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Optimization of Joint Strength of Adhesively Bonded Glass Fiber Epoxy Based Double Strap Butt Joint

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Abstract*: *Fiber reinforced composite laminates has various industrial applications. It is important to investigate the joining methods of composite laminates. In this research paper, the effect of overlap length (OL), surface roughness (SR) and adhesive layer thickness (ALT) on the strength and failure modes of adhesively bonded double strap GFRP (glass fiber reinforced epoxy based composite laminate) butt joint was investigated. The adhesively bonded double strap GFRP butt joints were prepared from unidirectional glass fiber and epoxy by hand layup technique as per ASTM standard. The number of experiments was optimised using Taguchi's L9 approach. It is observed that the variation in overlap length has significant effect on butt joint strength. It is also observed that SR and ALT are less significant factors in comparison to OL. It is concluded that increase in ALT adversely affect the butt joint strength. The failure mode in specimens was generally thin layer cohesive failure or light fiber tear failure.

Keywords* : *Optimisation, Joint strength, Overlap, Surface roughness

I. INTRODUCTION

FRP composites are one of the most important materials in the field of construction, automobile, ship and aviation industries. The sheets of FRP are used in construction and many rehabilitation projects due to their advantageous properties such as short time for installation, low weight, non-corrosive nature and high strength of material [1,2,3,4].

The FRP materials are used as an internal reinforcement with a concrete to give strength to the column, repairing of column which was damaged by corrosion and other type effect [5]. The use of FRP composite increased the strength and stiffness of components used in construction industries [6]. Due to many advantageous properties there would be many more applications in future. There are many applications of adhesively bonded FRP composite in the field of maritime, aerospace, aircraft and automobile industries. These are commonly used in the manufacturing of components and structures which can be used in deep sea such as frame of unmanned or manned vehicles, propellers, containers etc.

In automobile and aircraft applications, the thickness of adhesive layer used for bonding joints is usually very thin as compared to structural applications [8,17]. In aerospace and automobile sector, FRP components are generally joined by bolted connection. However by the application of bolts the weight of component could increase and drilling holes may facilitate ingress of moisture [8]. However, adhesive bonding can be a better alternative to conventional bolting system and by doing this various problems can be overcome [9]. Experiments has been done to compute the bolted, bonded and bonded-bolted composite-metal joints and mechanical properties were evaluated [1,2,7]. H.K.Lee et al.[13] investigated effect of overlap length, adhesive type, adhesive thickness on joints strength of double strap and single lap GFRP joints by the means of tensile test. Valle and Keller [9] had developed a design method for adhesively bonded lap joints by experimental investigation and compared the numerical result with two-dimensional finite element analysis. In the present study, the effect of design parameters such as overlap length, surface roughness and adhesive layer thickness on the interfacial joint strength of adhesively bonded GFRP butt joints have been investigated. Taguchi L9 approach is used to optimise the number of experiments and the results recorded are compared to each other.

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II. MATERIALS AND METHODS

2.1 Materials

The specimens were prepared from unidirectional glass fibre (Sikawrap-430G), epoxy resin (Sikadur-330IN) and epoxy adhesive (Araldite) using hand layup technique as per ASTM D5868 [12]. The stacking sequence and the geometry of standard specimen is shown in figure 1.

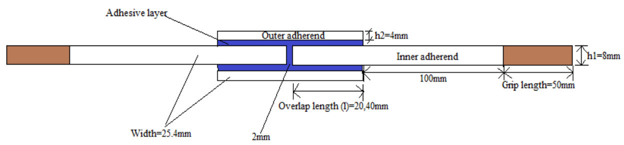

Fig.1.Specimen details and pictorial diagram of double-strap joint specimens.

2.2 Specimen preparation

The FRP sheets were made with the help of unidirectional glass fibers [15] and epoxy adhesive (sikadur 330). The epoxy adhesive was prepared by mixing one part of hardener in four parts of epoxy by weight [16]. The GFRP sheets were produced by using hand layup technique and cured for a week at the room temperature. Two sheets of 4 mm and 8 mm thickness were made and cut into strips of width of 25.4 mm and required length according to designed parameters. The surface quality of the strips was depends upon sand paper grades. Three surface conditions using sand paper of grade 320 and grade 150 and grade 50 were used to vary the surface roughness of the joined surfaces. After preparing the surface of strap and component, both are joined using epoxy adhesive. After joining, the surfaces were made in contact under pressure and cured for 24 hours at room temperature. The specimens were labeled as for example A-40-320G-0.5, where “A” stands for “ double strap GFRP joint”, “40” stands for overlap length i.e. 40mm,” 320G” represents type of sand paper used for creating surfaces rough i.e. 320 grade, and 0.5 represents the thickness of adhesive layer. Table 1 and 2 represents the properties of the raw materials.

Table 1. Properties of raw materials.

Materials	Major properties			
	Density (gm/cc)	Modulus (N/mm^2)	Failure strain (%)	Strength (N/mm^2)
Glass fiber	2.56	76000	2.8	3400
Epoxy	1.3	3500	0.9	30

Table 2. Properties of adhesive (araldite)

Property	Araldite® Standard Resin	Araldite® Standard Hardener	Araldite® Standard mixed
Colour (visual)	neutral	pale yellow	pale yellow
Specific gravity	ca. 1.17	ca. 0.97	ca. 1.07
Viscosity at 25°C (Pas)	30 - 50	20 – 40	30 - 45
Pot Life (100 g at 25°C)	-	-	100 – 150 minutes

III. EXPERIMENTATION

3.1 Tensile test

For testing of specimens, the method and apparatus used were based on ASTM D3528. The universal testing machine was used for tensile test with load capacity of 150 kN and with the constant head-loading rate of 1.27 mm/min until the failure of the specimen. The grip of 50 mm length was used for clamping specimen. There are many design parameters which can influence the failure mode and joints strength of adhesively bonded GFRP butt joints such as adhesive types, overlap length, adhesive layer thickness etc. In this paper the focus is on the evaluation of the effect of overlap length, surface roughness and adhesive layer thickness on joint strength. To examine the influence of surface roughness, sand papers of grade 320, grade 150 and grade 50 were used and also some specimens were used as it is or we can say that without any abrasion. To examine the effect of overlap length, three overlap lengths as 20 mm, 40 mm and 80 mm were used to prepare double strap butt joints. Figure 2 displays the butt joint specimen loaded on universal testing machine.

3.2 Optimisation of experiments

The Taguchi process is a most popular method to optimise the process parameters. This method is based on orthogonal array, results in the less variance in experimental results and generate optimum process setting. The Taguchi technique facilitates in less number of experiment runs. The S/N ratios were used to identify larger the better optimal setting. In the present case, the primary objective is to maximize the butt joint strength. Therefore, Larger the better principle is considered to maximize the joint strength. Taguchi L9 array was used to reduce the number of experiments. Three variables Overlap, Surface roughness and Adhesive layer thickness were considered along with their three levels as shown in table 3. Only one outcome i.e. joint strength was considered to be maximized. The resulted combinations are mentioned in table 4.

Fig.2. Double-strap joint specimen on UTM.

Table 3 List of variables and their levels

Variables	Level-1	Level-2	Level-3
Overlap (mm)	20	40	80
Surface Roughness(Grit size)	50	150	320
Adhesive Layer Thickness (mm)	0.5	1.0	1.5

Table 4 Combinations as per Taguchi L9 array

Specimen type	Overlap (mm)	Surface Roughness (Grit size)	Adhesive Layer Thickness (mm)	Joint Strength (kN)	S/N Ratio
A-20-50-0.5	1	1	1	10.2583	20.2215
A-20-150-1.0	1	2	2	10.3633	20.3100

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A-20-320-1.5	1	3	3	10.6226	20.5246
A-40-50G-1.0	2	1	2	12.4283	21.8882
A-40-150-1.5	2	2	3	13.1820	22.3996
A-40-320-0.5	2	3	1	16.3435	24.2669
A-80-50-1.5	3	1	3	15.6073	23.8666
A-80-150-0.5	3	2	1	18.6314	25.4049
A-80-320-1.0	3	3	2	19.1643	25.6499
Mean of joint strength (MJS)				**14.06678**	

IV. RESULTS AND DISCUSSION

For the combinations mentioned in table 4, the dependence of butt joint strength on the three variables is shown in figure 3. It is clear that the optimal process setting is to be 3 3 1, i.e. third level of overlap length, third level of surface roughness and first level of adhesive layer thickness.

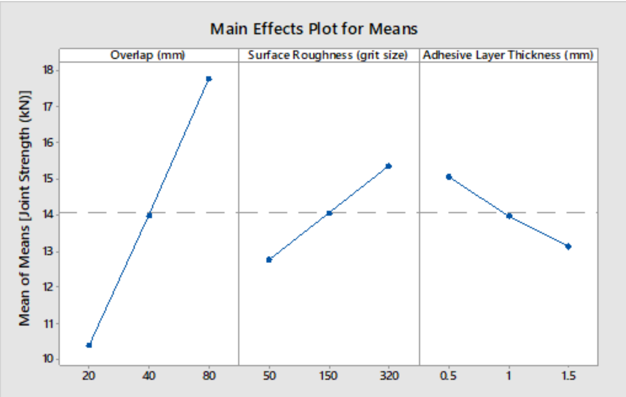

Fig. 3- Variation of butt joint strength at three variables levels

The S/N ratio values for the threes variables and one outcome are shown in figure 4. The confirmation experiments were performed for the optimal setting and the average values are reported in table 5. The average experimental results (for optimal setting) were compared with the predicted value to compute the percentage error.

Table 5. Experimental results for the optimal setting

Overlap (mm)	Surface Roughness (microns)	Adhesive Layer Thickness (mm)	Joint Strength (KN)
3	3	1	19.6532

The analysis of variance (ANOVA) was performed to evaluate the most significant variable for the butt joint strength. The confidence level of 95 % was considered keeping in mind the industrial practice. The ANOVA table is shown in table 6. From ANOVA analysis it is found that all the variables have significant effect on the butt joint strength as their p- values are less than 0.05.The butt joint strength value is predicted as below.

Butt joint strength (Predicted) = MJS + (17.8010-MJS) + (15.3768-MJS) + (15.0777-MJS)

= 14.06678 + (17.8010-14.06678) + (15.3768-14.06678) + (15.0777-14.06678)

= 14.06678 + (3.7343) + (1.3101) + (1.011)

= 20.1221 KN

% error = [(20.1221-19.6532)/ 20.1221] x 100 = 2.33%

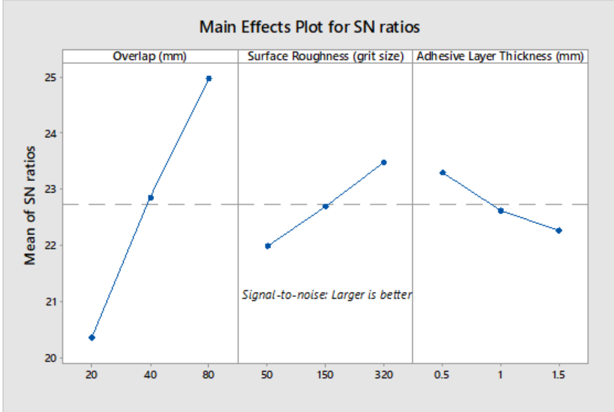

Fig. 4 S/N ratio at three variables levels

Table 6 Analysis of Variance (ANOVA) table

Source	DF	Adj SS	Adj MS	F-value	P-value	% Contribution
Overlap (mm)	**2**	81.8658	40.9329	552.24	0.002	83.59
Surface Roughness (Grit size)	**2**	10.2354	5.1177	69.04	0.014	10.45
Adhesive layer thickness (mm)	**2**	5.6778	2.8389	38.30	0.025	5.797
Error	**2**	0.1482	0.0741			
Total	**8**	97.9272				

From table 6, it is found that the overlap length is the most significant variable affecting the butt joint strength and the adhesive layer thickness is the least significant variable.

4.1 Failure behavior of test specimens

Most of the specimens suddenly fracture with slightly burst sound, indicating brittle failure, catastrophic failure. According to ASTM D5573 [11] failure between adherent and adhesive are classified into two six categories. In present study, most of the specimens were fractured suddenly and classified as thin-layer cohesive (TLC) or the light-fiber-tear (LFT) failure pattern as based on ASTM D5573 as shown figure 5.

Fig.5 The thin-layer cohesive (TLC) or light-fiber-tear (LFT) failure observed in test.

V. CONCLUSION

The double strap GFRP joints were prepared and tested as per ASTM standards to evaluate their butt joint strength. The Taguchi method was used to reduce and optimise the number of experiments. From the above study the following conclusions are drawn.

1) The joint strength of double strap GFRP joints increase with increase in overlap length. The butt joint strength largely depends upon the overlap length variation. The maximum joint strength recorded at overlap length of 80 mm as 19.6532 kN.

2) The other variables such as surface roughness and adhesive layer thickness are less significant for the butt joint strength. The maximum effect of surface roughness and adhesive layer thickness was recorded for 320 G sand paper (level-3) and 0.5 mm (level-1) respectively.

3) Most specimens are fractured suddenly with a slight bursting sound, indicating a brittle, catastrophic failure. Most failure behaviors of the joints show thin layer cohesive failure pattern or the light-fiber tear failure pattern.

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