (C.I.) [19]. It has a maximum and minimum value between which the observed value should fall. It can be calculated by statistical way by using following expression, C.I. = $\pm\sqrt{(F(1,n_2) \times V_e)/N_e}$ [19]

Where F (1, n_2) is the F value from F table at a required confidence level at DOF 1 and error DOF n_2.

N_e = Effective number of replications

$= \frac{\text{Total number of results}}{\text{DOF of mean} + \text{DOF of all factors}}$

Using these equations confidence interval for all three responses is calculated which is shown in table 18. The F value is taken for 95% of confidence.

Table 18 Summary of results with confidence interval

Sr. No.	Response	Predicted Results	Confidence Interval (C. I.)		Observed Results
			Lower	Upper	
1	Breaking strength (KN)	2.683	2.031	3.336	2.6
2	Shearstress (N/mm^2)	5.078	3.794	6.362	5
3	Tensile stress (N/mm^2)	8.054	6.815	9.294	7.5

So from above table it is clear that the observed results are failing within the confidence interval of predicted result hence the confirmation result is validated the result.

5 CONCLUSIONS

After performing experimental tests on scarf adhesive joint and analyzing the results for the scarf adhesive joint using the signal to noise ratio approach, analysis of variance (ANOVA) and using Taguchi's optimization approach following is the conclusions from the present study:

1. The most dominating factor in scarf adhesive joint is scarf angle which affect the joint strength greatly as compared to other factors like surface roughness, layer thickness, mixture ratio. Whereas adhesive layer thickness is the least dominating factor.

2. Design of joint with optimum levels of control factors especially scarf angle results in maximum strength. The scarf angle of 60^0 resulted in high breaking strength as well as sustained the maximum stresses whereas 45^0 of scarf angle sustained maximum tensile stresses.

3. It is seen from results that the optimum level for remaining control factors like surface roughness, layer thickness and mixture ratio is same for all the three responses. The exact values are 3µm for surface roughness, 0.5 mm for layer thickness and 1:1 for mixture ratio.

4. The maximum load taken by scarf adhesive joint was observed as 2.68 KN in which scarf angle, surface roughness, layer thickness and mixture ratio were 60^0, 3µm, 0.5 mm and 1:1 respectively.

5. After observing the failure surfaces it is seen that in most of the cases failure was cohesive failure but in some cases it was adhesive failure in which surface roughness was low.

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