A Parametric Study of Hybrid (Adhesive and Bolted) Single Lap Joints

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***Abstract*: Hybrid joints are a combination of adhesive bonding and mechanical fastening and are known to combine the advantages of both joint types. In this paper, we evaluate the mechanical behavior of a representative structure consisting of composite material and metal under tensile load. We have considered the properties of both bolted and adhesive joint. And it is believed that the adhesive layer between bolted lap joint results in a two stage failure of the joint. Hence a modified joint is obtained with increased strength. . In the present study, the influence of the base material, bolt geometry, and adhesive on tensile shear strength was assessed.**

Keywords- Hybrid joint, Composite joint, lap joint in automobiles

1. INTRODUCTION

Joint design in the composite structures is a very important consideration because improper design may lead to overweight or defective structures. The joining of composite materials has traditionally been achieved by mechanical fastening or adhesive bonding in this technique the important idea how we can get high ability to load transfer hence composite materials can be two or more than two materials in similar or dissimilar materials the purpose of composite is to get high properties of materials and to improve the ability of load transfer [7]

Adhesive bonding does not require holes and distributes the load over a larger area than mechanical joints; however, adhesive bonding joints are very sensitive to the surface treatment of the material, service temperature, humidity and other environmental conditions.

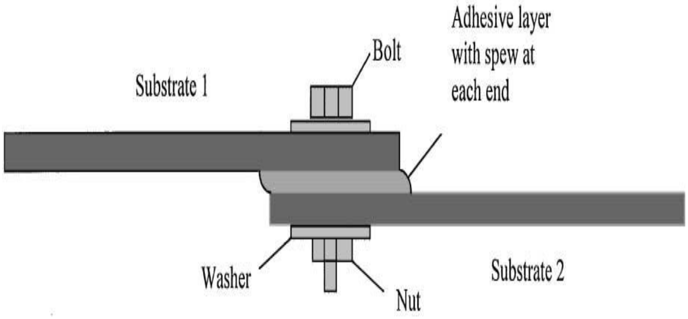


Figure1.1 Sketch of hybrid (adhesive/bolted) joint.

Hybrid joint is a process that makes use of two different joining techniques. They, in principle, bring together the advantages of two different techniques. In hybrid joining two or more joining operations are carried out either simultaneously or sequentially, leading to enhanced properties of the joint. Hybrid joining is used in the assembly of modern light weight automotive and commercial vehicle structures. Combining adhesive bonding with mechanical joining can offer advantages in terms of process ability and load bearing capacity.

Any number of papers can easily be found about mechanical joints that use bolts, rivets, or pins. These papers consider various approaches, including Design of Experiments methodology [4] and the 3-dimensional finite element method [9,10] and/or test [2,5]

We are going to use Bolted joint as mechanical joining and adhesives to prepare a hybrid joint that will be useful for automotive applications. Mechanical Joints (bolted joints) often fails under fatigue loading and adhesive alone often peels off. So, to prevent adhesive peel action we are using adhesives with bolts which in result provide more strength of the joint and avoid failure.

2. LITERATURE REVIEW

M. Lucić [1] investigated aluminum single lap adhesively bonded joints. Maximal strength of joint might be reached if optimal overlap length of joint is applied. The influence of the adherend elastic/plastic behavior is very significant for joint strength. It is important to note that final adherend roughness influenced with joint preparation procedure could affect joint strength.

Patel Vijaykumar V [3] in this paper presents about optimization of the automotive chassis with constraints of maximum shear stress, equivalent stress and deflection of chassis under maximum load.Structural systems like the chassis can be easily analyzed using the finite element techniques.

A.C. Manalo [6] in this paper presents about the behavior of an innovative hybrid Fibre Reinforced Polymer (FRP) composite with bolted joints was investigated. Coupons and full-size specimens were tested to determine the effect of applied bolt torque and the contribution of adhesive bonding on the load capacity and failure mode of the hybrid FRP with bolted joints. The hybrid FRP composite girder with joints connected using bolts and epoxy adhesives exhibited the same strength and stiffness as the girder without joints while bolting alone resulted to a beam with only 65% of the stiffness of those without joints.

A. Barut [8] In his study, a semi-analytical method was developed for the coupled in-plane and bending analysis of composite bonded–bolted single-lap hybrid joints.. The following particular cases were investigated in this study: The joint has no initial defects, no debonding occurs, and all loads are transferred by the adhesive bond, The adhesive bond is partially debonded, resulting in the bolt transferring some of the load.

3. DESIGN OF EXPERIMENTS AND ANOVA

The experimental setup, the machine required for experimentation was STAR TENSILE TESTING MACHINE. The lap joints are prepared. One of the ends of the plate was held fixed and other end subjected to tension loading by the load cell at 5mm/min speed.

Figure 3.1Star Tensile Testing Machine

The following factors are used for experimentation:

1. Base Metal (Aluminium and Composite)
2. Adhesive type (H3151 & E120HP)
3. No of bolts (Single or Double bolted)

A. Number of Observations:

The 2k factorial design is used and there are three independent variables in this experiment. Meaning three variables are varied at 2 levels i.e. low and high. Hence the minimum number of observations are 2^3 i.e. 8.

Parameters	Nomenclature	High(+)	Low(-)
Base Metal	B_M	Al	FRP
Adhesive	A	H3151	E120HP
No of bolts	N_B	2	1

4. EXPERIMENTATION AND DATA COLLECTION

The design is created for an experiment. The data is collected. The experimental factor have some level. For example in the experiment the base metal taken at two levels as mentioned above high abbreviated as '+1' and low abbreviated as '-1'. The runs combined as per the higher and lower levels as shown in the table below :

A. DOE in coded form:

Input Parameters			
Run	Factor 1 (BM)	Factor 2 (A)	Factor 3 (NB)
1	Al(+)	H3151 (+)	SINGLE BOLTED (-)
2	FRP(-)	E120HP (-)	DOUBLE BOLTED (+)
3	Al(+)	E120HP (-)	DOUBLE BOLTED (+)
4	FRP(-)	H3151 (+)	SINGLE BOLTED (-)
5	FRP (-)	E120HP(-)	SINGLE BOLTED (-)
6	Al(+)	H3151(+)	DOUBLE BOLTED (+)
7	Al (+)	E120HP (-)	SINGLE BOLTED (-)
8	FRP (-)	H3151(+)	DOUBLE BOLTED (+)

B. Experimental Results:

Input Parameters				Output Parameters
Run	Factor 1 (BM)	Factor 2 (A)	Factor 3 (NB)	UTS (KN) (P)
1	Al(+)	H3151 (+)	SINGLE BOLTED (-)	47.089
2	FRP(-)	E120HP (-)	DOUBLE BOLTED (+)	11.65
3	Al(+)	E120HP (-)	DOUBLE BOLTED (+)	42.885
4	FRP(-)	H3151 (+)	SINGLE BOLTED (-)	13.79
5	FRP (-)	E120HP(-)	SINGLE BOLTED (-)	8.43
6	Al(+)	H3151(+)	DOUBLE BOLTED (+)	47.079
7	Al (+)	E120HP (-)	SINGLE BOLTED (-)	45.72
8	FRP (-)	H3151(+)	DOUBLE BOLTED (+)	18.48

5. ANALYSIS OF EXPERIMENTS

A. Mean square or variance (MS or V)

Sum of squares when divided degrees of freedom given mean square or variance. Variance is calculated for all the factors as well as interactions and following ANOVA table is formed.

MS = Sum of square / degree of freedom

Sr. No	Factors	Sum of square	Degree of freedom	Variance of mean square
1	B	2126.26	1	2126.26
2	A	39.3961	1	39.3961
3	N	3.2068	1	3.2068
4	BA	5.4896	1	5.4896
5	BN	14.4587	1	14.4587
6	AN	2.3058	1	2.3058
7	BAN	0.2294	1	0.2294

From the above table it can be observed that the value of variance ranges from 0.2294 to 2126.26 .which is very wide range to avoid tedious calculations all sum of squares below 5.4896 can be pooled together to form of square due to error(SS_{error})

Following sources can be pooled together.

N+BA+AN+BAN
=3.2068+5.4869+2.3058+0.2294
Pooled error = 11.2316

Mean square or variance for error can be calculated as.
$MS_{error} = SS_{error}/V_{error}$

= 11.2316/4
=2.8079

These pooled figures are removed from their place in ANOVA table and recorded as error factor at the bottom of ANOVA table.
Various tables with Pooled Error

Sr.No.	Factor	Sum of square	Degree of freedom	Variance of mean square
1	B	2126.26	1	2126.26
2	A	39.3961	1	39.3961
3	BN	14.4587	1	14.4587
4	Pooled error	11.2316	4	2.8079

B. Calculation for F value

Our main aim in this method of analysis is to see if the signal created by the factor is stronger than the background noise (error).the F test is used to compare two variances.

$F_O = SS_A/V_{factor} \div SS_E/V_{error} = MS_{factor}/MS_{error}$

Including this F factor, we form are final ANOVA table as below.

Final ANOVA table

Sr.No.	Factor	Sum of square	Degree of freedom	Variance of mean square	F_O
1	B	2126.26	1	2126.26	757.24
2	A	39.3961	1	39.3961	14.030
3	BN	14.4587	1	14.4587	1.142
4	Pooled error	11.2316	4	2.8079	

Now, in calculation of F ratio,
Degree of freedom for numerator = 1
Degree of freedom for denominator =4

There for consulting F distribution table, for 95% level of confidence we find that F value is $F_{0.05,1,4}$ F limit =7.71 since all the F value in the table are lesser than the limiting value of F ratio.

6. REGRESSION ANALYSIS

In many problems there are two or more variables that are related, and it is of interest to model and explore this relationship. in general, suppose that there is a single dependent variables or response y that depends upon k independent or regression variables, for eg, x1,x2,x3…….Xk.
A mathematical model called a regression model characterizes the relationship between these variable, it is important to express the result of an experiment quantitavely, in terms of an empirical model to facilitate understanding, interpretation, and implementation.
In general, the response variable y may be related to k regressor variable.
The model-
Y= βo + β1x1+ β2x2+………….. βkxk+€…………
Is called a multiple linear regression model with k regressor variable.
The parameters BJ,J = 0,1………..k, are called the regression coefficient. this model describes a hyper plane in the k dimensional space regressor variables (xj).the parameter bj represent the expected changing in response y per unit change in xj when all the remaining independent variables xi(I ≠J)are held constant.

A. Multiple line regression model

For the current problem the regression model is in the form

Y = βo + β1x1+ β2x2+ β3x1x2

Where x1,x2 are the factors A,C respectively,x1x2 represent the interaction between A and C.

B. Calculation of coefficient

In coded form of the equation, coefficient βo = the avg values of response value.

$$\beta o = \sum^{N} yi/N$$

i=1

therefore $\beta_o = 235.123 / 8$
$= 29.3903$

Other coefficients can be calculated by using the effect estimates for corresponding factors interaction.

The effect of particular factor is the difference between the average values of response at the high and low setting of the factor.

i.e. Effect of factor B = $\bar{y}_{B+} -= \bar{y}_{B-}$

= (182.773) / 4 – (52.35) / 4

= 45.6932-13.0875

= 32.6057

C. Effect estimation

Final ANNOVA table

Remark	Factor /Interaction	Effect estimate	Sum of square	Percentage contribution
Model	B	32.6057	2126.26	97.0298
Model	A	4.4382	39.3961	1.7978
Model	BN	-2.6887	14.4587	0.6598
Error	N	1.2663	3.2068	0.1463
Error	BA	-1.6567	5.4896	0.2505
Error	AN	1.0737	2.3058	0.1052
Error	BAN	0.3387	0.2294	0.0104
			∑= 2191.3464	

Percentage contribution for B = (2126.26/2191.3464)*100

= 97.0298

Now the regression coefficient is exactly one half of the usual effect this is always true for a 2k design. Hence the regression coefficient in equation
can be calculated as below:

$\beta 1$ = ½ (effect estimate for factor B) = 32.6057 / 2
= 16.3028

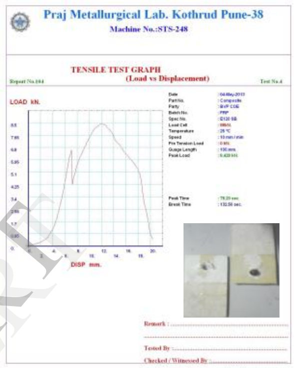
β 2= ½ (effect estimate for factor A) = 4.4382 / 2
= 2.2191

β 3 = ½ (effect estimate for factor BN) = - 2.6887/ 2
= - 1.3443

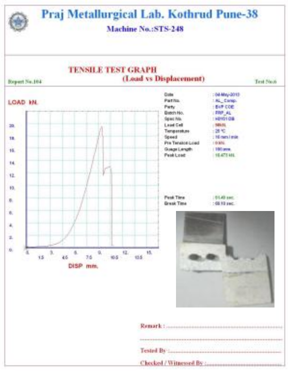
7. RESULTS AND DISCUSSION

Single Lap Joint 1

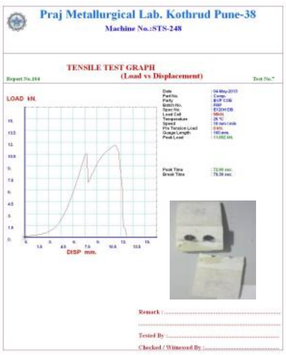
Single Lap Joint 2



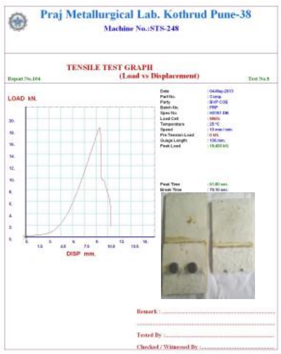
Single Lap Joint 3



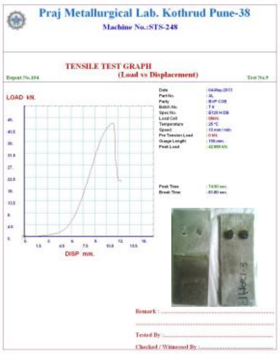
Single Lap Joint 4

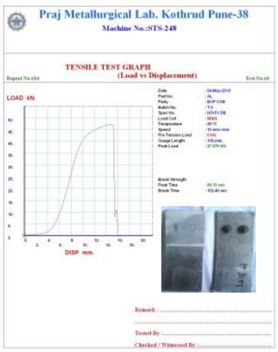


Single Lap Joint 5

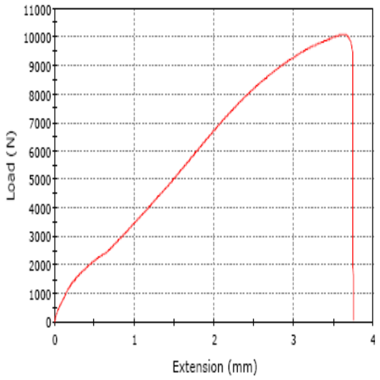


Single Lap Joint 6



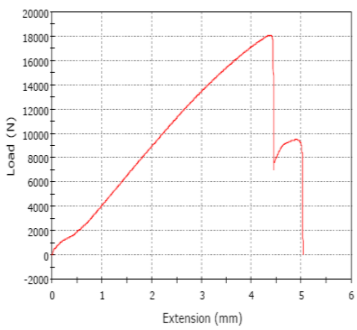


Single Lap Joint 7 Single Lap Joint 8



Aluminium Single Bolted Lap Joint

Result Table (Tensile Testing) Load Cell: 50kn			
Maximum Load (KN)	Extension at Break (mm)	Load at Break (N)	Tensile stress (N/mm^2)
10.09617	3.74561	9350.61723	4.03847



Aluminium Double Bolted Lap Joint

Result Table (Tensile Testing) Load Cell: 50kn			
Maximum Load (KN)	Extension at Break (mm)	Load at Break (N)	Tensile stress (N/mm^2)
18.09946	5.03029	7864.27408	7.23978

9. CONCLUSIONS

This dissertation work entitled 'A Parametric Study of Hybrid (Adhesive and Bolted) Single Lap Joints' taking input parameters as Base Metal (Aluminium and Composite), Adhesives (H3151 & E120HP) , Number of bolts (Single or Double bolted) & output parameter as Ultimate tensile strength (UTS) of hybrid joints.
Following facts can be concluded:-

Final equation in terms of coded forms:

Peak Load = 29.3903 + 16.3028×B + 2.2191×A - 1.3443×BN

1. If we used base metal as Aluminium and Composite (FRP), then Ultimate tensile strength of hybrid joint is increases (97.02%)
2. If we used adhesive as H3151 and E120HP, then the UTS of hybrid joints increases (1.79%)
3. Number of bolts also has less effect on UTS (0.14%),
4. The strength of a hybrid joint is significantly greater than that of simple bolted joints.

10. REFERENCES

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