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Fatigue Life Improvement of a Composite-Metal Bolted Joint of a Heavy Vehicle Cabin

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ABSTRACT

As the use of composite material has increased in recent years across many sectors like Automobile, Aerospace, Marine, Consumer Products and Electronics etc. the developments in the composite materials and composite adhesives have also gained the required momentum. Design and analysis of such new composite structures and joints require extensive testing and experimentation so that the developed components can function properly throughout their life. This needs the comparative developments in the testing of composite structures and composite joints for different failure criterions. As composite bolted joints are more susceptible for bearing failures and subsequently for fatigue failure, more sophisticated and precise fatigue life prediction models are required to be designed. Currently there are numerous fatigue life prediction models available which do not always give the expected results. Also some specific fatigue life prediction models work for certain group of materials or conditions. In this paper a specific concentration is given for FEA analysis of the low cycle, uniaxial tension-tension fatigue failure of the composite bolted joints.

Keywords— **Bolted Joints, Composites, Fatigue failure, FEA Analysis.**

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I. INTRODUCTION

The fatigue life improvement of the composite bolted joint from low cycle life to infinite life will advance and ensure the proper use of composites as preferred option for semi-structural components in heavy trucks. Heavy truck parts like cabin roof wind deflectors, side fairings, chassis fairing, side skirts etc. are manufactured using Glass fibre Reinforced Plastics for improvement of aerodynamic efficiency which also results in improvement of fuel economy up to 10% and better aesthetics of trucks. The objective of using FRP instead of metals is to gain the weight reduction advantage which also helps in reducing the carbon footprint. The total weight reduction also helps in improving fuel economy of the trucks. In order to use GFRP for these parts it must be ensured that they will function without damage for given period of time or for given number of cycles. The use of FRP as semi-structural part life cabin roof wind deflector requires the addition of brackets or provision for assembly of these parts with the main cabin of the truck. In many cases these parts are bolted with the help of brackets. Here bolted joints are more susceptible for damage in longer run. The required fatigue life will not be achieved if the part fails near bolted joints in the working life. This leads to the improvement of fatigue life of the bolted joints. To improve fatigue life of the part it must, first of all, needs to be predicted or estimated correctly which will be possible when all the parameters contributing to fatigue life are understood and simulated correctly. There are numerous papers published regarding the mechanical behaviour of the bolted composite joint. In the paper published by P.P. Camanho, M.L. Matthews [1] stress and strength Analysis of joints is studied and experimental observations of effects of joints geometry, Ply - orientation, lay-up, through-thickness pressure on joint behaviour are obtained. I.P. Bond, I.R. Farrow [2] have presented the method for Fatigue life prediction of CFRP to Complex load time history and used modified Miner's damage summation rule and rainflow analysis in their experiment. An experimental investigation of Static and fatigue behaviour of sandwich composite panels joined by fasteners is done by G. Demelio, K. Genovese, C. Pappalettere [3] where effects of ageing on composite joints is studied and the S-N diagram of the fatigue test is obtained. The procedure for dimensioning double shear mechanically fastened joints and the relation between hole diameter and Specimen width for shear stress analysis in multi-axial conditions are given by P.P. Camanho, M. Lambert [4] in their paper. Srinivasa D. Thoppul, Joana Finegan, Ronald F. Gibson [5] have reviewed extensively the mechanics of mechanically fastened joints in polymer–matrix composite structures in which a study of mechanical test methods and standards, joint design methodologies, influence of geometric effects & fastener preload selection, fatigue failure modes, failure prediction for both statically and dynamically loaded joints, time-dependent joint preload relaxation, effects of temperature and moisture on joint strength and failure, non-destructive evaluation techniques for monitoring the joints is done. Anastasios P. Vassilopoulos [6] has presented different theories of fatigue life predictions models of composites in his book. M. M. Shokrieh and R. Rafiee [7] have presented the study of fatigue damage process of wind turbine blades in their paper. Robert M. Jones [8] has explained in detail the mechanics of Composite Materials in his book.

II. LAMINATED COMPOSITE MATERIALS

In the book named mechanics of composite materials by Robert Jones [7] in which mechanics of composite materials of fibrous, laminated, particulate and compound type are explained with detail and with their advantages, applications and terminologies. In this paper the main concentration is given to the laminated – reinforced type of composites. The general unbonded view laminate is shown in figure 1, in which layers of different laminae consisting of fibres are bonded together by matrix which can be metallic, organic, and ceramic or carbon. The major role of fibres is to provide strength or stiffness in their direction or orientation and the role of matrix is to provide support and protection to fibres and to distribute load among the fibres and also transmit load between the fibres. Laminae can have unidirectional or cross woven fibre arrangement in them.

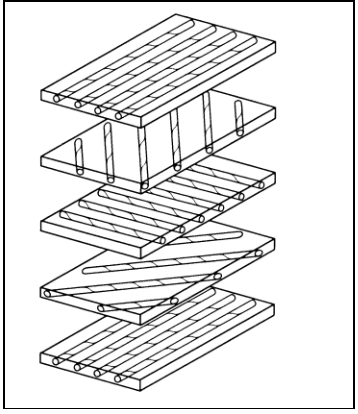

Fig. 1 Unbonded view laminate [7]

Layers of different laminae are arranged in such a way that the strength of the laminate should be high in the required direction only. For example, if require high strength in x- direction then the layers of 0^O laminates are arranged in x-direction. And as the laminated-reinforced composite materials are manufactured in such a way, their mechanical behaviour is anisotropic in nature. So define the mechanical property of such laminated-reinforced composite materials different values are required. i.e. Young's modulus in three directions(E11,E22,E33), tensile and compressive strengths in three directions, shear modulus, shear strengths and different Poisson's ratios. The strength to density and stiffness to density ratios of different fibres and wires are given in table I, because of these high ratios fibre reinforced materials are used where weight of the component plays significant role in a given applications.

TABLE I

FIBRES AND WIRES PROPERTY COMPARISON [7]

Fibres or wires	**Strength/Density ratio(km)**	**Stiffness/Density ratio(Mm)**
Aluminum	24	2.8
Titanium	41	2.5
Steel	54	2.7
E-Glass	136	2.9
S-Glass	197	3.5
Carbon	123	14
Beryllium	93	16
Boron	137	16
Graphite	123	18

The manufacturing of these composite materials is done by layup method, filament winding method, sheet molding method, Resin transfer moldingmethod, Roll forming method or by using combination of these methods. After which they are cured at specific temperatures for obtaining high strength and bonding.

The nomenclature of the laminated-reinforced composite materials can be given in different ways depending upon the fibre orientation. For example the symmetric laminate is specified as $[0^o/90^o/45^o]_S$.

III. ASTM STANDARDS FOR MECHANICAL TESTS

The mechanical tests required to be conducted for fatigue life calculation on the test specimen follow ASTM standards which are tabulated in table II. The composite bolted joint specimen is also modelled in the FEA software.

TABLE III

ASTM STANDARDS FOR FATIGUE TEST

Sr. No.	**ASTM STANDARDS**	
	Experiment	**Standards**
1	Specimen Conditioning	ASTM D618
2	Tensile Specimen Geometry	ASTM D3039
3	Open Hole Tensile Test	ASTM D5766/5766M-02
4	Filled Hole Tensile/ Compressive Test	ASTM D6742/6742M-02
5	Fatigue Test	ASTM E466 and E467

IV. NUMERICAL ANALYSIS

A. *Static Analysis of Open Hole plate*

First of all the a specimen test coupon is modelled and analysed for open hole condition in which a composite plate with w/d= 6 and hole of dia. 5mm for static analysis in

ABAQUS software. The engineering material properties of Glass Fibre Reinforced Plastic are given in table III which are provided by the manufacturer. The von misses stress for the open hole plate is 74.5 N/mm^2 for a tensile load of 1000N. Figure 2 shows the meshed and analysed snapshots of the test specimen coupon. Here we can see that the hole in plate is deformed largely which is increased for visualisation purpose using higher factor for deformation visualisation.

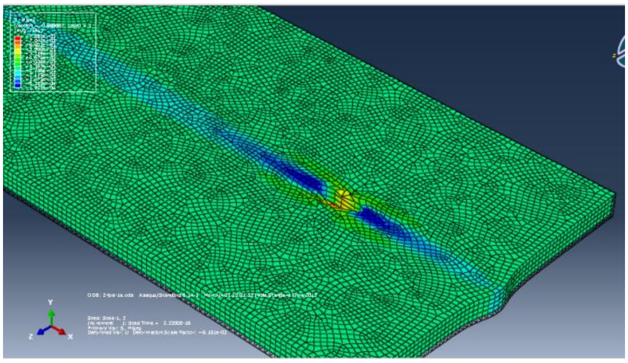

Fig. 2 Von Misses Stresses in Open Hole Test Coupon

B. *Static Analysis of Filled Hole plate*

Then a second specimen test coupon is modelled and analysed for filled hole condition in which a composite plate with w/d= 6 and hole of dia. 5mm for static analysis in ABAQUS software. In this analysis a bolt of 5 mm dia. is assembled in the hole. The material properties are same as the plate tested above in Open hole condition. The von misses stress for the filledhole plate is 32.04 N/mm^2 for a tensile load of 1000N. Figure 3 shows the meshed and analysed snapshots of the test specimen coupon. As the plate now acts as continuous one the von-misses stress is now reduced by more than 56% which shows the importance of fitment of bolts in the assembly. If the assembly consisting of bolts resembles the press or intersection fit the stresses will be low as compared to open hole plate.

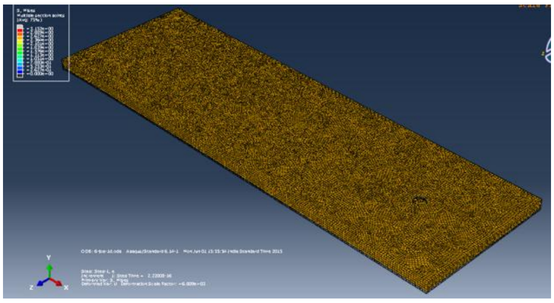

Fig. 3 Von Misses Stresses in filled Hole Test Coupon

C. *Static Analysis of Single Lap Joint Composite plate*

Now a specimen test coupon with single lap joint is modelled and analysed for closed hole condition in which two composite plates with w/d= 6 and hole of dia. 5mm are assembled with a bolt of diameter = 5mm for static analysis in ABAQUS software. The bolt is represented as kinematic coupling which simulates the rigidity of the fastener. Also a contact interaction between these two plates is applied with coefficient of friction of 0.36.The engineering material properties of Glass Fibre Reinforced Plastic are same as earlier case. The von misses stress for the Single lap composite bolted joint is 87.14 N/mm^2 for a tensile load of 1000N and 47.85 N/mm^{2}for tensile load of 500N.There is reduction of von misses stress up to 45% due to reduction of load by 50%.

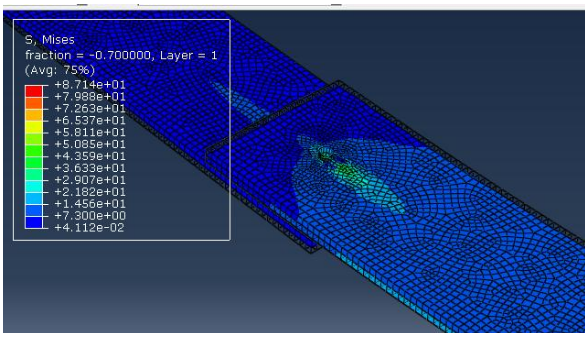

Fig.4 Von Misses Stresses in Single Lap Composite Bolted Joint Test Coupon for 1000 N load.

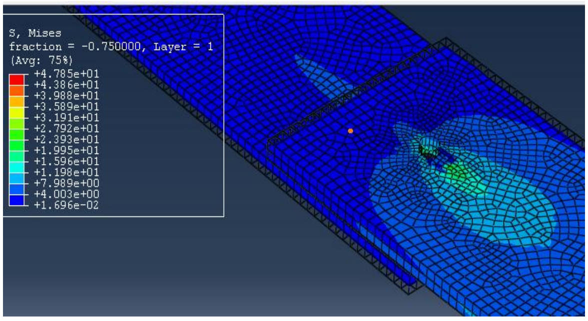

Fig.5 Von Misses Stresses in Single Lap Composite Bolted Joint Test Coupon For 500 N load.

VI.NUMERICAL FATIGUE ANALYSIS

Fatigue life analysis of the single lap composite bolted joint specimen is performed in FEMFAT software where the CAE data of the static or dynamic analysis performed in ABAQUS is imported firstly and then required material parameters are provided. And also the required fatigue life influencing parameters are selected as per the ASTM standards and then fatigue life or Damage is obtained. This FEA analysis in FEMFAT also requires the stress ratio to be given which is a ration of min. stress to max. stress. For Tensile-Tensile Fatigue Life estimation this Ratio should be greater than or equal to zero. i.e. Minimum stress and amplitude stress should be positive. In this case value of R=0.1 and Amplitude stress is the max. Stress from the static analysis of the test coupon.

The additional parameters required to be selected in FEMFAT where the influencing parameters like surface finish of the material, temperature condition, Mean and Amplitude stress arrangement, fibre orientation are required for fatigue analysis of the composite material. The relation between the stress ratio and fatigue life on the basis of S-N diagram can be shown as $\left(\frac{\sigma 2}{\sigma 1}\right)^{k} =$ where ‘k’ is the slope of S-N graph. Thus if we consider a 5 to 10% error acceptable in Static or dynamic FEA analysis then the error acceptance limit is 313 % for the fatigue life calculations. And also when the stress is doubled the fatigue life decreases by 4096 times considering the slope ‘k’ = 12. i.e the induced stress value plays a significant role in determining fatigue life of the component.

TABLE III
MATERIAL PROPERTIES OF THE UNSATURATED POLYESTER GFRP

Sr. No.	MATERIAL PROPERTIES	
	Property Name	**Value**
1	Young’s Modulus, E11	1.95*e^5 MPa
2	Young’s Modulus, E22	1.25*e^4 MPa
3	Young’s Modulus, E33	1.25*e^4 MPa
4	Poisson’s Ratio ,Nu11	0.28
5	Poisson’s Ratio ,Nu22	0.25
6	Poisson’s Ratio ,Nu33	0.25
7	Shear Modulus, G11	2400 MPa
8	Shear Modulus, G22	1600 MPa
9	Shear Modulus, G33	1600 MPa
10	Tensile Strength in fibre-direction	195 MPa
11	Tensile Strength in transverse direction	90MPa
12	Compressive Strength in fibre-direction	130 MPa
13	Compressive Strength in transverse direction	40MPa
14	Shear Strength	90 MPa
15	% elongation at rupture	8%

VII.CONCLUSION

The finite fatigue life, (10^3 to 10^5 Cycles), of the composite bolted joint for the given material is improved to 2* 10^6 cycles by varying the ply orientation, by increasing thickness from 2 to 4mm or more and by varying the hole diameter from 3 mm to 5 mm. The static analysis of the test specimen is done in ABAQUS. As per the Constant Life Diagram or by Haigh diagram the endurance strength of the single lap composite bolted joint comes to be 48 MPafor R= -1 and 89 MPa for R= 0.1. The further improvement of fatigue life of the single lap Composite bolted joint can beachieved in future by considering following parameters i.e.

1. Changing Ply orientations of the Composite material so that the overall yield strength of the composite material in fibre direction can be increased. Also increasing the number of plies of the fibre will increase the yield strength which will increase the endurance strength of the material.
2. Changing Width to Thickness Ratios of the bolted joint for reductionof the induced stresses in material which will increaseoverall life of the material drastically.
3. Changing Hole Diameter of the bolted joint will also help in reducing von misses stresses and subsequently increasing the fatigue life of the composite joint.

REFRENCES

[1] P.P. Camanho, M.L. Matthews, Stress Analysis and Strength Prediction of Mechanically Fastened Joints in FRP- a Review, Composite Elsevier, Dec. 1996.

[2] Bond IP, Farrow IR. Fatigue life prediction under complex loading for XAS/914 CFRP incorporating a mechanical fastener. International journal Fatigue 2000;22(8): 633–44.

[3] M.Demelio G. An experimental investigation of static and fatigue behavior of sandwich composite panels joined by fasteners. Composite B: Engg. 2000;32(4):299–308.

[4] P.P. Camanho, M. Lambert, A design methodology for mechanically fastened joints in laminated composite materials, Composites Science and Technology 66 (2006) 3004–3020.

[5] Srinivasa D. Thoppul, Joana Finegan , Ronald F. Gibson , Mechanics of mechanically fastened joints in polymer–matrix composite structures – A review, Composites Science and Technology , 7 October 2008.

[6] A.P.Vassilopoulos, *Fatigue Life Prediction of Composites and Composite Structures*, CRC, 2010.

[7] Shokrieh M M and Lessard L B (2000a), ‘Progressive fatigue damage modeling of composite materials, Part I: Modeling’, J Composite Materials, 34(13), 1056–1080.co, Switzerland.

[8] Robert M. Jones, *Mechanics of Composite Materials*, 2nd ed., T&F, 1999.