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Comparative Analysis of Single Lap, Double Lap and Stepped Hybrid Composite Adhesively Bonded Joints at Variable Load

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Abstract. Composite material is generally used nowadays in the aerospace and automotive industries for improved strength of the structure. In industries, mechanical fastening is generally used to join the composite material. High-stress concentration at the hole and localized load transfer cause reductions in the fatigue and fracture strength of the joint. Adhesive can be used instead of fasteners for continuous load transfer, which causes better stress distribution.

Nowadays, in many cases, the combination of mechanical fastening and the adhesively bonded joint is typically used in the aerospace industry. In the hybrid joint, the load is transferred by both the metal as well as by the adhesive. By the use of adhesive with high epoxy resin, in this case, the adhesive layer transfers most of the load without any appreciable benefits in the performance of adding bolts. Instead of high modulus epoxy resin, if the low modulus epoxy resin is used, then it gives better load distribution between the bolt and the adhesive and also greater strength stiffness and fatigue life. In the present paper, a comparative study is done between Single lap, double-lap, and stepped hybrid joints.

Keywords:- Hybrid joints, Composites, Adhesive, Bonded/Bolted, Single lap, double lap and stepped hybrid joint.

1. INTRODUCTION

Most industries, particularly the aircraft industries, use composite materials due to their being lightweight, highly heat resistant, high strength-to-weight ratio, low density, and high stiffness. Now a day adhesively bonded joining method is preferred over mechanical fasteners for continuous load transfer with better stress distribution It also reduces high stress concentration at the hole, and limited load transfer, which further affects decreases the fatigue strength and the fracture strength of the joint. The use of the mechanical joint combined with the adhesively bonded joint is very useful for the aerospace industries on a performance basis. In this method, most of the load is transferred by the adhesive.

In hybrid joining, two or more joining operations are carried out either simultaneously or sequentially. The most frequent type of hybrid joint includes an adhesive in coexistence with a point connection, such as a mechanical fastening or a spot weld. It is largely used for joining plate materials, but there are also applications involving expulsion and also in thin castings. The main advantages of combining a point joining method with an adhesive are enhanced strength (static and dynamic), production of continuous and leak-tight joints, increased impact and peel resistance, and improved joint stiffness.

The joint geometry and adhesive, mechanical properties were established to be major parameters leading to the load transfer distribution in the joint. As a persistence of the previous studies, the present paper addresses the static strength, failure mechanisms, and fatigue confrontation of the joints.

The adhesive bonding technique is a process of combining the materials in which an adhesive is positioned between the contacting surfaces of the parts called adherents and heat or pressure or both are applied to bring about the joint. Adhesive joints can offer thermal and electrical insulations with a soft surface look, resulting in uniform stress distribution. Adhesive joining is the same as to soldering and brazing of metals in that a metallurgical connection does not take place through the surfaces being united may be heated, but they are not melted. An adhesive may be a glue, a cement, mucilage (sticky liquids from plants), or a paste. The advantages of adhesive bonding contain bonding of dissimilar materials at low processing temperatures of 65 to 175°C. Thin gauge materials can be combined effectively. Even if natural adhesives, both of organic and inorganic beginning, are present, artificial organic polymers are generally employed to adhesive connection metals. Various types of adhesively bonded joints are shown in the figure below.

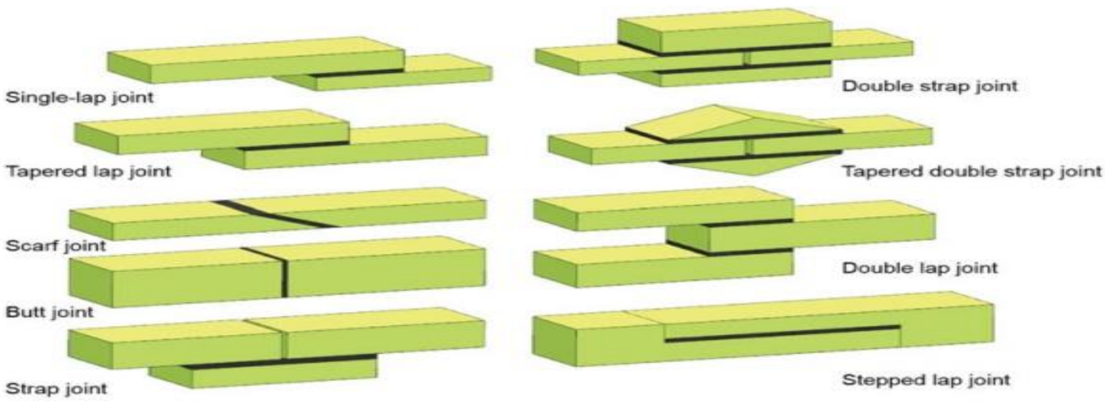


Fig. 01Various types of adhesively bonded joints.

2. LITERATURE REVIEW

E Armentani, F Laiso et al. 2018 analyzed single lap hybrid joints with a different dimension of the bolt and evaluated load transfer capacity numerically and compared it with FEM analysis. They observe that the numerical analysis points out a lesser load transfer when the gap increases this is due to a greater relative displacement between two laminates needed to close the gap and then allow the bolt to work. From the numerical analysis, they observed that the use of the bolt allows the reduction in the shear stress acting on the adhesive layer in comparison to the simply adhesive bonded joint[1]

F. Esmaeili , T.N. Chakherlou, M. Zehsaz 2014 studied and investigated about the consequence of bolt compressing force on the life of the fatigue strength of the double lap simple bolted and the hybrid (bonded/bolted) connections by analytically and also by mathematically. The two types of connections, one is double lap simple and another one is hybrid (bolted/bonded) connections, are investigated by them. They used three sets of specimens for all kinds of connections and subjected tightening torque of 1, 2.5, and 5 N-m. They experimentally observed that the hybrid joint shows a greater fatigue life in contrast with the simple bolted connections. In the mathematical method, the FEM set of symbols was utilized by them to get stress distribution in the united plates due to the clamping force and longitudinal loads which is to be applied. From the numerical simulation and analytical results, they observed that the fatigue life of samples was enhanced by growing the clamping force caused by the compressive stresses produced near the hole. The improvement of fatigue life can also be related to compression around the hole caused by the compression of the plates by the bolt pretension.

Such negative stresses can reduce the total amount of resultant stresses that cause fatigue crack initiation and propagation in the plate due to the applied tensile external loads. Furthermore, in the hybrid joints, direct metallic contact between the plates does not occur; therefore, the possible fretting fatigue is eliminated.[2]

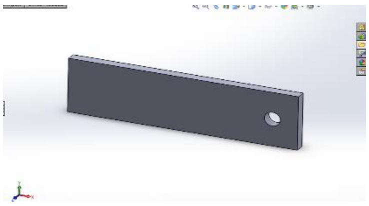
Ioannis K. Giannopoulos, Damian Doroni-Dawes et al. 2017 investigated the outcomes of the bolt tightening torque on the strength and fatigue plan of the bolted AS7/8552 fibre reinforced polymer laminates. In this paper they also analyze the condition of the static bearing loading and also for the bolted joints on the FRP material tested by them. They observed that for the moderately greater torque pre-tightened in the connection, failure generally takes place on the specimen parts after the washer. They also observe that by raising the bolt pre-tightening, the static strength allowable increased, which provided an apparent increase in the fatigue life.[3]

E. Paroissiena, F. Lachauda et al 2017 presented a simplified form for the stress estimation of single-lap HBB joints. They found that the distribution and displacements in the adherents and in the fasteners, as well as the distributions of adhesive shear and peel stresses along the overlap. Their model can address both boundary cases: the pure bonded joints and the pure bolted joints. A simplification of the fastening simulation is presented in their model. Their model is able to predict the quasi-static mechanical behavior up to the failure of HBB joints, experimentally measured. The failure is initiated at overlap ends in the adhesive layer and propagated toward the first fasteners. For the analysis of the stress of the hybrid joint, they uses an analytical model of FEM (Finite Element Method). In their analysis, quasistatic test and the numerical test is also carried out.[4]

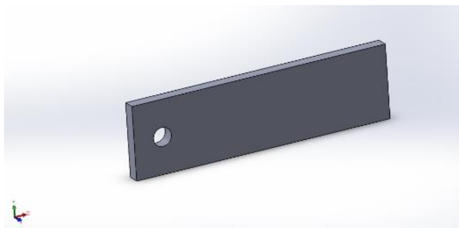
Shashikant Dashore, Mr. M. J. Patil et al 2016 conducted the experiment by using the Taguchi function. Uses a total of 27 such joint samples were tested as per ASTM D5968 standard to obtain the strength of the Hybrid joint and Load distribution. The load distribution on the hybrid joints is evaluated by the tensile test, where the joint strength is calculated from the ultimate limit of the material. The test results are also validated with the Numerical analysis using Finite Element analysis by them. Validation of the ANOVA and experimental results are also validated with the FE result. From the FE result, they also observed that the load share by the bolt is near 0% at the breaking load. From the comparison of different material types, it is observed that stresses are less than the other type of joints. They observed that the Load capacity of the joint increases with an increase in bolt dimension as larger bolts are having larger shear areas. Also, the load capacity of the joint decreases with the increasing bolt-hole clearances as it allows the relative displacement between the bolt and hole, which further reduce the capacity of the joint.[5]

In the current study single lap hybrid composite joint, double lap hybrid composite joint and stepped hybrid composite joint are studied. In order to fulfil the requirement, we have design single lap hybrid composite joint, double lap hybrid composite joint and stepped hybrid composite joint using SOLID WORK 2014. Finite element analysis of single lap hybrid composite joint, double lap hybrid composite joint and stepped hybrid composite joint is conducted by ANSYS 18.1. Four different loads of 1500 N, 2000 N, 2500 N, and 3000 N are applied at the end of each joint, the stresses in each direction and deformations are analyzed obtained results are used for the comparison with the single lap hybrid composite joint.

3. DESIGN PART OF THE SINGLE LAP HYBRID JOINT



Adherend part of single lap hybrid joint



Adherend part of single lap hybrid joint

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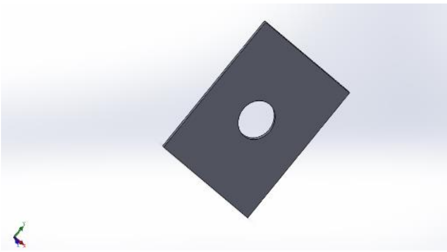
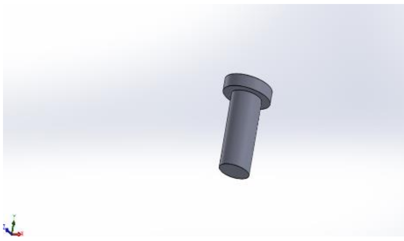


Adhesive part of single lap hybrid joint



Pin of single lap hybrid joint

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Collar part of single lap hybrid joint

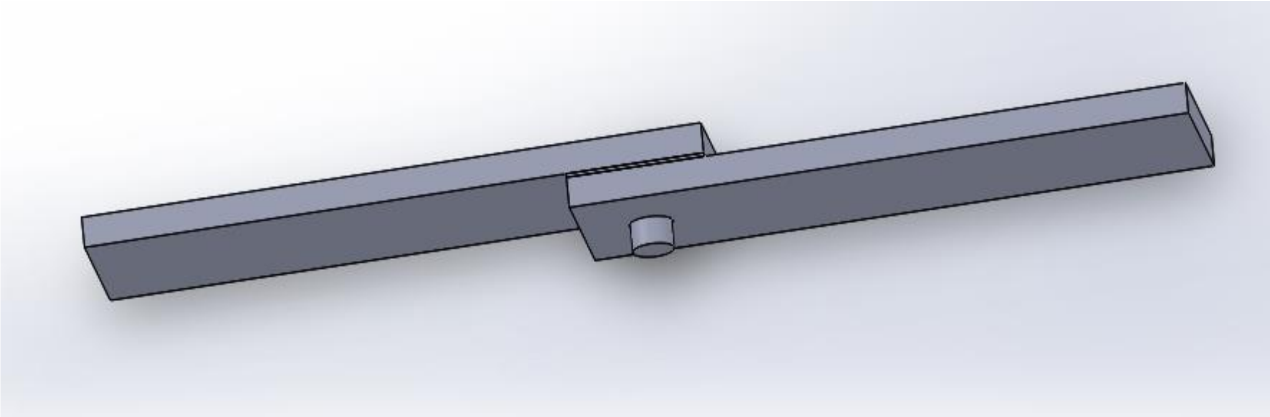

Fig. 02 Single lap hybrid joint

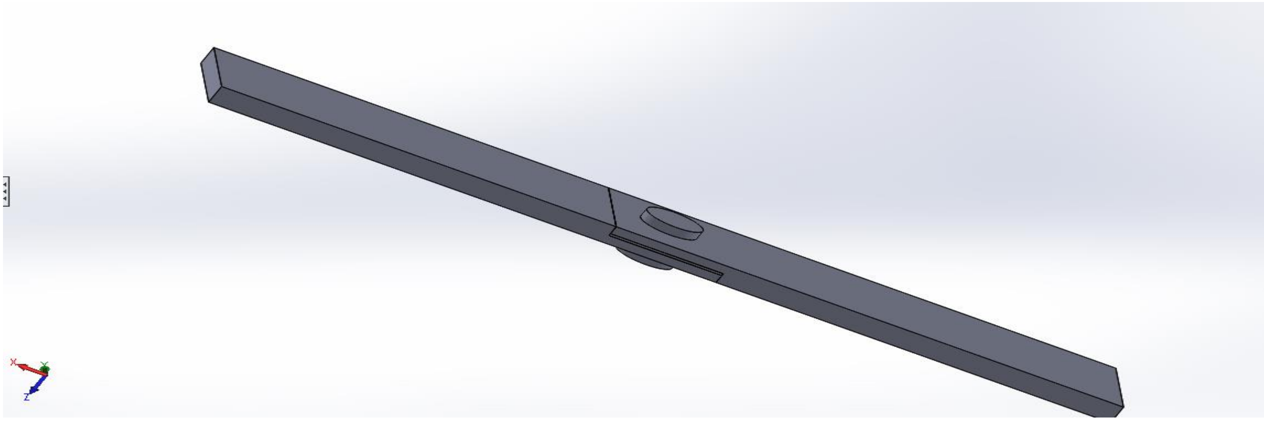

Fig. 03 Double lap hybrid joint

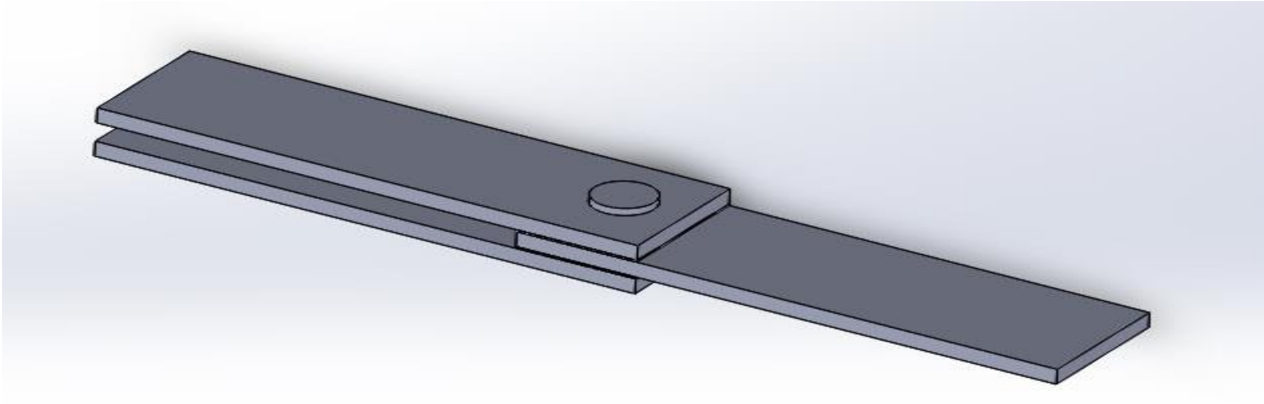

Fig. 04 Stepped lap hybrid joint

The present study is based on the modeling of geometry and computational analysis of the single lap hybrid composite joint, double lap hybrid composite joint and stepped hybrid composite joint.

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4. DESIGN PARAMETER

Table 01 Design parameter of model

Symbol	Description	Value(in mm)
H	Width of the adherend	25
L	Length of the adherend	90
d1	Diameter of the pin shank	6
d2	Diameter of the pin head	10
Clamp	Clamping length of the machine	30
S1	Thickness of the adherend	4.16
S2	Thickness of the adhesive	0.5

ADHESIVE MATERIAL: - PLIOGRIP7400

Table 02 Mechanical characteristics of adhesive material

Property	Description	Value
E	Young modulus	600 MPa
V	Poisson ratio	o.3
ρ	Density	1.28 g/cm3

ADHEREND MATERIAL: – PREPREG CARBON FIBRE WITH EPOXY RESIN

Table 03 Mechanical characteristics of adherend material

Mechanical parameter	Value
E11	140 GPa
E22	10 GPa
E33	11 GPa

G12	5.2 GPa
G13	5.2 GPa
G23	3.9 GPa
*v*12	0.3
*v*13	0.3
*v*23	0.5

PIN AND COLLAR MATERIAL: - TITANIUM

Table 04 Mechanical characteristics of pin and collar

Property	Description	Value
E	Young modulus	110 GPa
G	Shear modulus	41.045 GPa
v	Poisson ratio	0.34
ρ	Density	4.420 g/cm3

The maximum normal stresses are 273.78 MPa, 73.403 MPa and 54.28 MPa at the load of 3000 N of single lap hybrid composite joint, double lap hybrid composite joint and stepped hybrid composite joint, respectively. The maximum normal stress is obtained in the X –direction. From the comparison of obtained results, it can be seen that the maximum stress occurs at single lap hybrid composite joint and the minimum stress occurs at the stepped hybrid composite joint and the stress at the double lap hybrid composite joint the stresses are greater than stepped hybrid composite joint but lesser than single lap hybrid composite joint. Hence in Aviation industries and also in automobile industries double lap hybrid composite joints and stepped hybrid composite joints can be used instead of single lap hybrid composite joints. The normal stress of the single lap hybrid composite joint is greater in each of the loads as 1500 N, 2000 N, 2500 N and 3000 N in each direction as compared to the double lap hybrid composite joint and stepped hybrid composite joint. From the analysis, it can also be seen that as the load is increasing the stress is continuously increasing on the single lap hybrid composite joint, double lap hybrid composite joint and stepped hybrid composite joint.

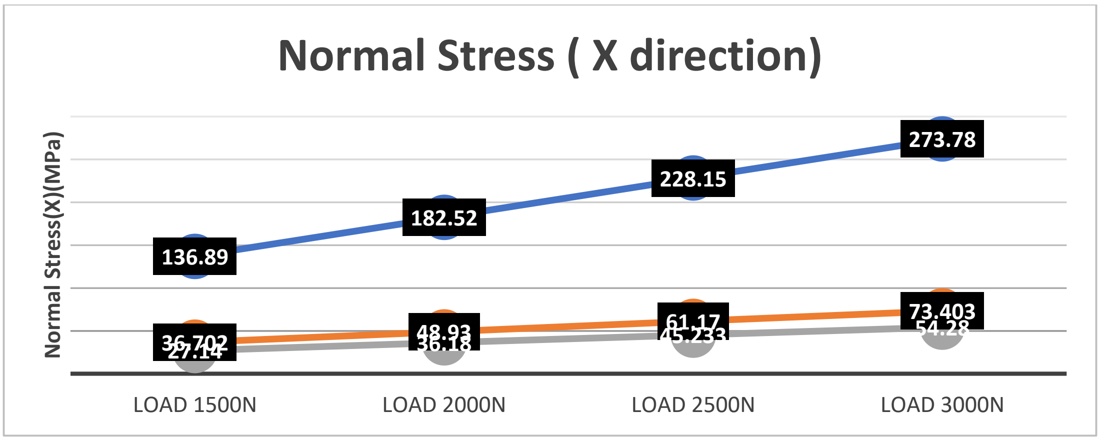

Fig.5 Graph between Normal Stresses (in X-axis) and Loads acting on Single lap, Double lap and stepped hybrid joint

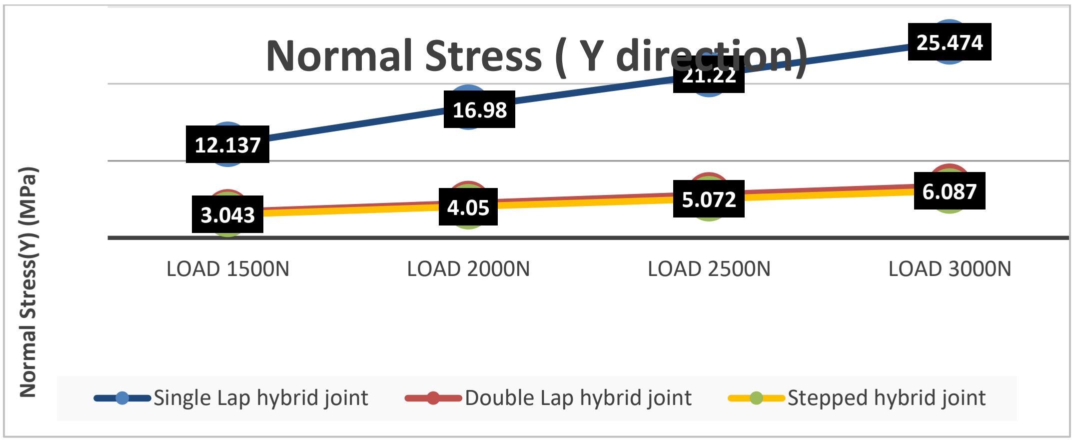

Fig.6 Graph between Normal Stresses (in Y-axis) & Loads acting on Single lap, Double lap and stepped hybrid joint

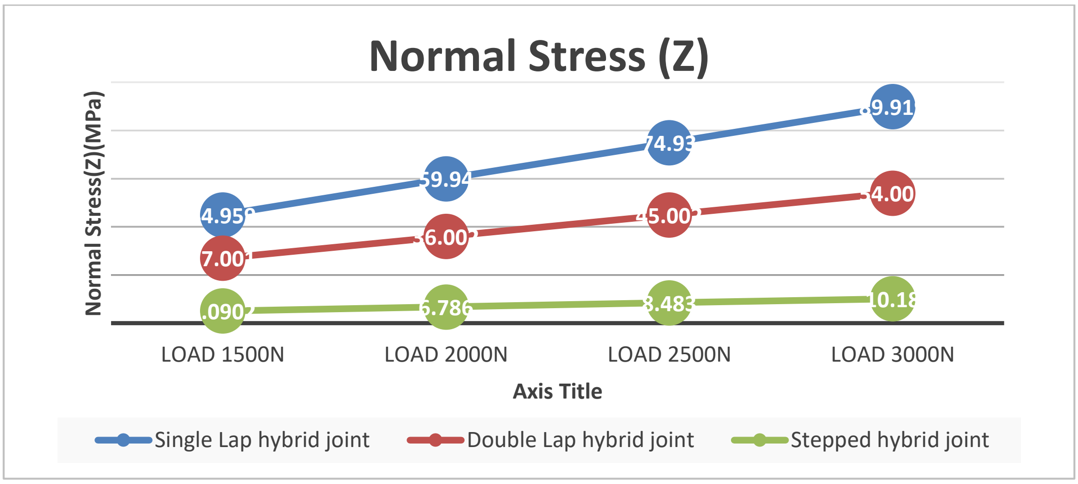

Fig.7 Graph between Normal Stresses (in Z-axis) and Loads acting on Single lap, Double lap and stepped hybrid joint

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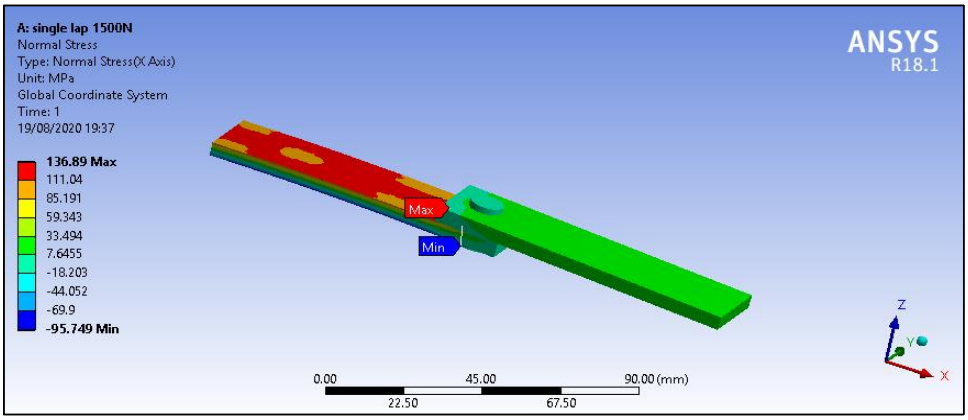

Fig.8 Normal Stress in single lap hybrid joint in X-axis at load 1500 N

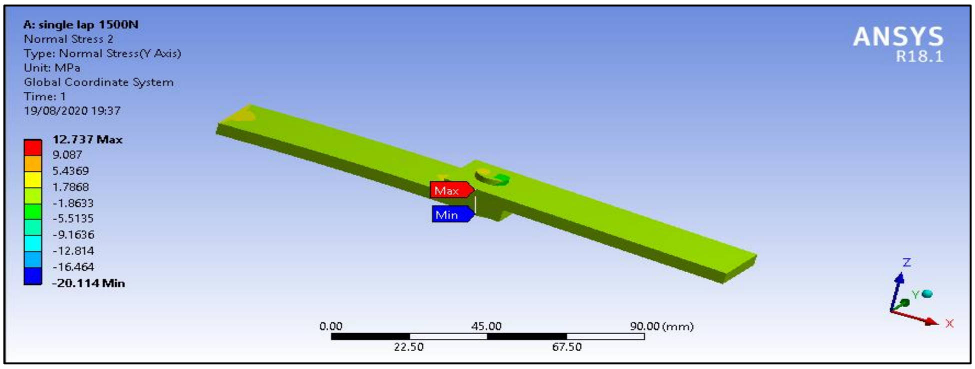

Fig.9 Normal Stress in single lap hybrid joint in Y-axis at load 1500 N

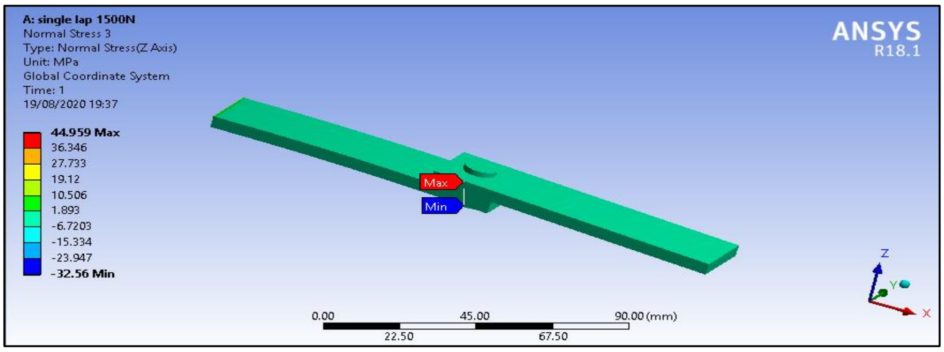

Fig.10 Normal Stress in single lap hybrid joint in Z-axis at load 1500 N

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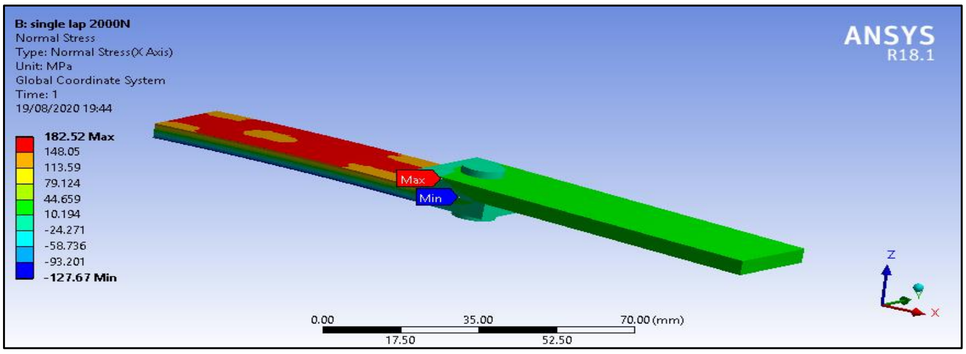

Fig11 Normal Stress in single lap hybrid joint in X-axis at load 2000 N

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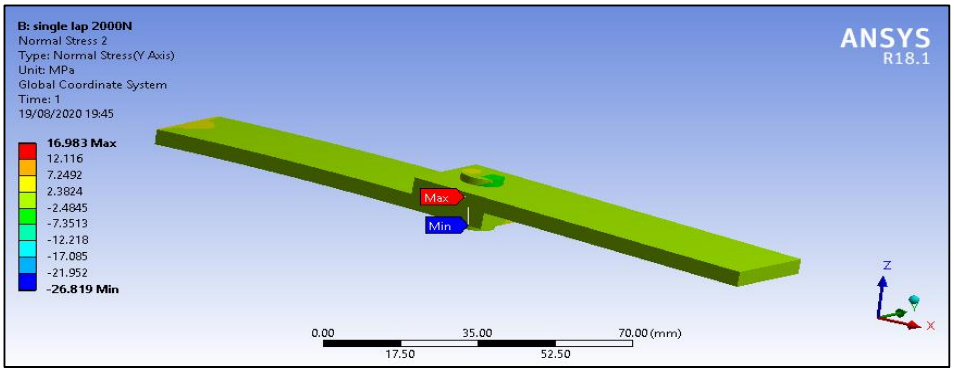

Fig.12 Normal Stress in single lap hybrid joint in Y-axis at load 2000 N

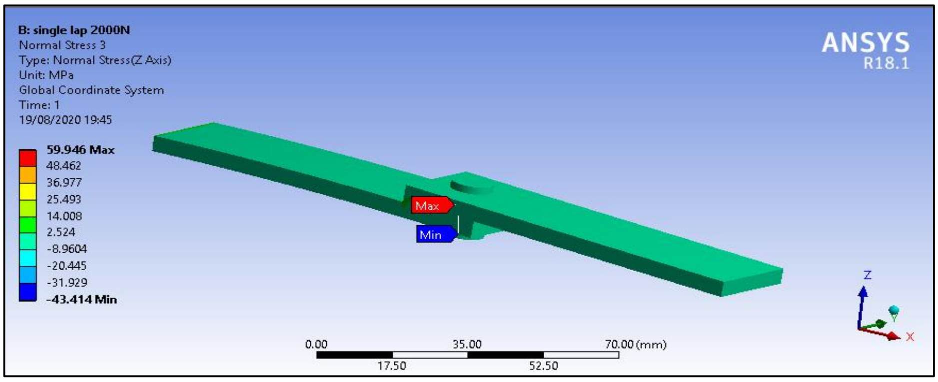

Fig13 Normal Stress in single lap hybrid joint in Z-axis at load 2000 N

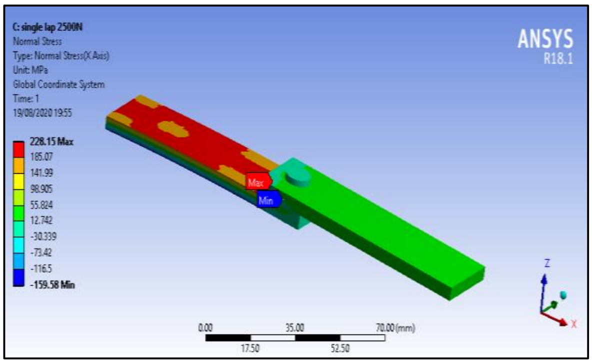

Fig.14 Normal Stress in single lap hybrid joint in load 2500N

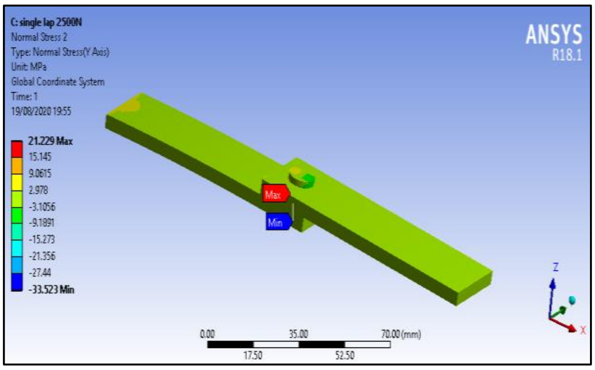

Fig15 Normal Stress in single lap hybrid joint X-axis at in Y-axis at load 2500N

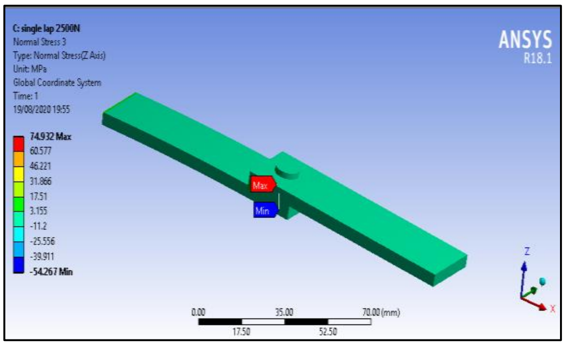

Fig.16 Normal Stress in single lap hybrid joint in 2500N

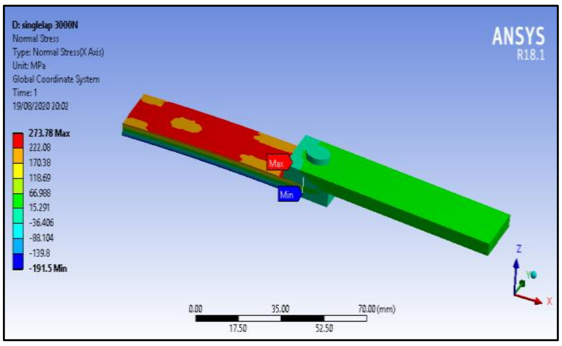

Fig17 Normal Stress in single lap hybrid Z-axis at load joint in X-axis at load 3000N

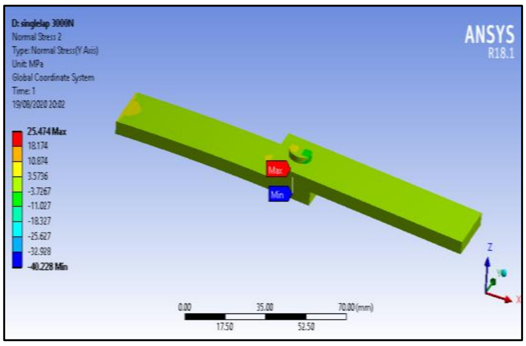

Fig.18 Normal Stress in single lap hybrid axis at load 3000N

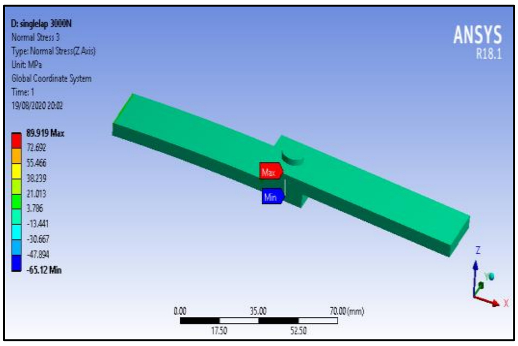

Fig19 Normal Stress in single lap hybrid joint in joint in Y-Z-axis at load 3000N

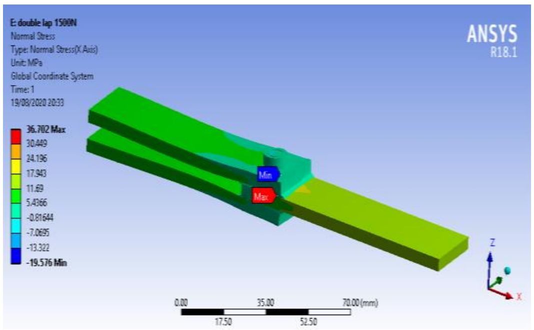

Fig.20Normal Stress in Double lap hybrid at load 1500N

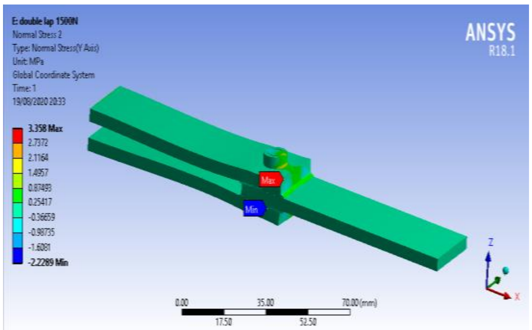

Fig21 Normal Stress in Double lap hybrid joint in X-axis joint in Y-axis at load 1500N

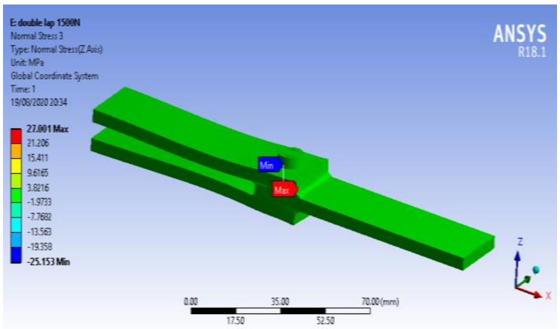

Fig.22Normal Stress in Double lap hybrid joint in Z-axis at load 1500N

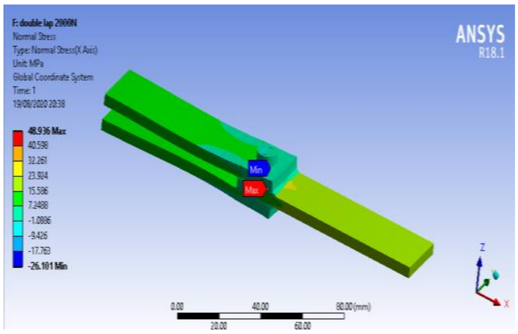

Fig23 Normal Stress in Double lap hybrid joint in X-axis at load 2000N

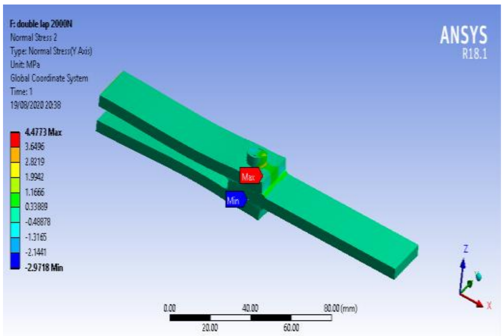

Fig.24Normal Stress in Double lap hybrid at load 2000N

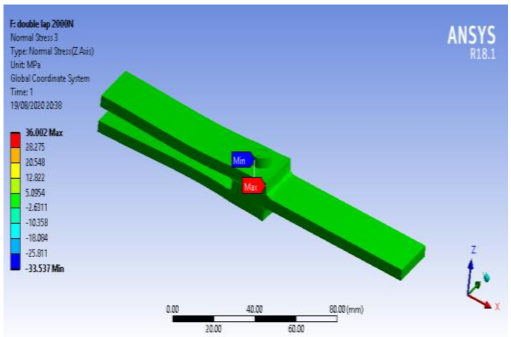

Fig25 Normal Stress in Double lap hybrid joint in Y-axis joint in Z-axis at load 2000N

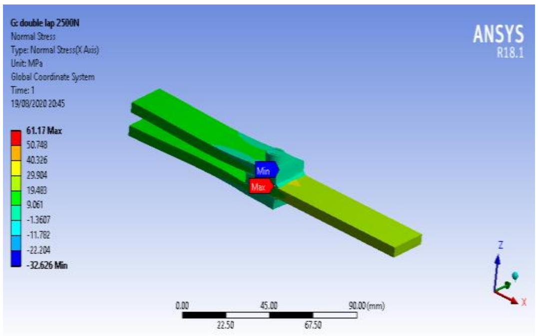

Fig.26Normal Stress in Double lap hybrid at load 2500N

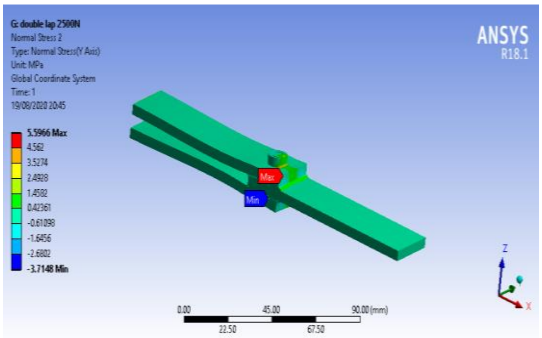

Fig27 Normal Stress in Double lap hybrid joint in X-axis

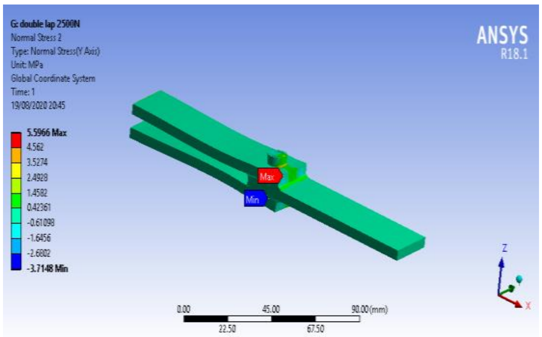

Fig.28Normal Stress in Double lap hybrid at load 2500N

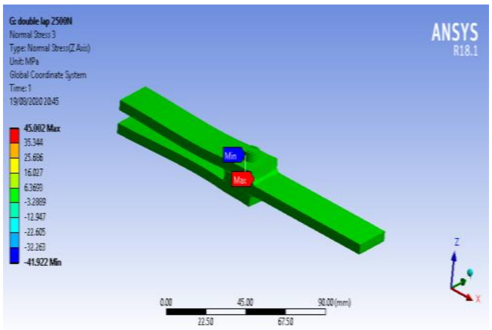

Fig29 Normal Stress in Double lap hybrid joint in Y-axis joint in Z-axis at load 2500N

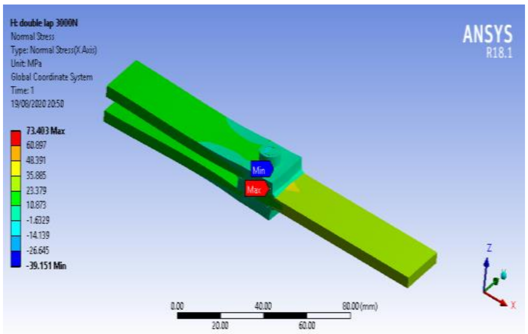

Fig.30Normal Stress in Double lap hybrid at load 3000N

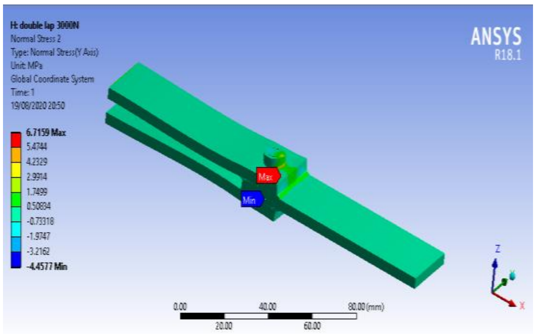

Fig31 Normal Stress in Double lap hybrid joint in X-axis joint in Y-axis at load 3000N

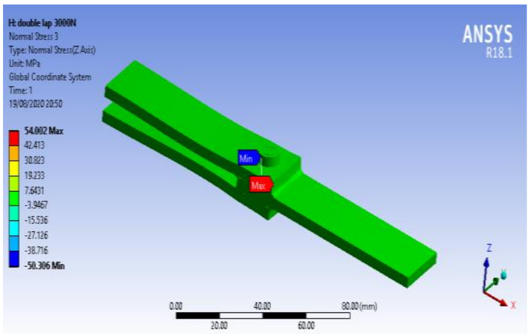

Fig.32Normal Stress in Double lap in Z-axis at load 3000N

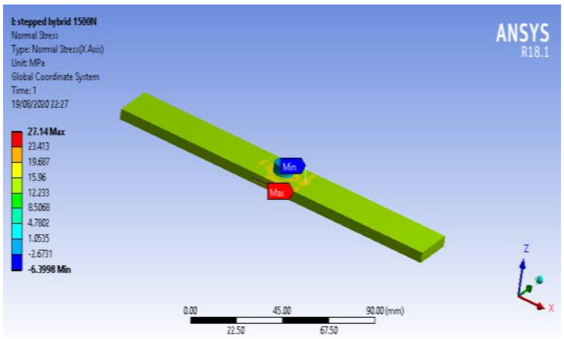

Fig33 Normal Stress in Stepped hybrid joint hybrid joint in X-axis at load 1500N

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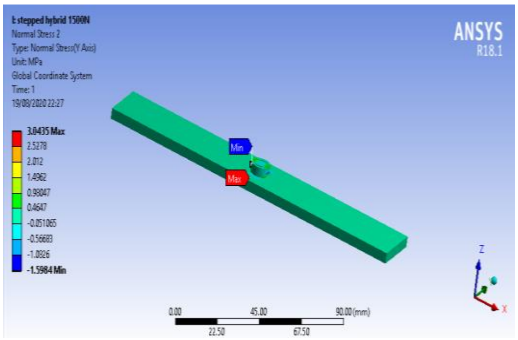

Fig34 Normal Stress in Stepped hybrid load 1500N

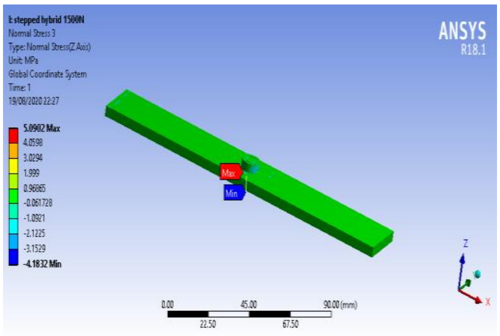

Fig35 Normal Stress in Stepped hybrid joint in Y-axis at joint in Z-axis at load 1500N

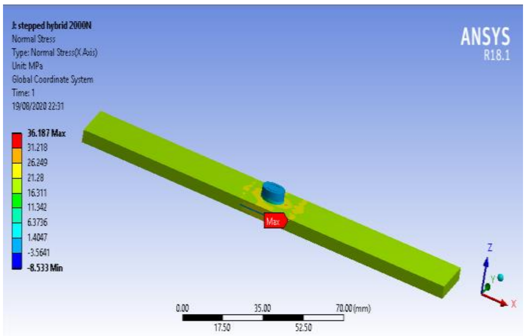

Fig36 Normal Stress in Stepped hybrid load 2000N

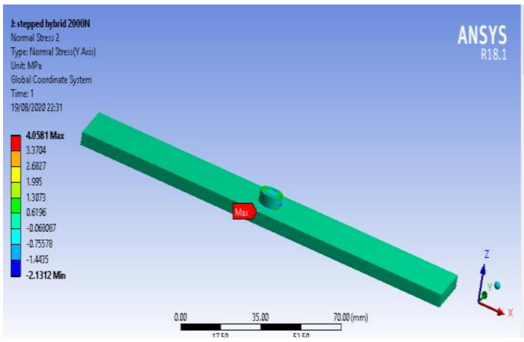

Fig37 Normal Stress in Stepped hybrid joint in X-axis at joint in Y-axis at load 2000N

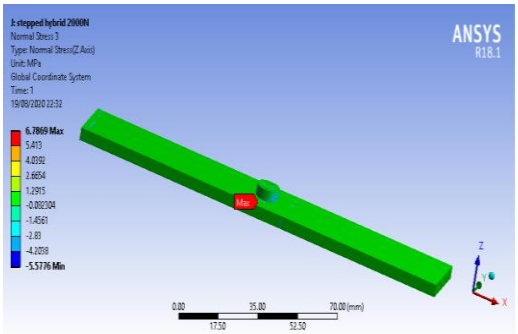

Fig38 Normal Stress in Stepped hybrid axis at load 2000N

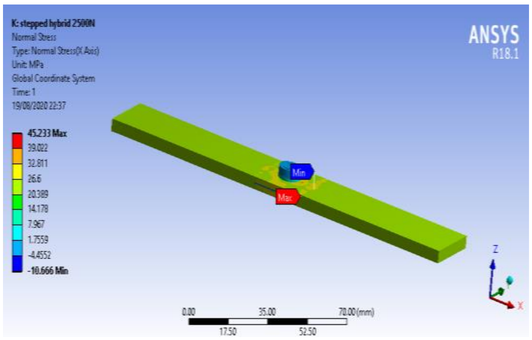

Fig39 Normal Stress in Stepped hybrid joint joint in Z-in X-axis at load 2500N

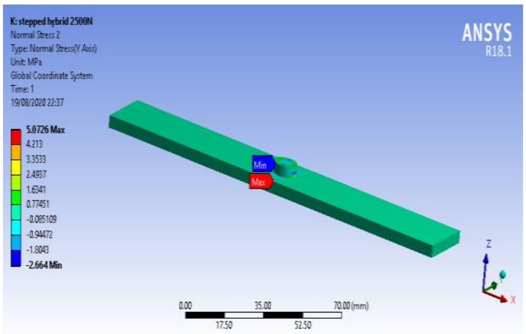

Fig40 Normal Stress in Stepped hybrid axis at load 2500N

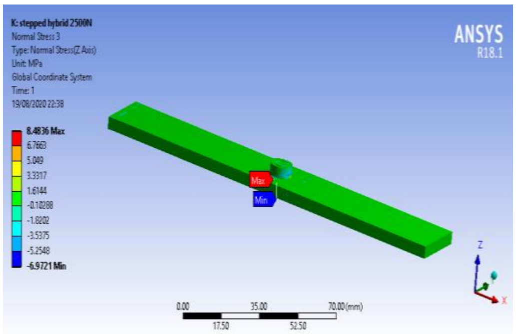

Fig41 Normal Stress in Stepped hybrid joint joint in Y- in Z-axis at load 2500N

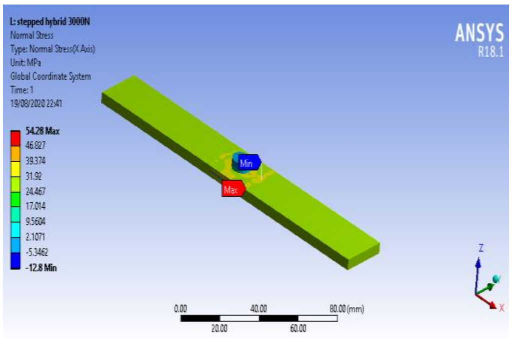

Fig42 Normal Stress in Stepped hybrid at load 3000N

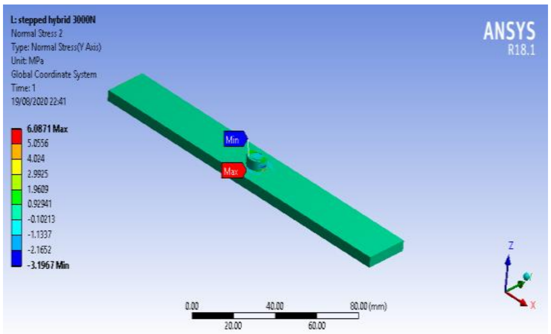

Fig43 Normal Stress in Stepped hybrid joint in X-axis joint in Y-axis at load 3000N

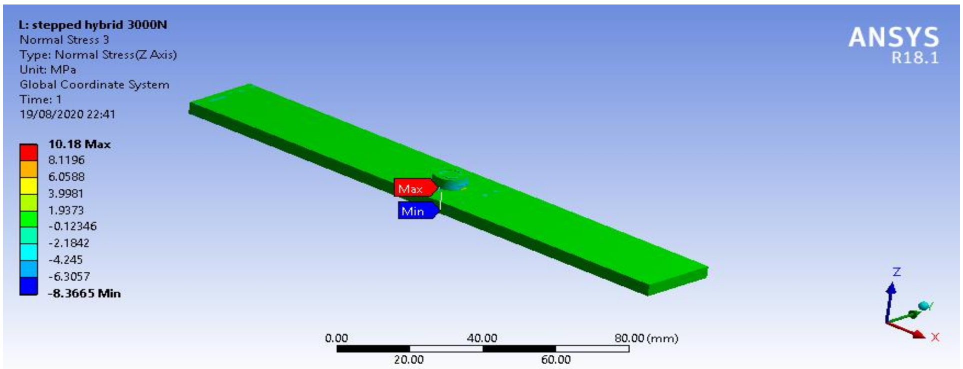

Fig44 Normal Stress in Stepped hybrid joint in Z-axis at load 3000N

5 CONCLUSION

The present study is based on the modeling of geometry and computational analysis of the single lap hybrid composite joint, double lap hybrid composite joint and stepped hybrid composite joint.

The ANSYS analysis by applying the different tensile loads of 1500 N, 2000 N, 2500 N, and 3000 N at the ends of the single lap hybrid composite joint, double lap hybrid composite joint and stepped hybrid composite joint. The maximum normal stresses are 273.78 MPa, 73.403 MPa and 54.28 MPa at the load of 3000 N of single lap hybrid composite joint, double lap hybrid composite joint and stepped hybrid composite joint, respectively.

The maximum normal stresses are also obtained in the X –direction. From the comparison of obtained results, it can be seen that the maximum stress occurs at single lap hybrid composite joint and the minimum stress occurs at the stepped hybrid composite joint, and the stress at the double lap hybrid composite joint stresses are greater than stepped hybrid composite joint but lesser than single lap hybrid composite joint. Hence in aerospace industries and also in automobile industries double lap hybrid composite joint and stepped hybrid composite joints can be used instead of single lap hybrid composite joints. From the analysis, it can also be seen that as the load increases, the stresses are continuously increasing on the single lap hybrid composite joint, double lap hybrid composite joint and stepped hybrid composite joint.

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