Design and Optimization of Adhesively Bonded Metallic Insert Joints in Vinyl-Ester Balsa core Sandwich Panels Using ANSYS APDL

Submitted in partial fulfillment of the
requirements of the degree of
(Bachelor of Technology) by

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Dedication Sheet

We dedicate my dissertation work to our family and many friends. A special feeling of gratitude to our loving parents, whose words of encouragement and push for tenacity ring in my ears. We also dedicate this dissertation to my many friends who have supported us throughout the process. We will always appreciate all they have done for us during our entire graduation program especially in this critical situation.

Approval Sheet

This B. Tech report entitled Mechanical Characterization of Adhesively Bonded Metallic Insert Joints in Vinyl-Ester Balsa core Sandwich Panels using ANSYS APDL by Raja Swarnakar(AP17110030018), Akash Yadav(AP17110030016) and Dibya Chaudhary(AP17110030015) is prepared and submitted as partial fulfillment of the requirement for the degree of Bachelor of technology in mechanical engineering.

Examiners

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Date: 22-05-2021

Place: SRM University, AP-Amaravati

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Signature

HOD, Mechanical Engineering

Declaration Sheet

We, hereby declare that the final year project report entitled "**Mechanical Characterization of Adhesively Bonded Metallic Insert Joints in Vinyl-Ester Balsa core Sandwich Panels using ANSYS APDL** " is our original work except for quotation and citation which have been duly acknowledged .We also declare that it has not been previously and concurrently submitted for any other degree at SRM University AP, Andhra Pradesh India or at any other institution.

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ABSTRACT

Various design configurations of adhesively bonded stainless steel inserts were investigated with the objective of developing a structurally efficient joint for composite structural and vehicle applications using Mechanical ANSYS APDL. The composite construction under consideration is a fiberglass reinforced vinyl ester balsa cored sandwich panel with local hard points for highly loaded attachments. The adhesively bonded steel inserts were analyzed in ANSYS APDL for characterization for pull-out load conditions at room temperature. Failure modes of adhesive, insert and sandwich composite panel were investigated. Adhesive, cohesive and mixed mode failures were observed in the bonded region. The data generated by these tests will serve as basic guideline for the design of such joints in applications where composites are required for weight reduction and high localized loads due to bolted attachments are present.

Keywords: *Sandwich panel, vinyl ester balsa core, Plain Surface Bolt, Hysol and Solid pucks*

Nomenclature

Symbol	*Definition*
%	*Percentage*
SIP	*Structural insulating process*
Fig	*Figure*
ASTM	*American Society for Testing and Materials*
Mpa	*Megapascal*
Gpa	*Gigapascal*
2D	*Two Dimensional*
lb	*Pound*
in	*Inches*
μ	*Dynamic viscosity of dye water*

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Chapter 1

Introduction

1.1 Background

Mechanical fasteners are widely used to join composite parts throughout a number of industries, such as the aeronautical, civil construction and chemical industries. Hart-Smith showed that due to high stress concentrations created by the presence of the hole in composite structure, maximum joint efficiency of only 40% only is obtained for a simple bolted joint. Low efficiencies lead to weight and cost penalties in composite structures. Hence some attempts have been made by the researchers to improve the efficiency of mechanically fastened composite joints by introducing the use of adhesively bonded metallic insert joints. This technique offers a number of advantages over the other joining methods such as the tolerance to environmental effects, ease of inspection and assembly, possibility of part replacement and the simple preparation of the material. Camanho proposed different techniques to improve the efficiency of single-shear composite bolted joints using bonded inserts. He showed both numerically and experimentally that the use of bonded metallic inserts with tapered ends increases the failure load and efficiency of single-shear joints and that aluminum inserts are preferable to steel inserts.

Herraro-fraco used photo-elasticity to study the effect of the use of plastic and aluminum bonded inserts on the stresses in a joint. Use of aluminum insert showed a reduction of 75% in normalized bearing stress, reduction of 38% in the normalized tensile stress and reduction of 71% in shear strains. Plastic inserts showed increase in all stresses and strains. Nilsson made a comparison of strengths of bolted joints with and without inserts using carbon fiber reinforced plastic double shear joints. Aluminum inserts showed 12% increase in bearing strength compared to an all composite joint, however, steel inserts showed a decrease of 6% in bearing strength. Use of inserts showed a change in failure mode from bearing to tension-adhesive failure. Mirabella studied different configuration of the inserts in carbon fiber reinforced plastic single shear joints. Straight aluminum inserts decreased ultimate bearing strength by 65% while top hat aluminum inserts with tapered ends increased the bearing strength by 21%. Rufin performed fastener installation and removal tests that highlighted the ability of inserts to protect the laminate. The above mentioned published research shows that the use of adhesively bonded metallic inserts is a promising technique to improve the performance of bolted joints in composite structures. However, to understand the detailed failure mechanisms of adhesively bonded inserts in composite fastener joints under different loading conditions and also at room temperature and harsh environmental conditions, further work in this area is required. Also to further optimize the joint efficiency based on the surface preparation of inserts, additional work is required. The current research investigates the use of metallic inserts of different configurations in the typical composite joint to improve the joint performance at room temperature and harsh conditions; and proves that composite bolted joints with adhesive bonded metallic inserts perform exceedingly well under pull-out, bearing and torsion type of loading at room temperature and harsh environmental conditions.

In order to select the best surface preparation technique and adhesive for bonded metallic insert joints used in composite structures subjected to typical application environments, a preliminary study has been performed by the authors. Environmental durability tests have been performed on adhesively-bonded 303 stainless steel materials to investigate the effects of chemical and mechanical surface pre-treatments to achieve optimum bond line performance. So, in order the select the best adhesive material for better performance, we analyzed in ANSYS APDL.

1.2 Composites

Two or more materials make up a composite material with significantly different chemical or physical properties when they combine. As a result, it produces material different characteristics from the individual components. Usually with carbon, glass, aramid, polymer or natural fiber embedded in a polymer matrix.

1.3 Adhesives

Any substance that is capable of holding materials together in a functional manner by surface attachment that resists separation. Example: Hysol EA 9394. Dexter's Hysol EA-9394 is a room temperature curable paste adhesive that is representative of the adhesives used in wind turbine blade joints. Dexter

Corporation's Hysol EA-9394 is an amine-cured epoxy paste adhesive with an aluminum powder filler. This adhesive combines high temperature performance with strength and toughness; it can be cured at room temperature.

1.4 Metallic Insert Joints

Structures that are used to transfer localized loads to a composite panel or to join two composite panels together.

1.5 Sandwich Panels

A structural panel consisting of a core of one material enclosed between two sheets of a different material. Sandwich panels (sometimes referred to as composite panels or structural insulating panels (SIP))consist of two layers of a rigid material bonded to either side of a lightweight core.

The three components act together as a composite; that is, the combination of the characteristics of the components results in better performance than would be possible if they were acting alone.

Chapter 2

Problem Setup

2.1 Specimen Preparation

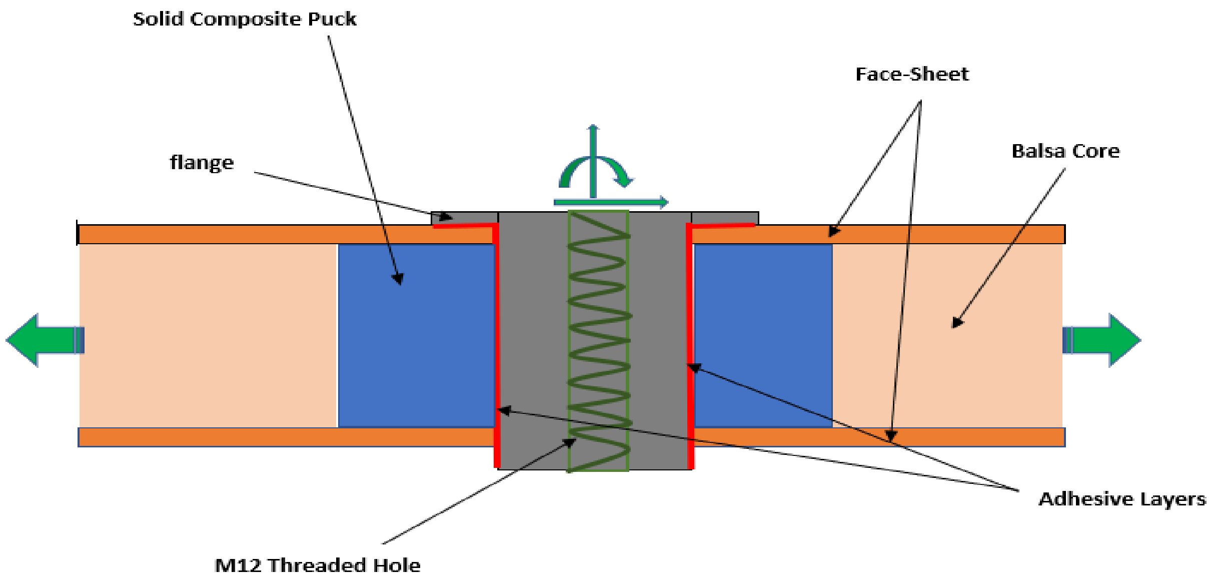

Fig 1: Vinyl ester-balsa core sandwich panel bonded insert configurations

Stainless steel (303) inserts were for testing. Structural adhesive Hysol EA 9394 was used to bond these inserts into the vinyl ester balsa core sandwich composite panel. The face sheets of sandwich panel are made of two layer resin infused quadraxial vectorply glass laminate E-QXM 3608.

2.2 Model Design

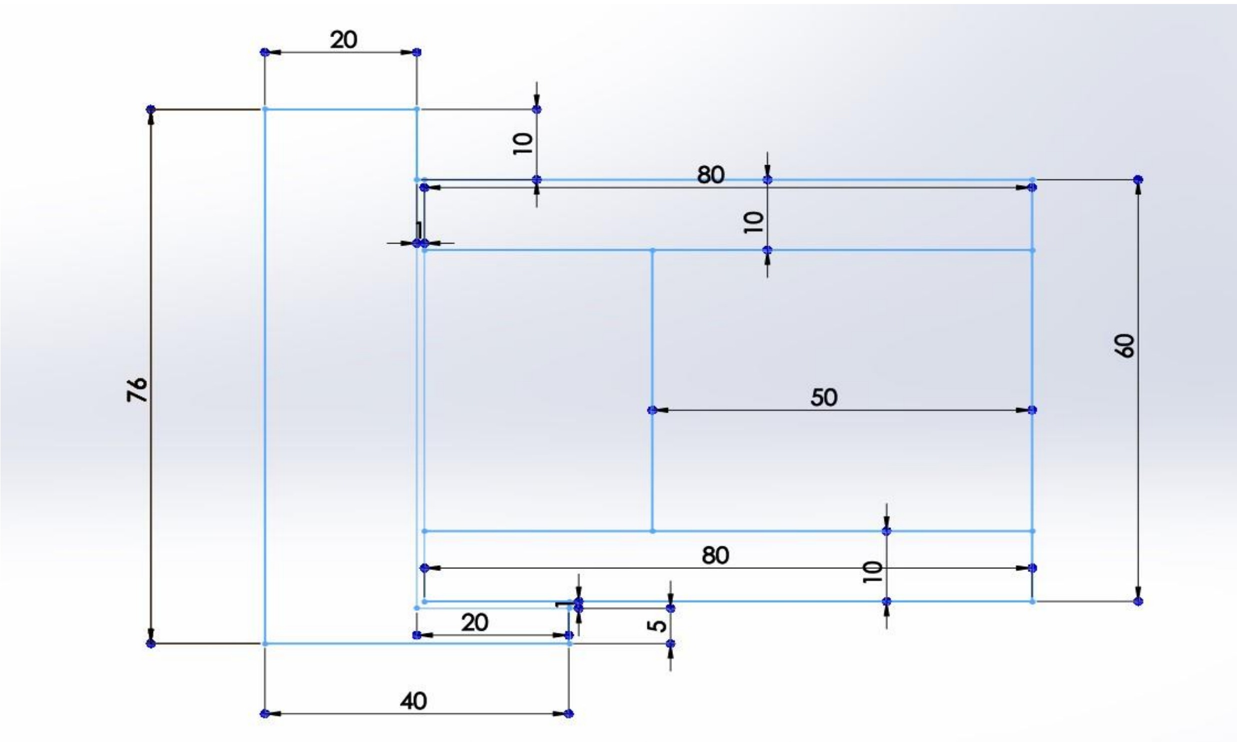

Fig 2: Quarter section front view of the specimen

A quarter view of the main specimen is designed using Mechanical ANSYS APDL. The height and width of the flange, the facesheets, the Adhesive and the balsa core is given as in the figure shown above. All the dimensions are in mm. Since the material is isometric, the results expected would be uniform for the whole specimen.

Fig 3: Quarter section front view of the specimen in ANSYS APDL

The materials description are as follows:

- Flange –Stainless steel 303
- Balsa Core-Vinyl ester balsa core
- Adhesive-Hysol EA 9394
- Facesheets- E-QXM 3608 glass laminate

2. 3 Materials properties

The properties of the materials used are in accordance with the ASTM standard. Basically, four different materials are used namely Stainless steels 303, Vinyl ester balsa core, Hysol EA 9394 and E-QXM 3608 glass laminate. Asper the requirement for the analysis purpose, two properties of each material are used, namely Young's modulus and Poisson's ratio.

Materials used	Young's Modulus(GPa)	Poisson's ratio
Stainless steel 303	193	0.25
Vinyl ester balsa core	24.6	0.126
Hysol EA 9394	4.067	0.37
E-QXM 3608 glass laminate	7.23	0.4

2.4 3D model

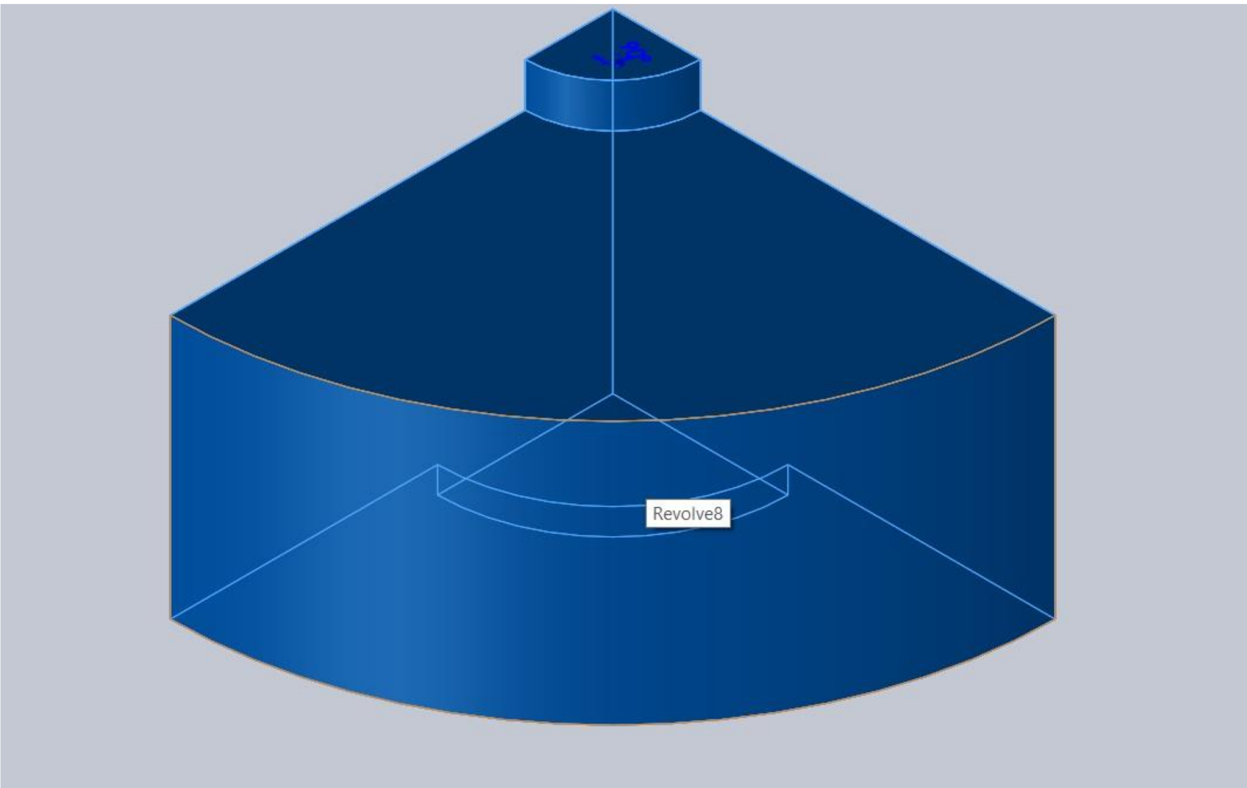

Fig 4: 3D quarter view of the specimen

After preparing the 2D design of the specimen, the sketch is sweep rotated at 90^0 and the above result is obtained in ANSYS APDL.

2.5 Meshing

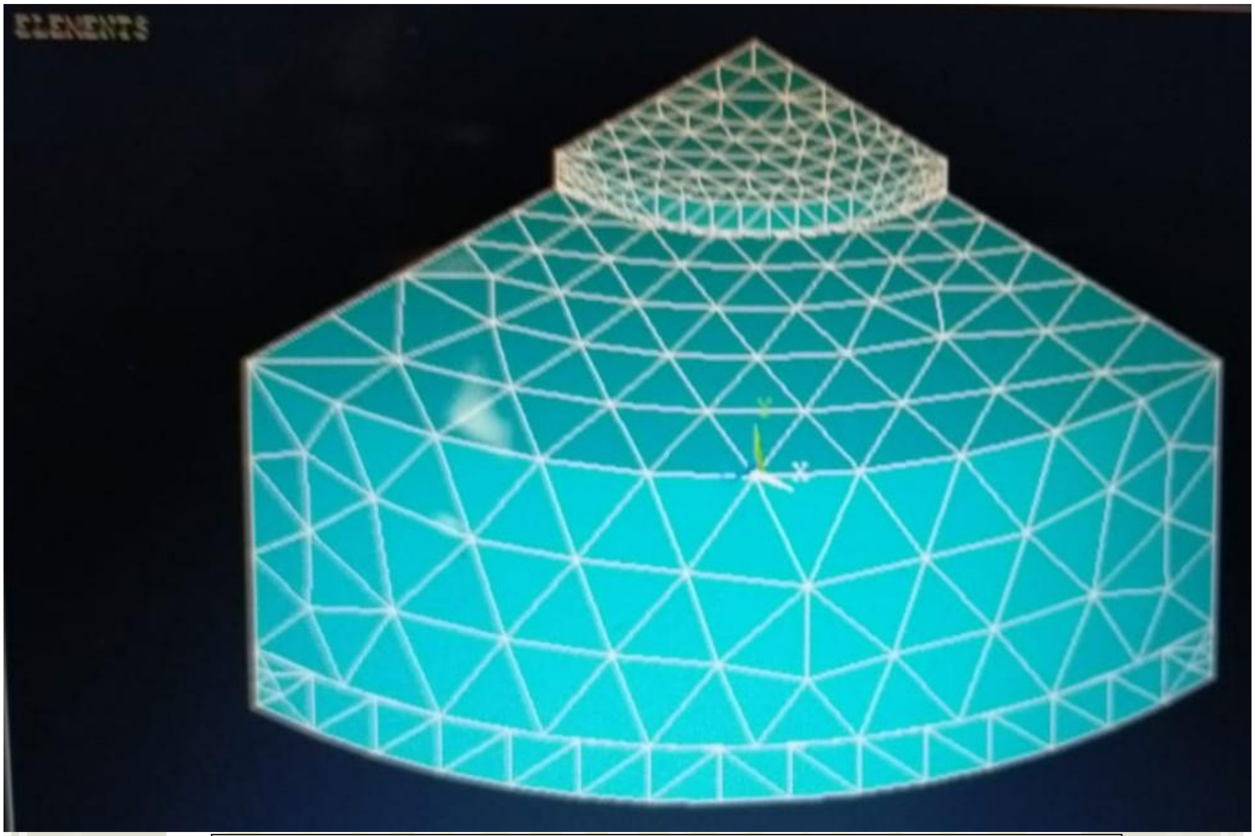

Fig 5: Hexagonal meshing using ANSYS APDL and smart sizing

An unstructured and upstretched hex-meshing is done using ANSYS APDL. The default feature of the software is used for meshing over the entire model at once. The quality used for the meshing is 5 which is considered to be fine meshing.

Chapter 3

Result and Discussion

3.1 Results

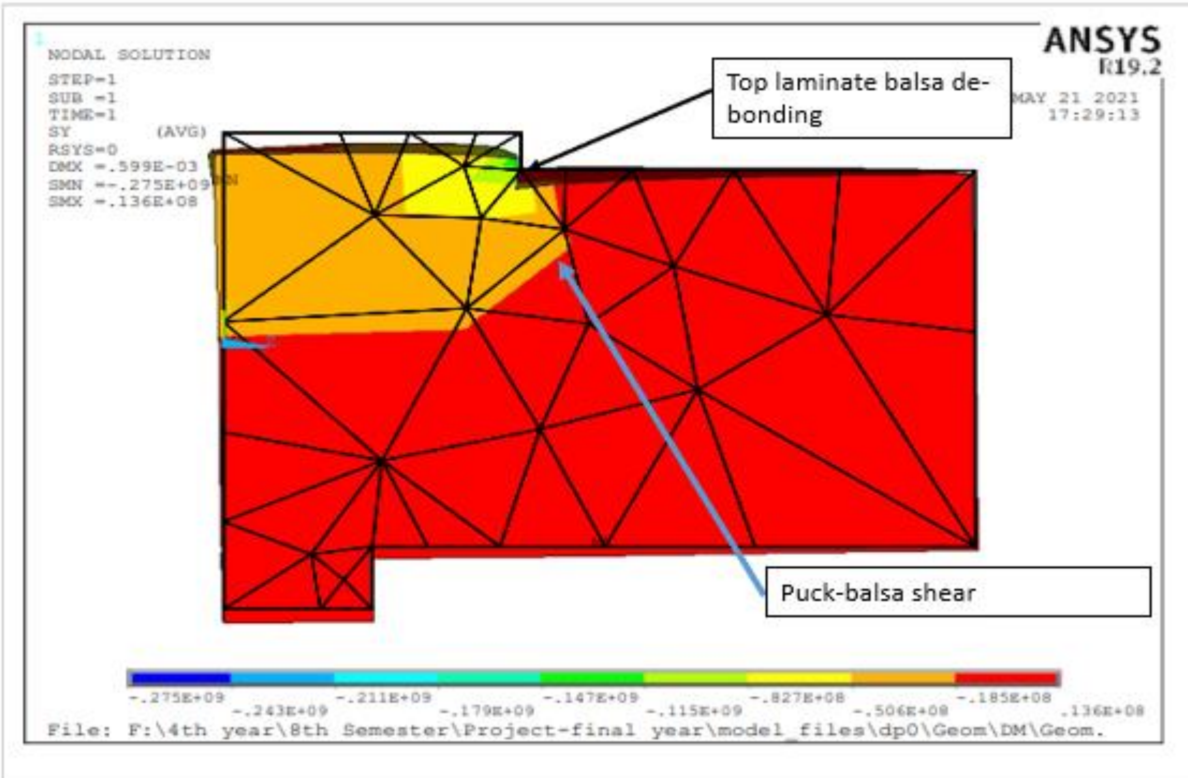

Fig 6: Deformation at Top laminate balsa de-bonding

A deformation of a spiral ribbed bonded insert pulls out configuration is shown in Fig 4. It shows initial failure in terms of first peak and then two more high peaks subsequently showing the contribution of progressive failure mechanism. It is found that the damage initiation in terms of top face-sheet debonding started around 2000 lbs and continues until the load drops due to de-bonding of bottom face-sheet. It is also assumed that at the load drop, many failure mechanisms worked simultaneously such as shearing of solid circular puck from the balsa panel and de-bonding of insert flange from pucks as shown in Fig 6. At final load drop, insert-puck combination is supposed to be come out of the balsa due to huge load drop. But it didn’t come out of the balsa core which indicates that the applied load is not much higher.

Although, the insert-puck combination was not come out of the balsa but the de-bonding almost took place at 2000 lbs, as it is supposed to be take place at 1800 lbs.

3.2 Deformation

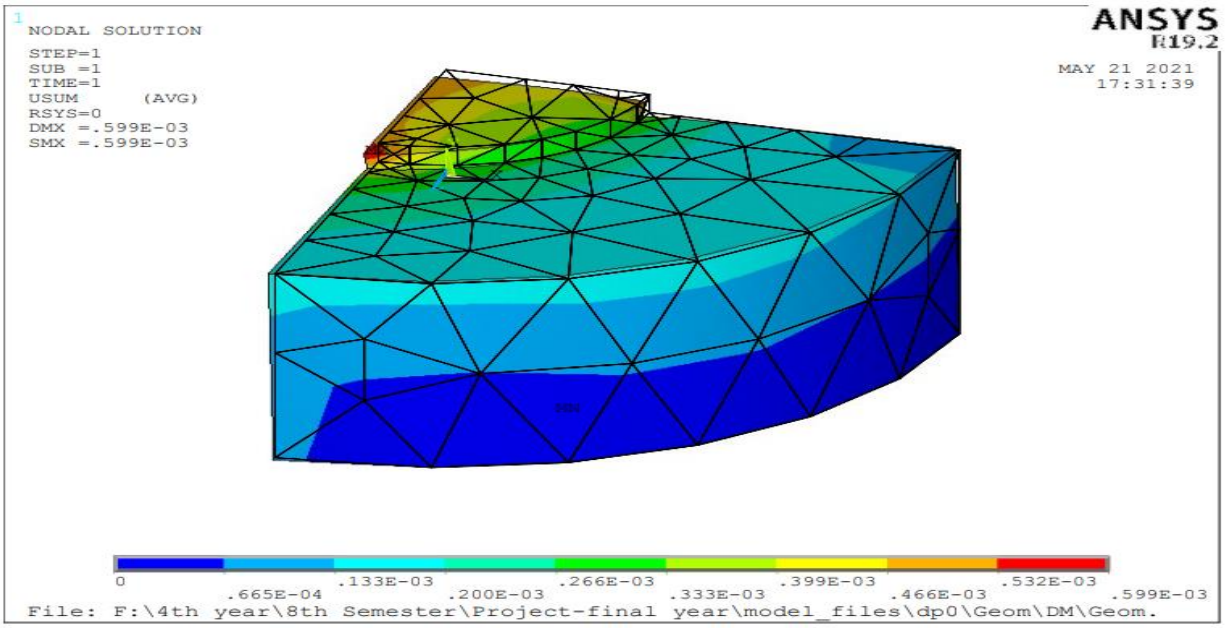

Fig 7: Deformation at Top laminate and balsa core

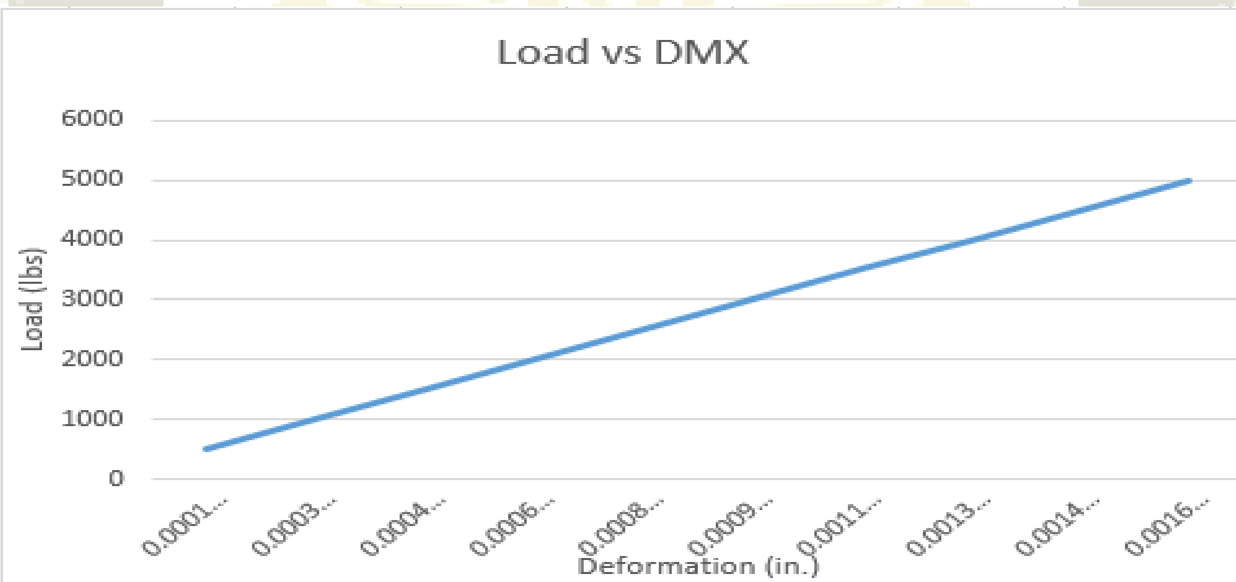

Fig 8: Deformation plot based on load applied

It is found that as the load continues to increases, the deformation also increases until the load drops due to de-bonding of face-sheet and balsa core. When huge load applied, the insert-puck combinations will come out and the load drops takes place. It is also seen that the maximum deformation takes place near top face-sheet and balsa core junction at maximum load as shown in Fig 7. The plot shows that deformation increases as the load applied increases as shown in Fig 8.

3.3 Shear Stress

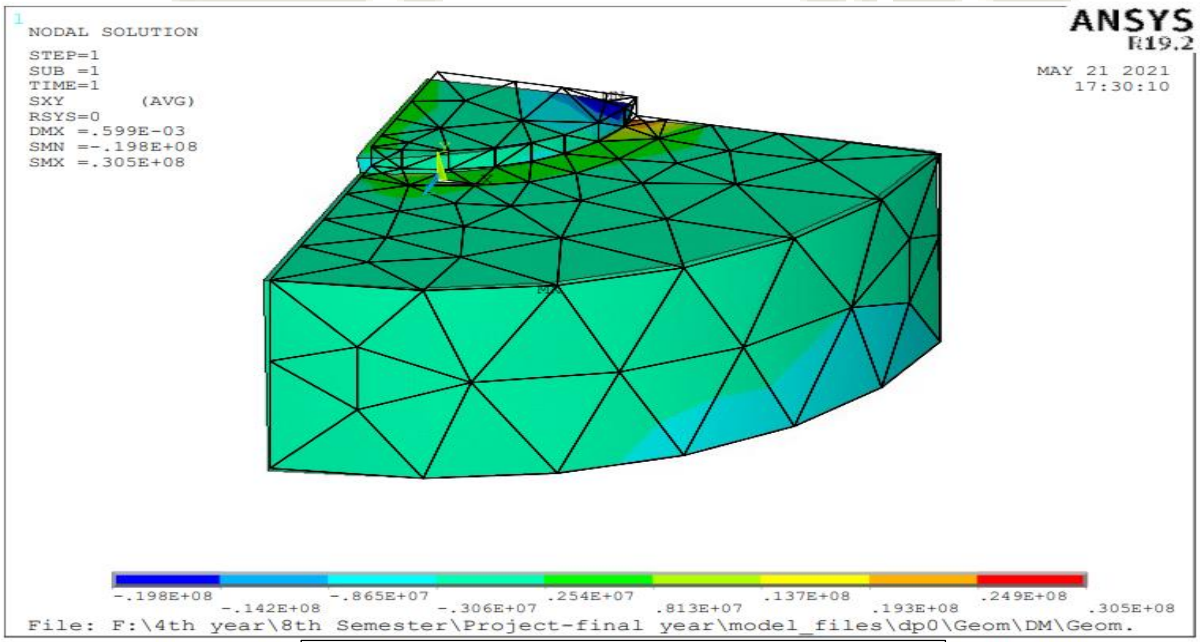

Fig 9: Shear stress at puck-balsa junction

At puck-balsa junction shearing takes place due to simultaneously load drop at puck-balsa junction. Also, many failure mechanisms such as shearing of the solid circular puck from the balsa panel, cohesive failure of the metallic insert from the puck due to shear and de-bonding of the insert flange from the puck. The maximum shear stress is found to be near puck-balsa junction in x-direction and very less impact on top face-sheet and balsa core junction in y-direction as shown in Fig 9. At this point maximum deformation is 0.599×10^{-3} in. and maximum stress developed is around 30.5 Mpa.

3.4 Stress Intensity

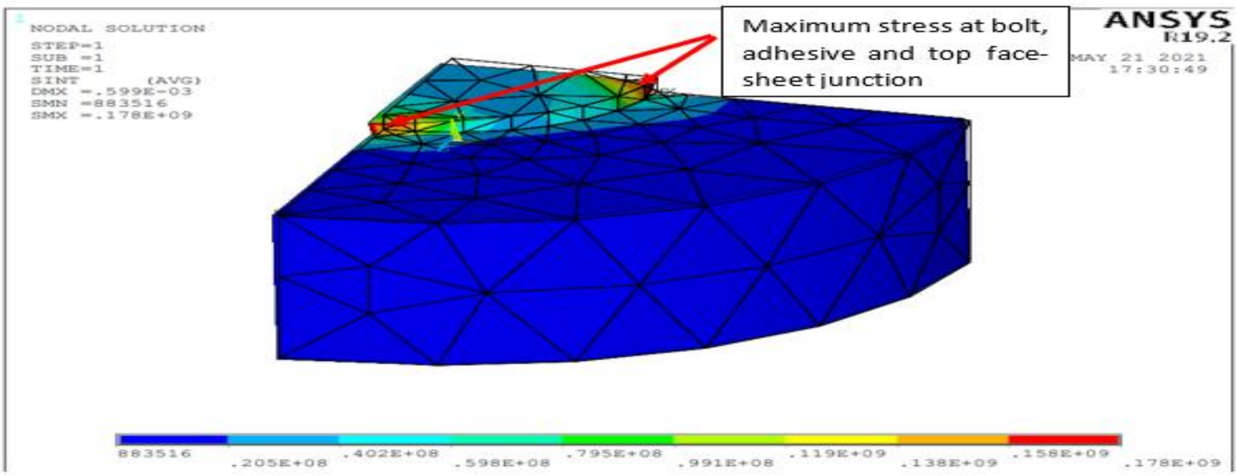

Fig 10: Stress Intensity at bolt, adhesive and top face-sheet junction

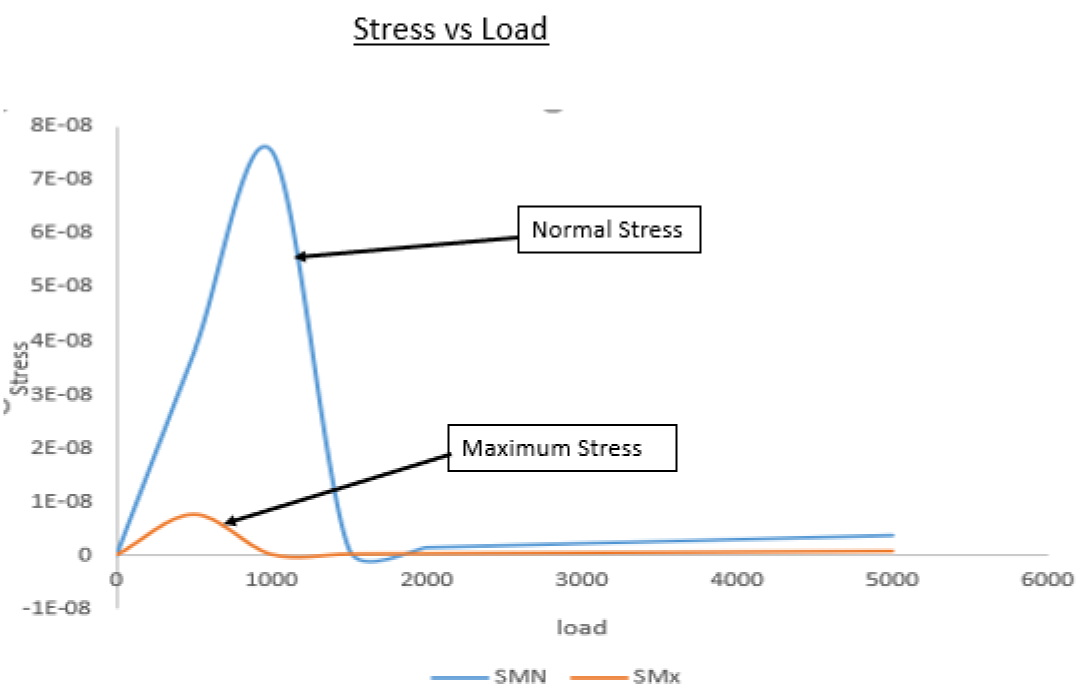

Fig 11: Stresses plot at bolt, adhesive and top face-sheet junction

It is found that stress intensity is more at bolt, adhesive and top face-sheet junction as shown in Fig 10. The normal stress is increases gradually and reach maximum at load of 1000 lbs and decreases drastically from 1000 to 2000 and remains constant after 2000 lbs. Whereas, maximum stress was not changing drastically as compared to normal stress and hence remains constants after 2000 lbs as shown in Fig 11.

Table 2: Load applied, Deformation, Normal Stress and Maximum Stress

Load	DMX	SMN	SMX
0	0	0	0
500	0.000166	3.78E-08	7.65E-09
1000	0.000333	7.55E-08	1.53E-10
1500	0.000499	1.13E-09	2.29E-10
2000	0.000665	1.51E-09	3.06E-10
2500	0.000832	1.89E-09	3.82E-10
3000	0.000998	2.27E-09	4.59E-10
3500	0.001164	2.64E-09	5.35E-10
4000	0.001331	3.02E-09	6.12E-10
4500	0.001497	3.4E-09	6.88E-10
5000	0.001663	3.78E-09	7.65E-10

Chapter 3

Conclusion

Design configurations of adhesively bonded stainless-steel inserts are investigated with the objective of developing a structurally efficient joint for composite application in the motor vehicle industry. The bonded insert joints were characterized for pull out loading at room temperature using Mechanical ANSYS APDL. Failure modes of the adhesive, the insert and sandwich composites panel were analyzed in ANSYS APDL at different load applied conditions. Adhesive, cohesive and mixed mode of failures were observed in the bonded region. The data generated by these tests will serve as basic guideline for the design of such joints in automotive industrial applications where composites are required for weight reduction. It is found that at 1800lbs, the failure of the material takes place.

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