ISSN: 2278 – 7798
International Journal of Science, Engineering and Technology Research (IJSETR)
Volume 5, Issue 6, June 2016

Load Distribution in Hybrid (Adhesive & Bolted) Joint

Shashikant Dashore, Mr. M. J. Patil, Dr. B. B. Ahuja

Abstract— **Hybrid joint are widely used in automotive and aerospace industries for various structural application. The feasibility and reliability of this system dependent on design of the joints and their type. Adhesive and Bolt joint technology is demanding research area now days. To reduce the weight of structures and enhance the load bearing capacity of joint with respect to the traditional joint composite joints can be used. New methodology for testing the hybrid joint is setup and the results are being validated with the Numerical analysis. The experiment are conducted by using the Taguchi function, 3 Level and 7 Factor i.e. Bolt size, Clearance bolt, Bolt tightening torque, Adhesive type, Adhesive thickness, overlapping length and Material of joint are used. Total of 27 such joint samples is tested as per ASTM D5968 standard to obtain the strength of Hybrid joint and Load distribution. The load distribution on the hybrid joints are evaluated by the tensile test where the joint strength is calculated from the ultimate limit of material. ANOVA is used to evaluate the contribution by each factor and best combination is found. Best combination achieved from the ANOVA is $A_3B_3C_2D_1E_3F_2G_2$; the confirmation test was performed and compared with the best combination results. The test results are also validated with the Numerical analysis using Finite Element analysis. The results obtained from the FE analysis are in good agreement with the experimental result.**

Index Terms—**ANOVA, FEA, Taguchi method, Hybrid joint, GFRP.**

I. INTRODUCTION

Hybrid joints are effective in enhancing the ability of joints to sustain maxium load. Applying the pressure bonding along with the mechanical joining by means of bolt improve the ability of any joint and also the load bearing capacity improves when high dynamic load appear on joint. In this work, focus is given to investigate the effect of the combination of Bolted and Adhesive joints.

Park, Jin-Ha [1], study on failure strength evaluation of hybrid composite joint. Author used double lap joint for tensile test; they have design the joint specimen with different width and depth. P. K. Mallick P [2], studies on the fatigue performance of the hybrid joint. Author has shown that the hybrid joint is having the higher failure load and last longer in fatigue life. Gordon K [3], studied on the load transfer in hybrid composite single lap joint. Author said that the load transfer is complicated due to stiffness difference in the load path.

Hart Smith [4] performed a theoretical study on the hybrid joint i.e. combination of bolted and bonded joint. This is performed between the titanium and carbon fiber, author has found no improvement in strength as compared to the perfectly bonded joint

Automobile weight can be reducing which will ultimately improve the fuel efficiency by implementing the hybrid joint. This is done without losing the structural strength. Apart from offering advantages it also offer reluctance if implemented with the limited awareness. This technique of joining is not as simple as of welding riveting and bolted joints, it need precise work to be done on the joints.

Manuscript received June, 2016.

Shashikant Dashore, P.G Students, Department of mechanical Engineering, Bharati Vidyapeeth College of Engineering Pune, India Phone/ Mobile No 8482840632.

Mr. M. J. Patil, Assoc. Professor, Department of Production Engineering, Bharati Vidyapeeth College of Engineering Pune, India. Phone/ Mobile No9890226638,

Dr. B. B. Ahuja, Director and Professor, Government College of Engineering Pune, India.

II. METHODOLOGY

A. Experimentation

Plates are glued using the adhesive of different type. The test is performed as per ASTM D 5686 standard, the design specifications of the Composite Hybrid (Adhesive & Bolted) joints Configuration of plates according to ASTM D 5686Standards are as following

- Length of the adherends-130mm;
- Width of the adherends-25.4mm;
- Thickness of the adherends-3.mm;
- Overlapping Length is Different i.e. 20mm, 25mm and 30mm.

Detailing of the hybrid joint is shown in Figure 1 and test setup is shown in Figure 2.

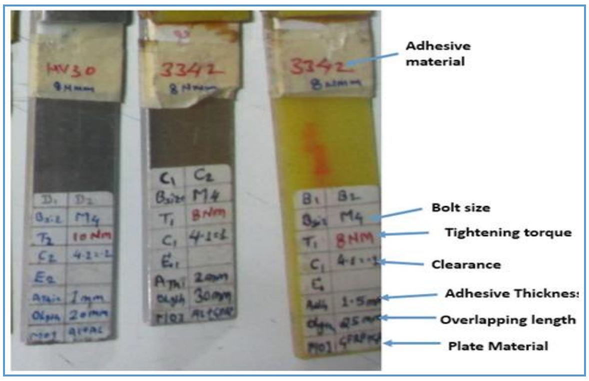

Figure 1: Detailing on the hybrid joint

Figure 2: Test Setup (GFRP + AL)

B. *Taguchi Method*

Using functional method 2187 combination is arrived and testing of this much combination is unrealistic for the experimentation and costly affair. Hence this method is obsolete method and alternative method is Taguchi method. In this work Taguchi method is used to identify the factors and sublevels which are the Adhesive type, bolt clearance, Bolt size, Tightening torque, Adhesive thickness and overlapping length as parameter which affect the response and gives the best combination among all tested specimens. The experiment is having three levels and seven factors. The factors are Bolt Size core series with 8.8 grad, Bolt Tightening Torques, Bolt Hole Clearance, Adhesive Types, Adhesive Thickness, Overlapping Length, and Material for Joint. Total of 3 levels are define for each factor which are -1, 0 and +1. This means each factor will go one grade higher and lower. Detail of all the factor and level are define and tabulated in Table 1. Similarly the load or responses at first and second breaking point are tabulated in

Table 2.

Table 1: Factor and Level Combination

Factors	Levels		
	-1	0	1
Bolt size	M4	M5	M6
Bolt Tightening torque [N-m]	8	10	12
Bolt Hole Clearance	0.1	0.2	0.3
Adhesive Types	E1	E2	E3
Adhesive Thickness [mm]	1	1.5	2
Overlapping Length [mm]	20	25	30
Material For Joint	AL + AL	GFRP + GFRP	AL + GFRP

Table 2: Result Table

Factor	Response 1 [KN]	Response 2 [KN]	Total Response	Mean	S/N Ratio
T1	7.29	7.30	14.59	7.30	17.26
T2	4.15	4.16	8.30	4.15	12.36
T3	4.89`	4.90	9.79	4.90	13.80
T4	6.78	6.80	13.58	6.79	16.64
T5	3.30	3.31	6.62	3.31	10.39
T6	3.92	3.93	7.85	3.93	11.88
T7	7.16	7.18	14.34	7.17	17.11
T8	3.83	3.85	7.68	3.84	11.68
T9	4.94	4.95	9.89	4.94	13.88
T10	5.24	5.26	10.50	5.25	14.40
T11	11.15	11.17	22.32	11.16	20.95
T12	3.72	3.74	7.46	3.73	11.44
T13	5.66	5.67	11.34	5.67	15.07
T14	11.46	11.47	22.92	11.46	21.19
T15	3.79	3.81	7.60	3.80	11.59
T16	5.56	5.57	11.13	5.56	14.91
T17	10.23	10.24	20.47	10.24	20.20
T18	4.52	4.53	9.05	4.52	13.11
T19	5.11	5.12	10.23	5.11	14.17
T20	5.20	5.22	10.42	5.21	14.34
T21	9.07	9.08	18.14	9.07	19.15
T22	5.18	5.20	10.38	5.19	14.30
T23	4.66	4.67	9.32	4.66	13.37
T24	10.66	10.68	21.34	10.67	20.56
T25	5.89	5.90	11.79	5.89	15.41
T26	6.62	6.64	13.26	6.63	16.43
T27	11.71	11.73	23.44	11.7	21.38

A. *Mean Change in Strength*

$$\sum A_1 = 14.5924 + 8.3028 + .. + 7.6786 + 9.8884 = 92.6436$$

$$\sum A_2 = 10.498 + 22.3188.. + 20.4724 + 9.0476 = 122.79$$

$$\sum A_3 = 10.2256 + 10.4226 + .. + 13.2616 + 23.436 = 128.31$$

---(1)

Dividing ΣA1, ΣA2 and ΣA3 by 7 x 2 (i.e. seven factor and 2 repetition), mean change in load under conditions of A1, A2 and A3

A1=92.6436/14 = 6.6174

A2=122.79/14=8.77

A3=128.319/14=9.16

S/N Ratio

S/N Ratio = $-10\log_{10}(\frac{1}{n}\sum\frac{1}{y_i^2})$ ----(2)

S/N Ratio T1 =

$$-10\log_{10}(\frac{1}{2}\sum\frac{1}{7.2912^2} + \frac{1}{7.3012^2})=17.26193$$

Similarly T2 to T27 is calculated. S/N ratio for A1 is calculated using following equation. S/N ratio for A1 = (17.26193+12.36386+…+13.88191)/14=13.88982. Similarly S/N ration for A2, A3, B1, B2, B3,C1,C2,C3,D1,D2,D3,E1,E2,E3,F1,F2,F3,G1,G2 and G3 is calculated. Detail of all parameter is tabulated in Table 3.

Table 3: Result Table

Factor	Total Result	Mean Change	S/N Ratio
∑A1	92.64	6.62	13.89
∑A2	122.79	8.77	15.87
∑A3	128.32	9.17	16.57
∑B1	111.76	7.98	15.32
∑B2	110.95	7.93	15.00
∑B3	121.04	8.65	16.01
∑C1	114.38	8.17	15.54
∑C2	116.81	8.34	15.44
∑C3	112.56	8.04	15.35
∑D1	123.04	8.79	16.05
∑D2	107.48	7.68	14.98
∑D3	113.23	8.09	15.30
∑E1	107.87	7.71	15.48
∑E2	121.32	8.67	15.66
∑E3	114.56	8.18	15.20
∑F1	99.63	7.12	14.59
∑F2	118.48	8.46	15.55
∑F3	125.65	8.97	16.20
∑G1	171.14	12.22	19.38
∑G2	79.10	5.65	21.35
∑G3	93.51	6.68	14.23

C. FE methodology

All the plates are meshed with the hexahedral and pentahedral element, these are the 3D elements of Finite element. Bolt connection are modeled as 1D beam and connected to the plate using the spider connection. The bolts are assigned with appropriate bolt diameter and standard structural steel is considered for the analysis. The detail meshed model of hybrid joint is shown in Figure 3.

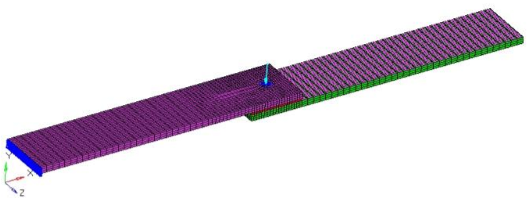

Figure 3: FE Mesh model

The contact elements are defined between the plates and glue material to transfer the load. Detail contact element is shown in Figure 4. Rectangular contact elements are defined which define the segment to segment contact between the plates and glue material.

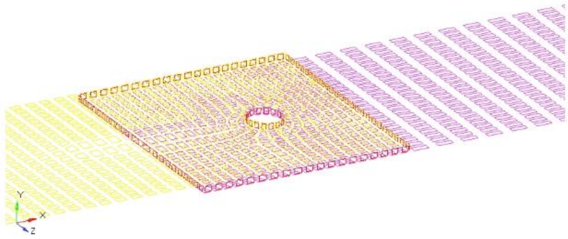

Figure 4: FE Contact modeling

Breaking load from the test data are applied on the end of plate. Load applied is the second breaking load from the test at which the bolts fail. Detail of the load applied in end of plate is shown in Figure 5. Preload load as per the sub levels are applied as shown in Figure 6.

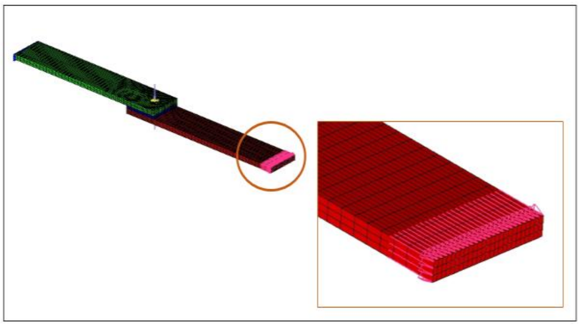

Figure 5: Breaking load at end of plate

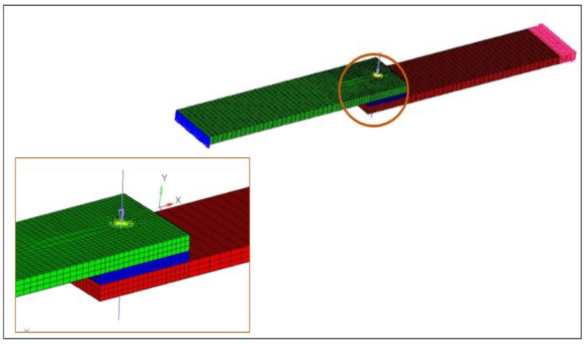

Figure 6: Applied preload

Other end of plate is constraint in all DOF i.e. X, Y and Z direction is constraint. Only translation DOF is constraint as solid elements have only 3 DOF at single node. Detail of the boundary condition for the FE analysis is shown in Figure 7.

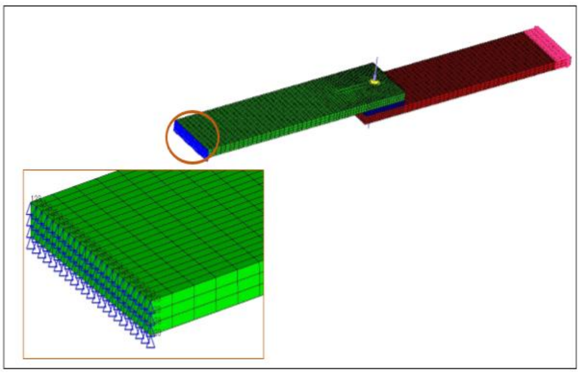

Figure 7: Boundary condition

ISSN: 2278 – 7798
International Journal of Science, Engineering and Technology Research (IJSETR)
Volume 5, Issue 6, June 2016

III. Result and Discussion

A. Analysis of Variance (ANOVA)

Overall Mean = $\bar{Y} = \dfrac{\sum\sum y_{ij}}{n_T}$ --- (3)

$$\bar{Y} = \frac{(14.5924 + 8.3028 + ... + 23.436)}{54} = 6.3658$$

Total Sum of Square (SSTO)

$$SSTO = \sum\sum (y_{ij} - \bar{Y})^2$$ ---- (4)

SSTO = 361.47

DOF = 53

Treatment of Sum of Square

SSTR $= \sum n_j (y_j - \bar{Y})^2$ ----- (5)

SSTRA = 16.56891

Similarly SSTRB=20.6256, SSTRC=20.56289, SSTRD = 65.2846, SSTRE=42.5698, SSTRF =52.45896 and SSTRG = 139.7405

Sum of All SSTR = SSTRA+ SSTRB+ SSTRC+ SSTRD+ SSTRE+ SSTRF+ SSTRG = 357.8114

DOF = 26

Error sum of square = SSE

$$= \sum_j [\sum_j (y_{ij} - \bar{Y}_j)^2]$$ ------ (6)

SSE = 3.649

DOF = 27

SSTO = SSTR + SSE --- (7)

SSTO = 357.8114 + 3.649

SSTO = 361.46 (verified)

Mean Change

MS = SS/DOF

Treatment mean square

MSTR = SSTR/26

MSTR = 357.8114/26

MSTR = 13.7619769

Error mean square = MSE = SSE/n

MSE = 3.649/27

MSE = 0.13514815

Variance (V) = Sum of squares/ DOF

VA= SSTRA/2

VA = 16.5691/2

VA = 8.284455

F = Mean square of factor/error mean square

FA = MSA/MSE = VA/MSE

FA = 8.28455/0.13514815

FA = 61.2990633

%p = Sum of square/Total sum of square

%pa= SSTRA/SSTO * 100

= (16.56891/361.46)*100 = 4.583882

F227(95%) = 3.35

F227(99%) = 5.49

ve = SSE/fe2

ve = 3.649/27

ve = 0.13514815

$$ne = \frac{Numbers\ of\ all\ measurement\ values}{No.\ of\ DOF\ for\ factor + No.\ of\ DOF\ for\ mean\ value}$$

ne= 54/(2+6)

ne = 9

$$95\%C.I. = \pm\sqrt{3.35 * \frac{0.13514815}{9}} = \pm 0.05030514$$

$$99\%C.I = \pm\sqrt{5.49 * \frac{0.1354815}{9}} = \pm 0.08244037$$

(Design of Experiment by Douglus Montgomery)

From the figure of main effect plot, the optimum factor of combination is $A_3B_3C_2D_1E_3F_2G_2$.

$$\mu = (A_3 - \bar{Y}) + (B_3 - \bar{Y}) + (C_2 - \bar{Y}) + (D_1 - \bar{Y}) + (E_3 - \bar{Y}) + (F_2 - \bar{Y}) + (G_2 - \bar{Y}) + \bar{Y}$$

$$\mu = A_3 + B_3 + C_2 + D_1 + E_3 + F_2 + G_2 - 6\bar{Y}$$

μ = 9.17+8.65+8.34+8.79+8.18+8.46+5.65-6x6.3658

μ = 19.0452 KN

$$X = \mu \pm \sqrt{F_{27}^2 (95\%) * V_e * (\frac{1}{n_e} + 1)}$$

ne takes the follow value

$$\frac{1}{n_e} = \frac{1(for\bar{Y}) + 1(forA) + 1(forB) + 1(forC) + 1(forD) + 1(forE) + 1(forF) + 1(forG)}{54} = \frac{8}{54}$$

$$X = 19.0452 \pm \sqrt{3.35 * 0.13514815 * (\frac{8}{54} + 1)}$$

$$X = 19.0452 \pm 0.72098532$$

The graph has been plotted for mean change for all the factors. Detail of the graph is shown in Figure 8 and Figure 9 respectively.

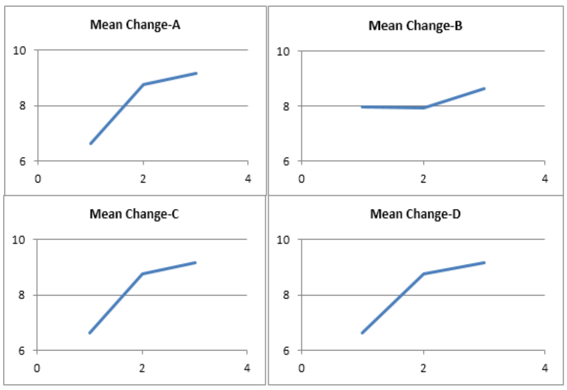

Figure 8: Mean Change for Factor A, B, C and D

ISSN: 2278 – 7798
International Journal of Science, Engineering and Technology Research (IJSETR)
Volume 5, Issue 6, June 2016

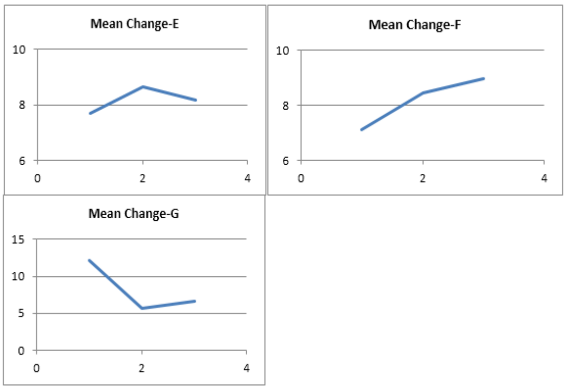

Figure 9: Mean Change for Factor E, F and G

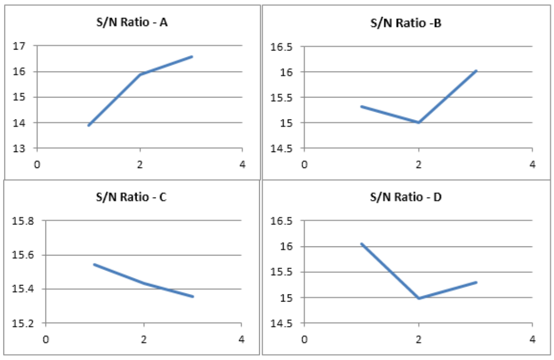

Figure 10: S/N ratio for Factor A, B, C and D

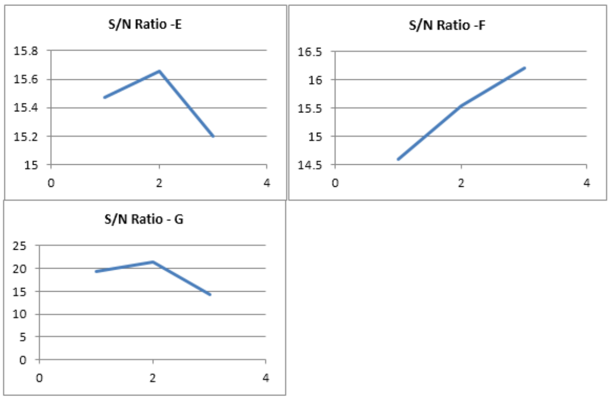

Figure 11: S/N Ratio for Factor E, F and G

From the ANOVA table, The best combination of factor is A3B3C2D1E3F2G2 i.e. A3 is a hybrid joint having bolt of diameter 6 mm, B3 is a applied tightening torque of 12 N-m, C2 is clearance of 0.2mm in bolt hole, D1 is adhesive of 3342 type whereas E3 is adhesive thickness of 2mm, F2 is bonding overlapping length of 25 mm and G2 is plate material type which is Aluminum and GFRP. This combination is the best joint among all tested joint. This particular combination may not be available in our 27 factors and testing all the factor is costly and laborious work. Hence the % of participation is calculated for each factor considered. From all the factor most contributing factor is Al + GFRP which is 39.3%, next higher contributing factor is adhesive type of Loctite AA 3342 which is 18.37%, other higher contributing factor is overlapping length of 25mm which is 14.7%. Remaining four factors are participating less than 10% or 5%. Hence factors which are contributing total of 80% is consider to be best, Factor T13 is having all parameter which are fitting in 80% criterion.

B. *Experimental result*

From the test it is observed that T13 factor is sharing the maximum load by plates and 0% load is transferred to the bolt i.e. the rupture of the material is occurred at the same point where the rupture of plate material occurred. Total load shared by T13 factor is 7477 N whereas the load sharing by other plate material keeping all factor constant are less than 7477 N. Detail of the load-displacement curve of T13 factor is shown in Figure 12.

First point represents the failure of glue material and second point corresponds to failure of the bolt. Detail of breaking load for 1st and 2nd point is tabulated in Table 4. In most of the factor second breaking load is higher than the first breaking load, but there are few factors where the 2nd breaking load is below the first breaking load or same as 1st breaking load. This represent glue member is taking the entire load and failing before the bolt failure.

Table 4: Experimental Result Table

Factor	Breaking Load		Breaking Strength [MPa]
	1st Peak	2nd Peak	
T1	6428.8	7291.20	14.73
T2	4174.8	4145.40	6.71
T3	4890.2	---	6.53
T4	6781.6	---	13.72
T5	3302.6	---	5.31
T6	3920.0	---	5.24
T7	3488.8	7163.80	14.50
T8	2440.2	3831.80	6.17
T9	2587.2	4939.20	6.60
T10	1852.2	5243.00	8.54
T11	2665.6	11152.4	14.75
T12	2116.8	3724.00	7.65
T13	7477.4	5664.40	12.19
T14	5507.6	11456.2	15.48
T15	3998.4	3792.60	8.22
T16	5556.6	---	9.04
T17	2744.0	10231.20	13.79
T18	4517.8	---	9.26
T19	4429.6	5105.80	6.98
T20	5203.8	---	10.91
T21	1754.2	9065.00	15.01
T22	2940.0	5184.20	7.07
T23	3831.8	4655.00	9.72
T24	3978.8	10662.40	17.60
T25	4939.2	5889.80	8.04
T26	6624.8	---	13.86
T27	11711.0	---	19.36

This type of joints is recommended in the automation and aviation industry such that glue material fails before failure of bolted joint. Detail of breaking image for joint T13 is shown in Figure 13. From the failure images it is observed that all the crack are generated near the bolt location in overlapping length. The best combination joint having factors of A3B3C2D1E3F2G2 is tested again and breaking strength is calculated which is 8492 N as compared to 7477 N the best available in the ANOVA list. After testing this particular factor load carrying capacity is increased by 13% as compared to best combination available from ANOVA.

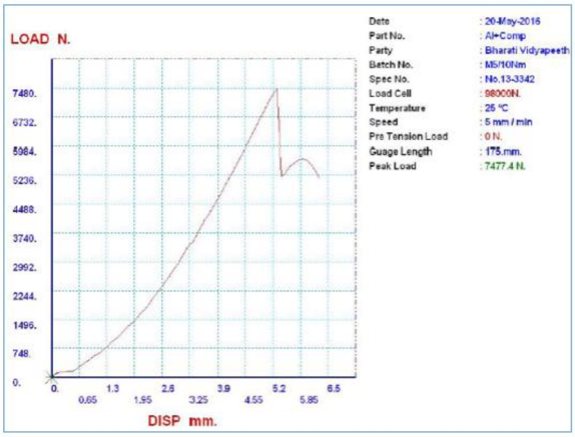

Figure 12: Test Result – Factor 13

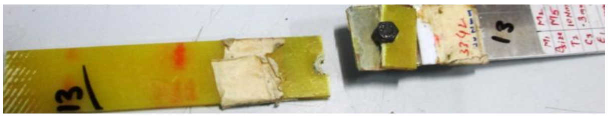

Figure 13: Breaking of Factor 13 joint

C. FEA result

In test % of load share by bolt is 1812 N i.e. 32.0 % of total load applied which is 5664 N. Whereas in FEA analysis the load on bolt is 1791 N which is nearly equal to 31.6 %. Detail result of the Factor 13 is shown in Figure 14.

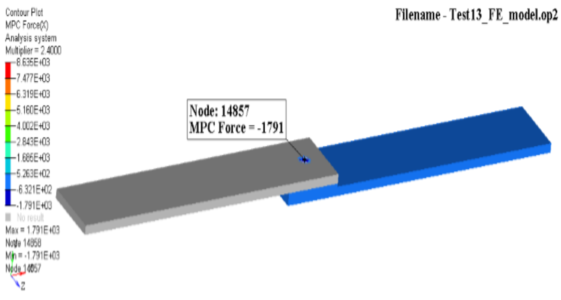

Figure 14: Bolt Load- Factor 13

Similarly the FE analysis is performed for the Factor 2, 8, 16, 24 and 27 and compared with the experimental results. To evaluate the best joint, Pulling load of 5000 N is applied in all the joint to evaluate their efficiency, other parameter are kept as per the test of individual joint. From the plot as shown in Figure 15, it is observed that the Al + Glass Fibre material is having less stress as compare to the Glass fibre + Glass fibre and Al + Al. Stress at contact region to be observed for evaluating the strong joint. Stresses in the overlapping region indicate the joint resistance. Joint with high stresses show strong resistance and will rupture at lesser load as compared to the Al + GFRP combination.

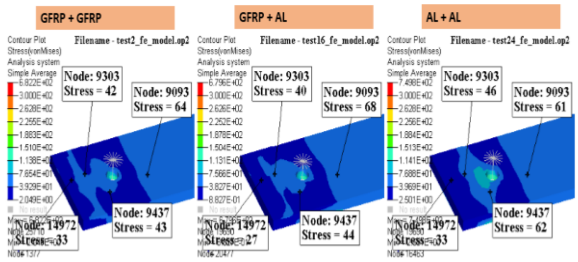

Figure 15: Joint strength comparison

D. Validation

Test results are compared with the Finite element result. Detail correlation between the test result and FE result is shown in Table 5. Deviation between the test result and FE result is calculated as difference. From the comparison, it is observed that the test results are in good agreement with the FE result. Maximum deviation of 0.62% is observed in the bolt load distribution, this deviation is very less and hence results are validated with the FE results. Joint strength of AL+ GFRP is greater as compared to the similar adherent material is also validated with the FE analysis.

Table 5 : Result correlation

Factor	Breaking Load [N]	FE Result	Test Result	Deviation [%]
		Bolt load [N]		
T2	4174	55	29	0.6
T8	3831	1382	1391	0.2
T13	5664	1791	1812	0.3
T16	5556	7	0	0.1
T24	10662	6670	6683	0.1
T27	11711	20	0	0.1

IV. CONCLUSIONS

Total of 27 factors are analyzed which are calculated as per Taguchi method. All the test samples are tested using the experimentation and load displacement curve has been extracted. The best combination of factor is calculated from the ANOVA, and the best combination is $A_3B_3C_2D_1E_3F_2G_2$ i.e. hybrid joint having bolt of diameter 6mm with applied tightening torque of 12 N-m, clearance of 0.2mm in bolt, adhesive of 3342 type with thickness of 2mm and having bonding overlapping length of 25 mm and plate material type Aluminium and GFRP is the best joint among all tested joint. This particular specification may not be available in our 27 factors as testing all the factor is costly and laborious work. Hence the % of participation is calculated for each factor considered. From all the factor most contributing factor is Al + GFRP which is 39.3%, next higher contributing factor is adhesive type of Loctite AA 3342 which is 18.37%, other higher contributing factor is overlapping length of 25mm which is 14.7%. Remaining four factors are participating less than 10% or 5%. Hence factors which are contributing total of 80% is consider to be best, Factor T13 is having all parameter which are fitting in 80% criterion. From the test it is observed that T13 factor is sharing the maximum load by plates and 0% load is transferred to the bolt i.e. the rupture of the material is occurred at the same point where the rupture of plate material occurred. Total load shared by T13 factor is 7477 N whereas the load sharing by other plate material keeping all factors constant is less than 7477 N.

Validation of the ANOVA and experimental result are also validated with the FE result. From the FE result it is also observed the load share by bolt is near to 0% at breaking load. From the comparison of different material type it is observed that stresses are less than the other type of joint. To verify the strongest joint constant load of 5 KN is applied and stresses are observed. Stresses in the overlapping region indicate the joint resistance. Joint with high stresses show strong resistance and will rupture at lesser load as compared to the Al + GFRP combination. Deviation between the test result and FE result is calculated as difference. From the comparison, it is observed that the test result is closely matching with the FE result. Maximum deviation of 0.62% is observed in the bolt load distribution, this deviation is very less and hence result are validated with the FE results

The best combination joint having factors of A3B3C2D1E3F2G2 is tested again and breaking strength is calculated which is 8492 N as compared to 7477 N the best available in the ANOVA list. After testing this particular factor load carrying capacity is increased by 13% as compared to best combination available from ANOVA.

The result from the parametric study is summarized as follows

- ❖ Load capacity of joint increases with increase in bolt dimension as larger bolt are having larger shear area
- ❖ Load capacity of joint increases with increase in adhesive thickness which result in less shear and peel stresses. However it is also observed that due to increasing the thickness of the adhesive, peel stresses near the bolt area remain unchanged and hence the crack may occur at same load as compared to the less thickened adhesive joint
- ❖ Load capacity of joint decreases with increase in overlapping length which seems opposite to physics but reason for dropping in the load capacity is shear stress in the area reduces which is obvious and hence the less load being transferred to the bolt due to less relative displacement between the plates. Increasing the load from 20mm to 30mm is
- ❖ Load capacity of joint decreases with the increasing bolt holes clearances as it allow the relative displacement between the bolt and hole which further reduce the capacity of joint. Press fit is always be the strong joint as it won't allow the any relative movement
- ❖ Load capacity of single component adhesive is greater than the mixing adhesive. Hence joint with adhesive 3342 is better load capacity as compared to the other two adhesive used.

References

[1] Jin-Ha. Park, Kang-Woo. Joeng, and Jin-Ho. Choi (2010). A Study On Failure Strength Evaluation Of Hybrid Composite Joint, Department of Mechanical Engineering, Research Center for Aircraft Parts Technology, Gyeongsang National University, South Korea. Vol. 23, No. 5, pp 123-149.

[2] M. Fu and P. K. Mallick, Fatigue of hybrid(adhesive/bolted) joints in SRIM. International Journal of Adhesion and Adhesives Vol. 21, No. 2, pp 145-159, 2001.

[3] Kelly G, Load transfer in hybrid (bonded/bolted) composite single-lap joints. Department of Aeronautical and Vehicle Engineering, Kungl Tekniska H€ogskolan, S-100, 44 Stockholm, Vol. 63, pp 35-43, 2005.

[4] Hart-Smith LJ. Bonded-bolted composite joints. J Aircraft 1985;22(11):993–1000.

[5] Chan WS, Vedhagiri S. Analysis of composite bolted/bonded joints used in repairing. J Compos Mater 2001;35 (12):1045–61.

[6] Ghanbari E, Sayman O, Mustafa O. Failure Load of Composite Single-Lap Bolting Joint Under Traction Force and Bending Moment. Dokuz Eylül University, Turkey. 6(9): 683-692, 2012.

[7] Yogesh T. L., Arunkumar N. Failure Mode and Analysis of the Bonded/bolted Joints between a Hybrid Fibre Reinforced Polymer and Aluminium Alloy. Department of Mechanical Engineering St. Joseph's College Of Engineering, Chennai, India. Vol.3, No. 2, 2015, 49-60.

[8] Oskouei R. H., Keikhosravy M, Soutis C. A finite element stress analysis of aircraft bolted joints loaded in tension. Department of Mechanical and Aerospace Engineering, Monash University, Melbourne, Australia. VOLUME 114 NO 1156, 2010.

[9] Chakherlou T. N., Mirzajanzadeh M, Vogwell J. Experimental and numerical investigations into the effect of an interference fit on the fatigue life of double shear lap joints. Department of Mechanical Engineering, University of Bath, UK. 16 (2009) 2066–2080.

[10] Jin-Hwe Kweon, Jae-Woo Jung, Tae-Hwan Kim. Failure of carbon composite-to-aluminum joints with combined mechanical fastening and adhesive bonding. School of Mechanical and Aerospace Engineering, Gyeongnam, Republic of Korea. 75 (2006) 192–198.

Shashikant Dashore M.tech 2ndyear (Mechanical Engineering CAD/CAM) Bharati Vidyapeeth Universitycollege of engineering Pune India. He has published two paper international Journals. His area of Interest is Design in CAD/CAM.

Mr. M. J. Patil Assoc. Professor, Department of Production Engineering, Bharati Vidyapeeth College of Engineering Pune, India. He has 12 years ofteaching experience in the collegelevel engineering education since2003. He has published Three papers, international Journals, Two national journalHisarea of Interest is Advanced Manufacturing Processes.

Dr. B. B. Ahuja Director and Professor, Government College of Engineering Pune, India.