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ModalAnalysis of optimization techniques of adhesively bonded Aluminum and CFRPComposites

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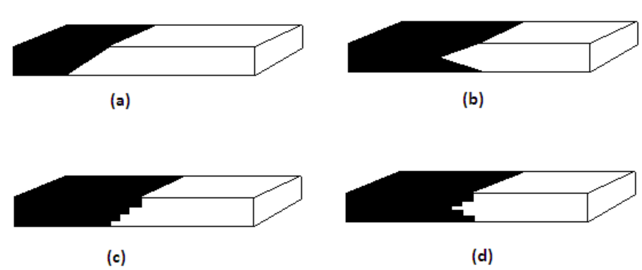
Abstract— Adhesive bonding is preferred joining technique over welding and mechanical fastening method because of its light weight and high strength characteristics. In aerospace applications, adhesive bonding is highly incorporated in FMLs (Fiber Metal Laminate). These FMLs usually fails under peel and shear stresses. In this research work, Adhesive lap joint between aluminum and CFRP is optimized through two different joint designs to find out the most effective and suitable joint design to avoid shear and peel stresses and hence to reduce the failure of adhesively bonded parts. Carbon fiber and aluminum are the structural component in most of the aircraft applications. So in this research project adhesive bonding between CFRP/Aluminum is optimized by two methods i.e. introduction of fillets and introduction of step configuration in standard lap joint configuration. Modal analysis in Ansys workbench is carried out to find out the most effective technique among the two proposed configurations that reduces the shear and peel stresses and hence minimizes the failures

Index Terms—Adhesive bonding, CFRP (carbon Fiber Reinforced Plastics), FMLs (Fiber Metal Laminate), Shear Stress, Peel Stress

1. INTRODUCTION

Past three decades, there has been search for materials that can replace the traditional aluminum and its alloys in aerospace structures[1]. For an optimal structural design, a material must have low density, high strength, high elastic modulus, improved toughness, corrosion resistance and fatigue resistant properties. Fiber reinforced composites materials almost envelop all these demands, except for fracture toughness that is presently overcome by the introduction of FMLs (Fiber Metal Laminates). Fiber Metal Laminates have great use in most commonly aerospace applications. FMLs are metal and fiber composites that are joined through adhesive bonding. Now companies are replacing the traditional aluminum components by FML composites[2]. Both ARALL and GLARE laminates are now being incorporated as structural materials in aircrafts. FMLs have been successfully introduced in building the structural components of the Airbus A380 [3]. CARALL is produced similar to ARALL and GLARE laminates. The combination of high stiffness and strength with good impact properties gives CARALL laminates a great advantage for space applications. Other applications for these laminates are impact absorbers for helicopter struts and aircraft seats [4].In literature various methods have been proposed to reduce the shear and peelstresses in FMLs. As the bond strength is a function of joint design, overlap length, introduction of spews, variation in bond thickness and composition of adhesives. Altering one parameter can significantly improve the properties of lap joint. In these FMLs a wide variety of combinations are possible when joining different materials such as metal to composites. The assemblies mostly used are single lap joint and double lap joint configurations. The more advanced forms of the lap joints are scarf and stepped joints as shown in Figure 1.These configurations are usually designed to reduce shear and peel stresses. The stress distribution at the ends of overlap is found to be non-uniform. Since the lap joint is not collinear, so due to non-uniform stress distribution of stress around the joint, a moment is generated to peel off the bond and these peeling stresses result in cohesive failure [5]. In order to minimize the failures one of the methods is the alteration in joint length. As the length varies the stresses varies across the overlap length. The shear stress is a minimum for the overlap length of 30mm while it is maximum when the overlap length is 10mm.Similarly, with a higher shear modulus the load transferrate is considerably greater. Therefore, high rate of load transfer causes a concentration of load at the joint end that induces problems.

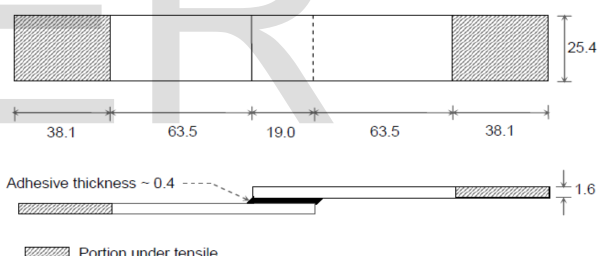
Fig.1.Various Configuration of Lap Joint (a) scarf configuration, (b) Double scarf configuration, (c) Step Configuration, (d) Double step configuration.



Such problems ultimately lead to a failure at the joint end.

However, stiffness losses in the adhesive do have an advantage, but a corresponding loss of strength will also be evident [6]. To optimize the adhesive lap joints, Belingardiet al. [7]Investigated the effects introduced by the joint geometry, namely the spew shoulders connecting the unloaded ends of the adherends and of chamfers at the ends of the adherends, on the stress field of a steel/fiber reinforced plastic single lap joints. In order to optimize the design, introduction of the geometrical configurationminimizes the stress peaks. All these configurations (spew & chamfer) result in less peel and shear stresses then original single lap geometry. Effect of carbon nano tubes on the strength of adhesive tapes was investigated by the Srivastava [8]. In addition to the importance of reinforcement and matrix in polymer composites, the bonding between the composite laminate and the metallic layer is a key issue for the overall metal–fibre laminate performance. Other parameter such as efficient surface treatment of the metallic layer is required to assure a good mechanical and adhesive bond between the metal surfaces and composite laminates. The effect of surface treatments improves the metallic surface morphology such as mechanical, electrochemical, chemical, coupling agents and dry surface treatments for a better bonding with composite laminates [9]. T. Sinmazçelika showed comparable performance to improve FMLs. They further investigated that mechanical properties of FMLs may be enhanced by the interface bond between composite and metal plies that could be controlled by various test methods [10]. Apart from joint design parameter the choice of adhesive is also significant in determining the strength of joint [11]. The structural components are subjected to various types of loadings. As adhesively bonded materials finds enormous application in aerospace structures. The aerospace structural components are continuously under vibration.In this research work modal analysis of adhesively bonded lap joint is carried out to find out the behavior of adhesively bonded lap joint under vibrations. Any vibratory motion can be described by natural frequency and mode shapes. Modal analysis is carried out to determine the natural frequencies and Mode shapes of vibrating bodies. The modes are important parameter for design and control. Once we determined the modes the dynamic nature of the system can be predicted. So modal analysis is carried out to develop, design and verify the performance of a component [12]. Patil et al. presented modal analysis of bonded beams with a single lap epoxy adhesive joint of plates of different materials. The three specimen used were of Al-Al plates, Cu-Cu plates and Ms-Ms plates. ANSYS 11.0 finite element software was used for modal analysis of single lap adhesive joint [13].Shailendra investigated the transverse vibration of an adhesively bonded single lap joint. Results showed that natural frequency increases with the increase of overlap length [14].Aniket D Kedem et al investigated the effect of adhesive bond thickness on the lap joint through Modal Analysis. It is concluded that with the increase in bond thickness natural frequency decreases [15]. As described earlier Lap joint cohesive failure occur due to high shear and peel stresses at the lap joint ends.There is need to modify the joint design in this research work modal analysis of the adhesively bonded Al/CFRP composites is performed in Ansys workbench. Two optimization techniques which are incorporated are introduction of step configuration and fillet configuration. After the analysis, a comparison is generated to conclude the most effective joint design among the two that produces the less deformation and hence the most stable design to reduce shear and peel stresses.In this research work modal analysis of adhesively bonded Al/CFRP hybrid composite is carried out in ansys. The geometry of standard Lap jointis optimized through the introduction of steps and fillets configurations. The lap joint is modelled according to ASTM D 1002-94 as shown infig [2].

Fig.2. Standard Lap joint geometry.[1]



2. ANALYSIS

The material properties are assigned to the geometry according to the mechanical properties of CFRP and Aluminum as given in Table 1. Modal analysis of the aforesaid configurations is carried out to analyze the behavior of the structure.The analysis is performed in accordance with the geometric specification of Patel et al [13]. The obtained Frequencyresponses are in accordance with the result obtained by Patel as shown in Table 2 while the displacements for every respective mode are given in Table 3. Further modification of the joints result improved values for both optimizations. From the values it can be seen that modal

TABLE I
MATERIAL PROPERTIES

Material	Density (g/cm^3)	Elastic Modulus (GPa)	Poisson ratio
Aluminum 2024	2.78	73.1	0.33
CFRP (UD)	1.60	85	0.10,

frequencies increases from simple lap to fillet and step configuration and the displacements decreases respectively.

3. RESULTS AND DISCUSSIONS

The increase in model frequencies and decrease in displacements shows the durability of Lap joint due to introduction of Fillet and Step configurations. Both affect the bond in following ways

TABLE 2
MODAL FREQUENCIES FOR DIFFERENT CONFIGURATIONS

Modes	Simple lap	Fillet	Stepped
1	28.9	33.9	34.18
2	191.20	199.7	203.09
3	442.32	500	525.8
4	555.53	556	557.37
5	548.52	561	561

TABLE 3
MODAL DISPLACEMENTS FOR DIFFERENT CONFIGURATIONS
(DIMENSIONS ARE IN mm)

Modes	Simple lap	Fillet	Stepped
1	50.67	48.17	39.01
2	48.09	51.84	48.09
3	50.64	49.41	40.14
4	52.49	52.91	41.94
5	56.45	52.91	51.4

a. Fillet configuration reduces the stress concentration areas and hence improves the adhesive bond strength.
b. The step configuration changes the non-linearity of the bond into in-line bond that reduces the moments and hence improve the strength of bond.

The increase is frequencies are not very significant but decrease in displacement is well considerable in modal analysis as indicated in Fig 3 and Fig 4.As fillets are introduced in the structure, it eliminates the sharp corners of the lap joint configuration and hence reduces shear and peel stresses which results in increase in the structural integrity of the joint and hence frequency increases. Further the introduction of stepped configuration change the nonlinear lap joint into linear joint configuration and hence increase the frequency of the system by reducing the effect of moments due to the non-linearity in joint.Comparison of these configurations shows the relative improvement in bond strength.

It can be seen that the change in frequncey and decrease in displacement is significant for steppeped configuration as compared to the fillet configuration. This can be attributed

TABLE 4
PERCENTAGE CHANGE IN MODAL DISPLACEMENTS FOR FILLET CONFIGURATIONS

Modes	Simple lap	Fillet	Percentage Decrease
1	50.67	48.17	4.9
2	48.09	51.84	3.75
3	50.64	49.41	7.79
4	52.49	52.00	0.93
5	56.45	52.91	6.27

Fig.3. Modal Frequencies of Lap configurations.

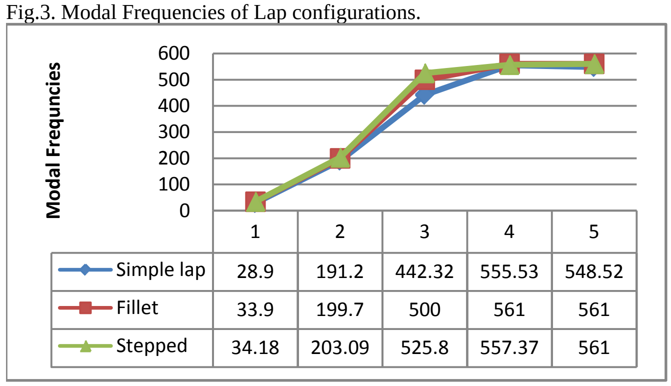


Fig.4. Displacement of Lap configurations.

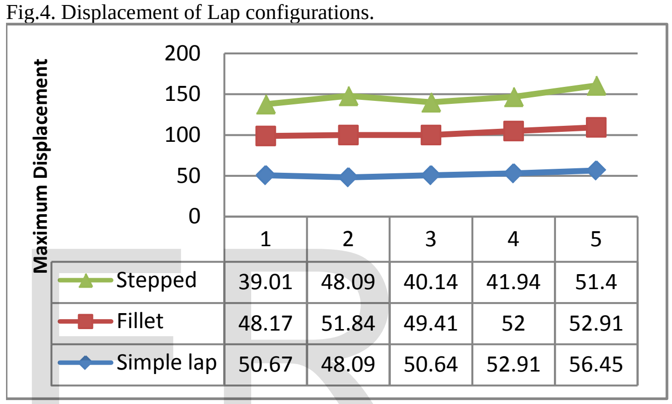


TABLE 5
PERCENTAGE CHANGE IN MODAL DISPLACEMENTS FOR STEPPED CONFIGURATIONS

Modes	Simple lap	Stepped	Percentage Decrease
1	50.67	39.01	21
2	48.09	48.09	0
3	50.64	40.14	20
4	52.49	41.94	20
5	56.45	51.4	8.9

to the lineality of the lap joint in stepped configuration as compared to the fillet configuration which although minmizes peel stresses but is insignificant in bond rotation as shown in Table 4,5,6,7,8.

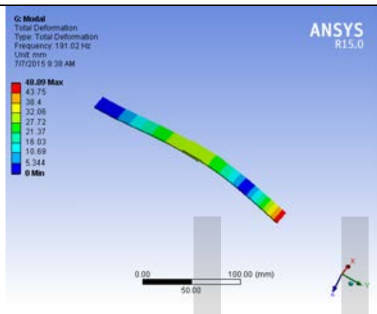
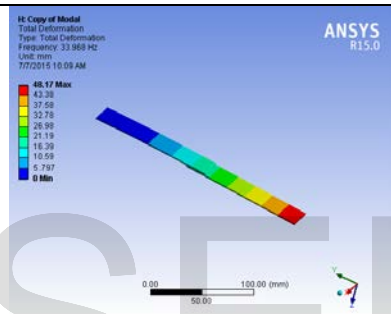
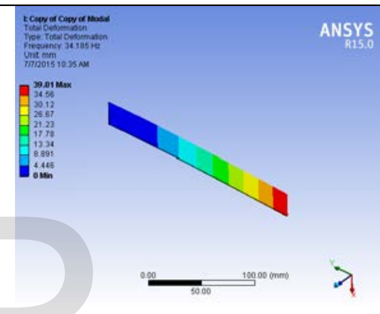
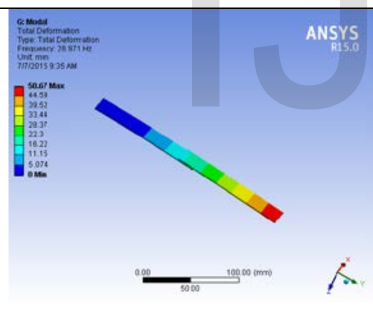
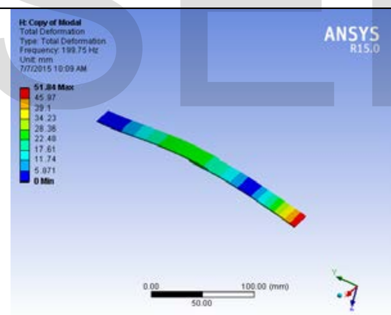
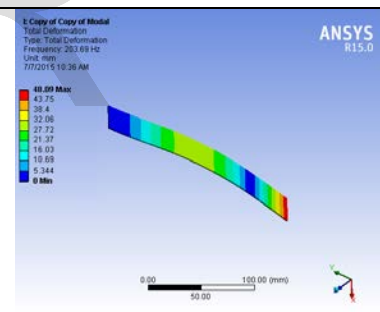
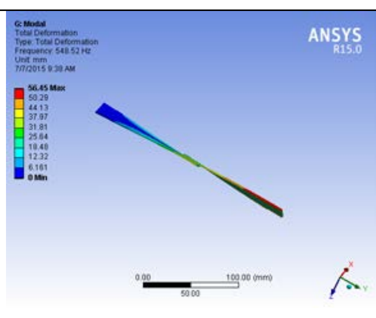
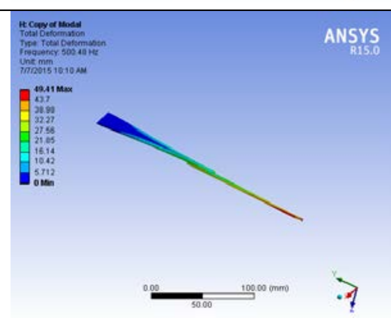
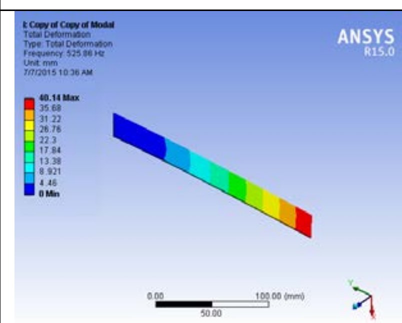
TABLE 6
PERCENTAGE CHANGE IN MODAL FREQUENCIES FOR FILLET CONFIGURATIONS

Modes	Simple lap	Fillet	Percentage increase
1	28.9	33.9	17
2	191.20	199.7	4.4
3	442.32	500	13
4	555.53	556	0.084
5	548.52	561	2.27

TABLE7
PERCENTAGE CHANGE IN MODAL FREQUENCIES FOR STEPPED CONFIGURATIONS

Modes	Simple lap	Stepped	Percentage increase
1	28.9	34.18	17
2	191.20	203.09	6.2
3	442.32	525.8	18.8
4	555.53	557.37	0.33
5	548.52	561	2.27

TABLE 8 MODAL ANALYSES OF ADHESIVELY BONDED ALUMINUM AND CFRP COMPOSITES

Modes	Lap joint	Fillet Joint	Stepped joint
Mode1			
Mode 2			
Mode 3			

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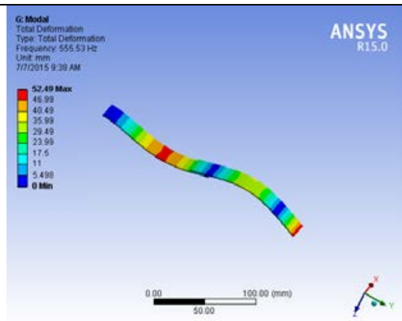
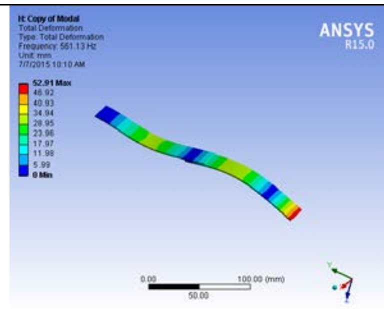
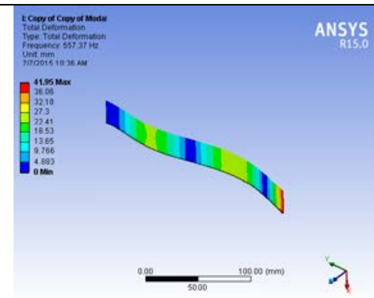
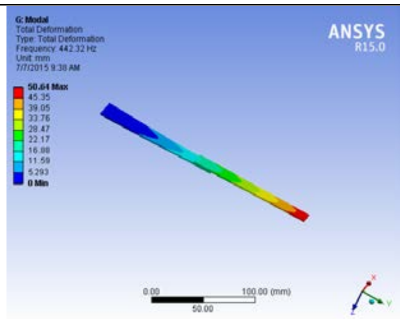
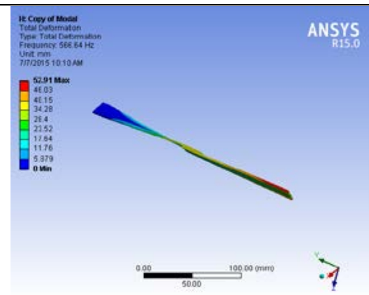
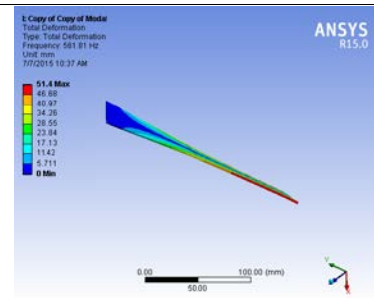
Mode 4			
Mode 5			

CONCLUSION

Fiber Metal Laminates finds enormous applications in aerospace structural components. Introduction of fillet configuration and step configuration in these structural components reduces the shear and peel stresses at the joint corner. In addition fillets reduce the shear stress by eliminating the sharp corners and stepped alter the non-linear bond into in-line bond thus minimizing bond rotation and hence peel stress. Both configurations reduce the chances of failure in the joint and hence increase the life of the component. It is evident from the results that Introduction of fillet and step layout reduces the modal displacement and increases the modal frequencies respectively, which shows the stability of joint. It can be concluded that stepped joint has more strength among other design and is good choice in Fiber Metal Laminates to reduce adhesive failures.

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