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Thermo-mechanical analysis of a double notched adhesive lap joint with FEA software

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Abstract— ***Conventional methods of joining two objects metallic and/or non-metallic are riveting, welding and screw threading. But in few applications above mentioned fastening methods are not possible to be implied on. For example when it is required to fasten a metallic object and a non-metallic object or when the assembly is to be working in a very extreme temperature condition, then conventional fastening processes does not hold good or does not work at all. In these situations adhesive joints are very useful. But it a matter of extreme research to perfectly design an adhesive joint as per the mechanical properties of the components to achieve optimum structural integrity and strength. In the present work an adhesive joint between a metallic and a composite material has been designed and its structural behaviour has been analysed numerically using a Finite Element Analysis software named ANSYS. To analyse the joint using ANSYS, its Cohesive Zone Modelling (CZM) technique has been used.***
Keywords— ***Adhesive joint, ANSYS, Cohesive Zone Modelling, Contact frictional stress.***

I. INTRODUCTION

Traditional methods of Joining two metallic objects used to be riveting, bolting and welding. But after the introduction of polymeric materials as the materials for construction of parts of an assembly concept of fastening method has been changed. Fro the time of World War II different adhesive materials are being used to fasten non metallic objects. But proper selection of adhesive materials and proper design of adhesive joint has always been a matter of research. In today's world with the introduction of composite materials use of adhesive joint has been increased drastically [3].

The main reasons behind the use of adhesive joint are its [4] High strength to weight ratio, Stresses distributed evenly over the joint width, No drilled holes needed, Weight and material cost savings, Improved aerodynamic surface design, Superior fatigue resistance and Outstanding electrical and thermal insulation.

Use of adhesives in fastening methods has few limitations. Extreme temperature and humidity can weaken the bond when the bond becomes under continuous stress. Creep is a predominant effect which must be taken care of when adhesive is used with polymers. Though we can avoid drilling, machining and riveting processes in the process of adhesive fastening but surface preparation is a very important aspect in adhesive joint especially when metals are used as adherent.

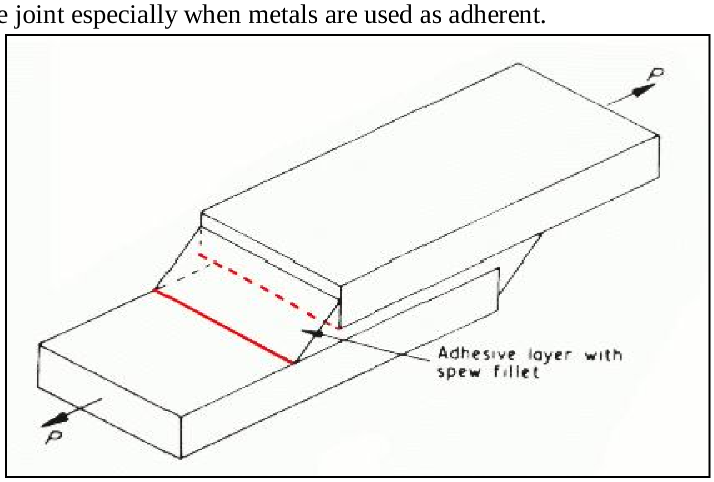

Figure1: Schematic representation of a SLJ showing forces and a red mark which depicts the area sensitive to crack initiation.

There are many types of joint configurations which are used in adhesive joint. Most commonly used joint is double lap joint (DLJ) which has been shown in figure above. When a DLJ is subjected to an axial load, tensile or compressive, maximum stress occurs at the end of the joint. This fact has been depicted in figure 3 where stress distribution of different joint has been represented graphically. From the stress distribution it is clear that stress at the edge of the joint is maximum and due to this crack opening starts there and peel opening continues until total failing occurs. The crack generated at the edge depends on the stress-concentration occurs and the stress concentration that occurred in turn depends on the material properties of adhesive, material properties of adherents and the design of joints. Figure below is the shear stress distribution between two carbon-fibre reinforced polymers joined by a DLJ using an adhesive.

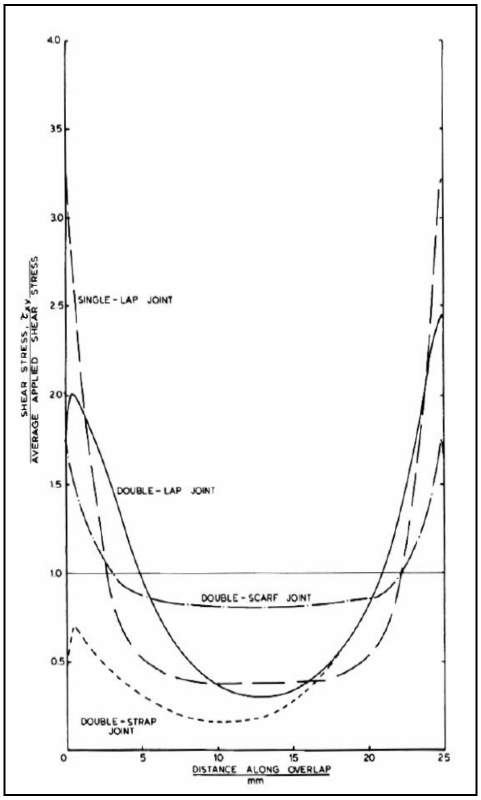

Figure 2: Distribution of contact shear stress between two CFRP objects joint by an adhesive with different type of joints

II. PROBLEM DEFINITION

From the above discussion it is clear that proper design of a joint configuration can increase the strength of the joint. Enhancement of strength of a joint ensures enhancement of required contact stress to initiate a crack at the edge due to stress concentration. In the present work few joint configurations have been analysed numerically with the help of a FEA software named ANSYS using its Cohesive Zone Modelling (CZM) technique.

In the present work a joint between pipe and flange of a turbine exhaust duct (TED) used in a rocket engine turbine has been analysed. The material of the pipe is a composite material named carbon fibre reinforced polymer (CFRP) and flange material is Titanium-Aluminum alloy Ti 6Al-4V (Which is also known as EA-9394). These two components has been joined by an adhesive through a double lap joint (DLJ) configuration. The details of the material properties of materials other design data has been used from references [12] and [14]. This joint has been used in a rocket engine named Vinci Engine and the TED for this engine has been designed by Volvo Aero Corporation. The maximum pressure which the TED has to bear is 10 MPa at a temperature range of room temperature to -140°C temperature.

III. REVIEW OF PREVIOUS WORK

The double lap joint which has been designed by Volvo Aero is a taper shaped DLJ [14]. Pravesh Kumar Soni and Hari Ram Chandrakar [16] have analysed a modified the taper DLJ by introducing a notch has shown that due to the introduction of notch the induced contact shear stress between the adhesive and adherents gets lowered significantly. In the present work analysis of original tapered DLJ as per reference [14] and notched taper DLJ as per reference [16] has been reproduced using ANSYS CZM technique and few modification has been done on the ANSYS APDL programming. Following figure is the configuration of the tapered DLJ used by Volvo Aero [14].

A. Geometry

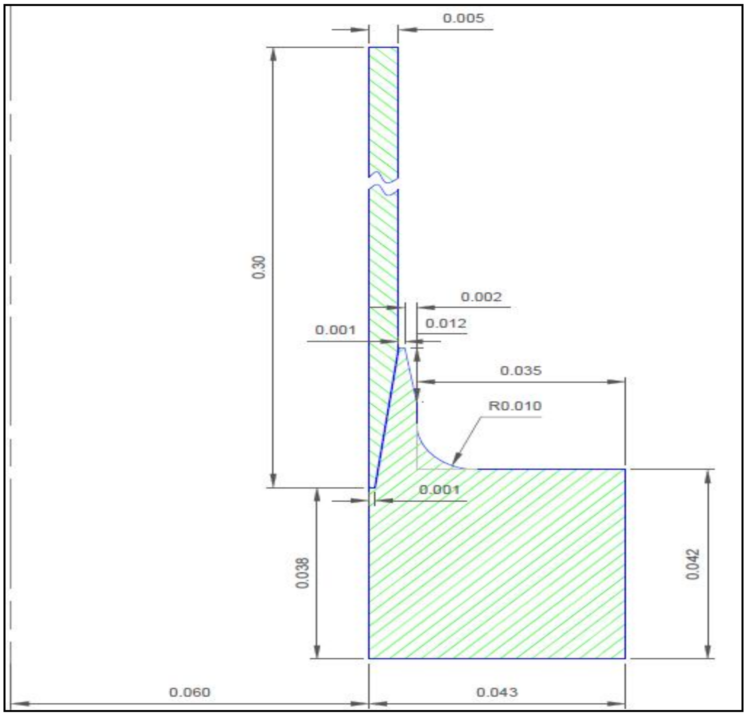

Figure 3: schematic representation of a tapered lap joint with all the dimensions.

A model has been generated in ANSYS as per the figure 10 which has been shown below.

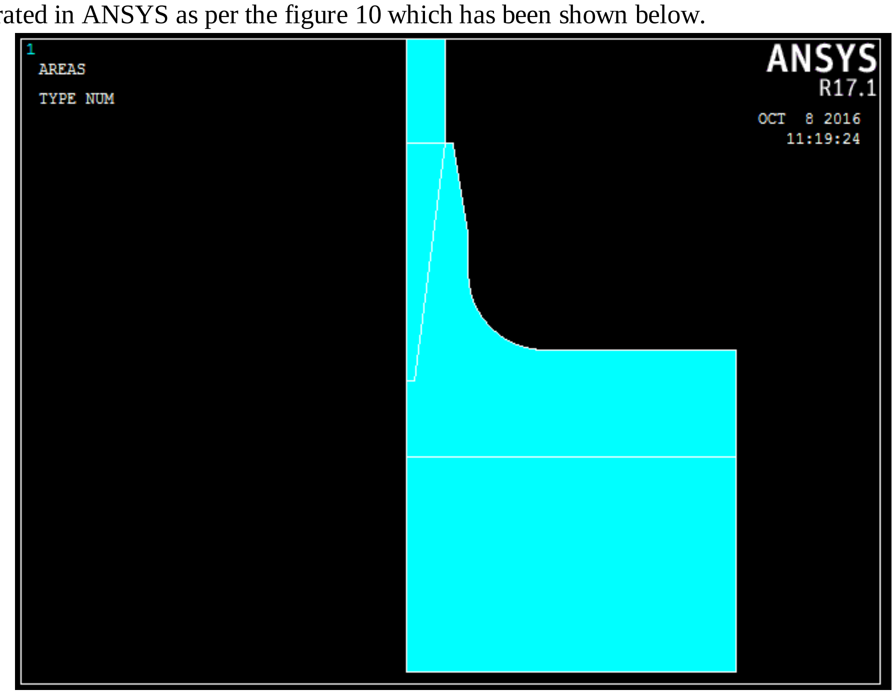

Figure 4: Topology of a tapered lap joint crested in ANSYS

After generating model material properties of the pipe which is made of Carbon fibre Reinforced Polymer (CFRP) and material properties of the flange which is made of Titanium-Aluminum alloy Ti 6Al-4V have been imparted. Table below shows different property values taken from reference [12] and [14].

Table 2: Material Properties of DLJ TED for Couple-field Transient analysis [12][14].

Parameters	CRFP (Composite)	EA 9394 (Isotropic) (Ti 6Al-4V)	Units
Elastic Modulus (E_x/ E_y/ E_z)	10.1/52.9/52.9	114	GPa
Poisson's Ratio (ν_{xy} /ν_{yz}/ν_{zx})	0.056 / 0.317 / 0.056	0.3	-
Shear Modulus (G_{xy}/G_{yz}/G_{zx})	3.69 / 20.1 / 3.69	-	GPa
CTE (α_{xx}/ α_{yy}/ α_{zz})	56.1×10^{-6} /3.8×10^{-6} /3.8×10^{-6}	69×10^{-6}	K^{-1}
Spec. Heat Capacity (C_p)	900	1340	J/kgK
Density (ρ)	1528	1150	Kg/m^3
Thermal Conductivity (k_{xx}/k_{yy}/ k_{zz})	0.78/5.54/5.54	0.24	W/ mK
Max contact stress (σ_{max}/ τ_{max})	-	44.5/40	GPa
Critical Fracture Energy (G_{Ic}/G_{IIc})	-	425/2000	J/m^2
Contact Stiffness (K_n/K_t)	-	2×10^{13}/1×10^{12}	N/m^2

To mesh the whole two dimensional topology of the pipe and flange PLANE 223 element has been used and construct the contact between pipe and flange representing double lap joint, TARGE 169 and CONTA 172 have been used. Following figure shows the meshed view of the tapered DLJ.

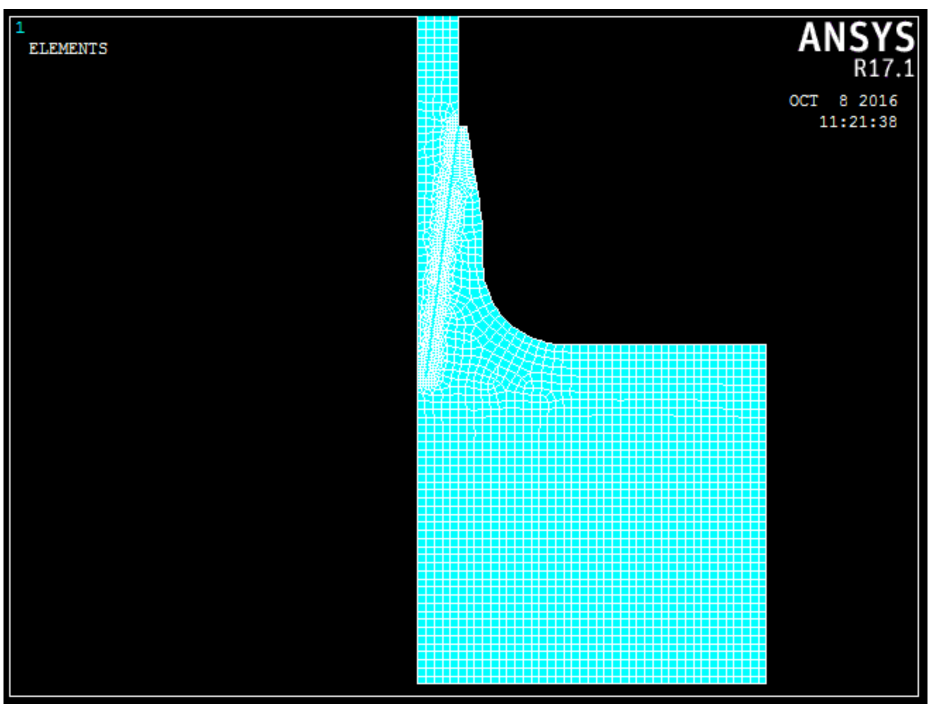

Figure 5: Meshed view of the 2D geometry.

After meshing, a nonlinear analysis has been performed which has evaluated following result.

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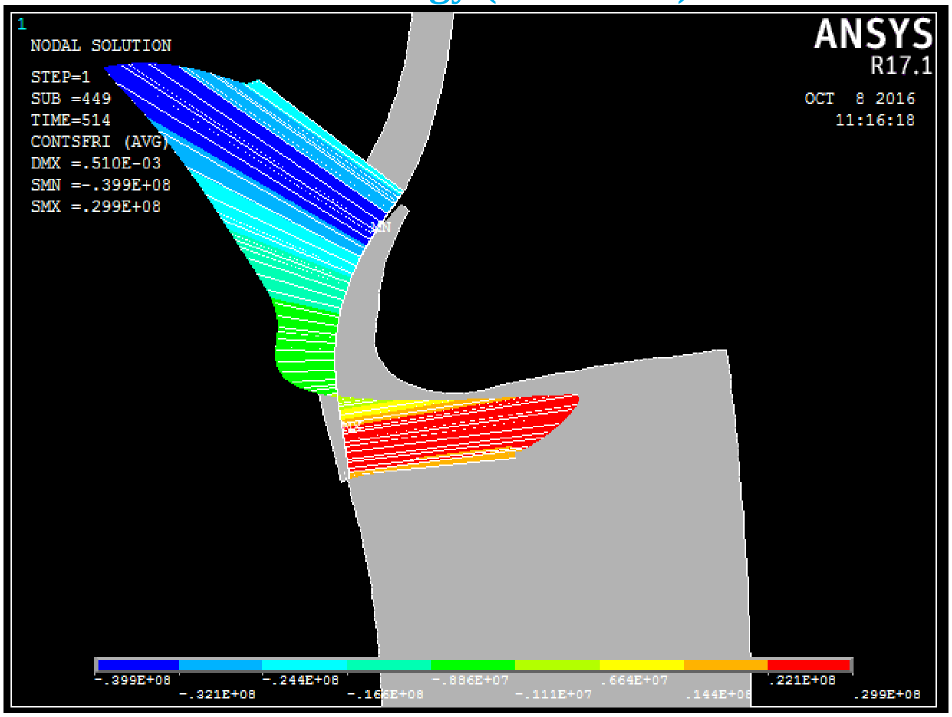

Figure 6: Contact frictional stress distribution under the thermo-mechanical loading.

The above result shows that result derived in reference [16] and result evaluated in the present work is little bit different as the APDL programme has been modified little bit to validate the result of reference [12] and [14] more closely.

After the minor modification of the APDL programme the notched DLJ has been reproduced. Following figure represents topology and meshed view of the joint.

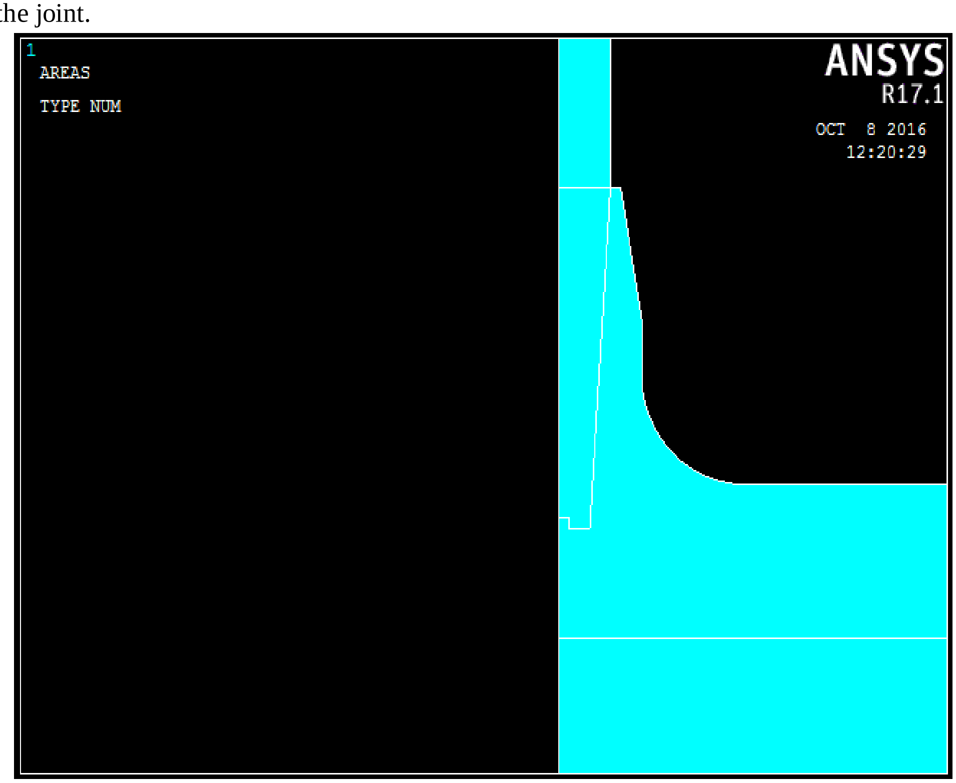

Figure 7: Two dimensional topology of notched DLJ.

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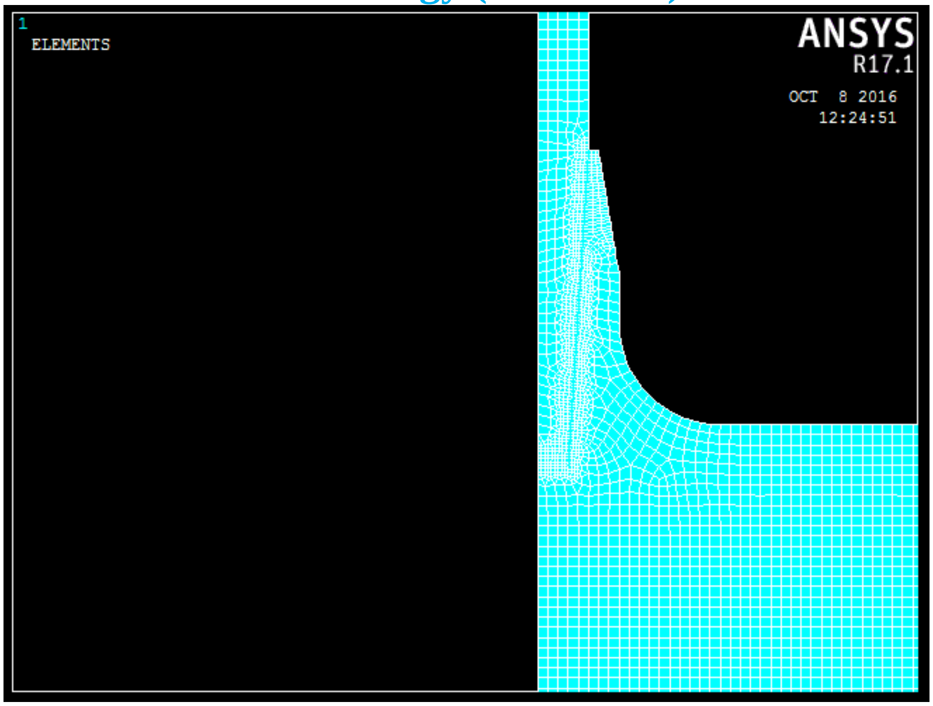


Figure 8: Meshed view of two dimensional topology of notched DLJ

After meshing stress distribution has been evaluated by non-linear analysis using the modified APDL. Following figure shows the contact stress distribution.

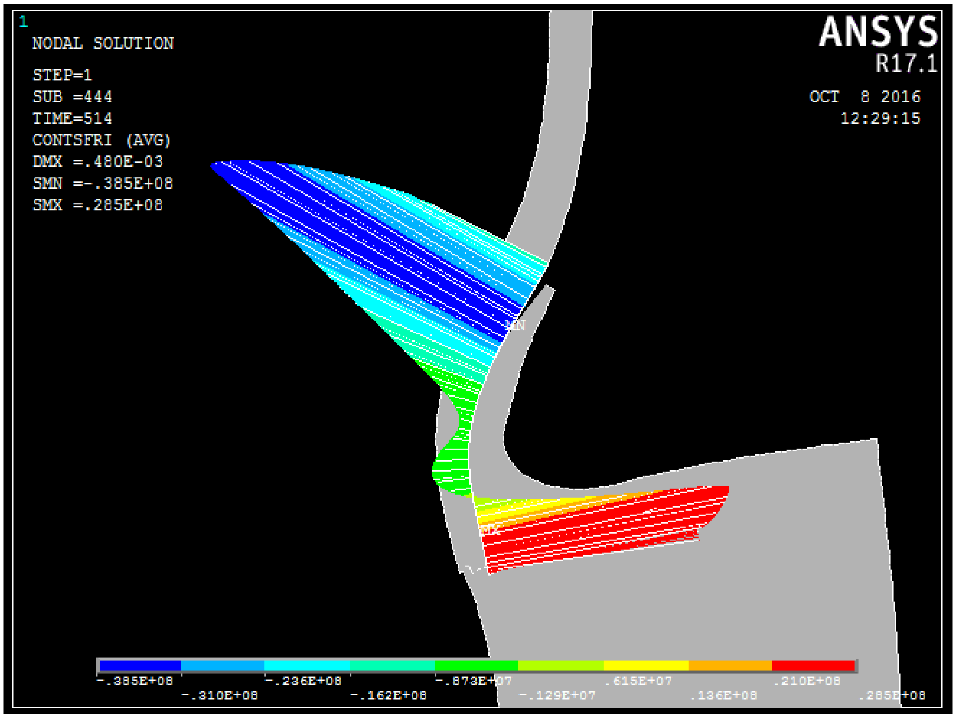
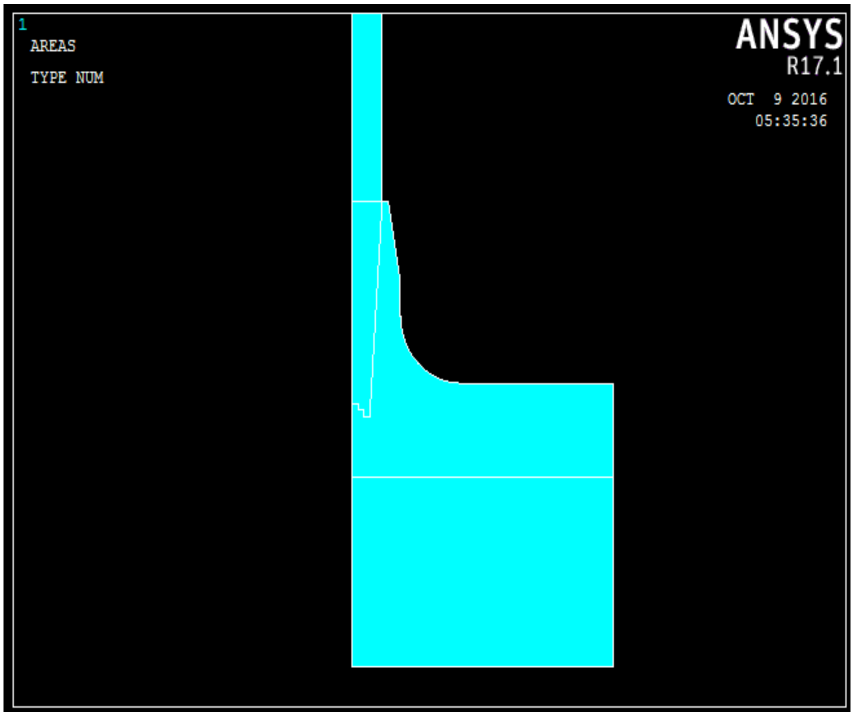


Figure 9: Contact Frictional stress of the tapered DLJ.

IV. FURTHER MODIFICATIONS IN TED GEOMETRY

A double notch has been introduced in the present work over the modification introduced in previous work of the authors which has been mentioned in reference [16]. Following figure shows the double notched lap joint where two notches have been given each of thickness 1mm and height 1mm. No taper has been given within the notch sections. These two straight notches will take more shear load along with bending load. This will reduce load on the axial contacts of the lap joint and thus reduce the induced contact shear stress that will be generated at the contact surface of the lap joint between adhesive and adherents.

Figures below shows the 2-dimensional topology of the double notched lap joint, meshed view of the double notched lap joint and the contact shear stress distribution that has been evaluated from the non-linear analysis of the joint under the predefined thermo mechanical load.



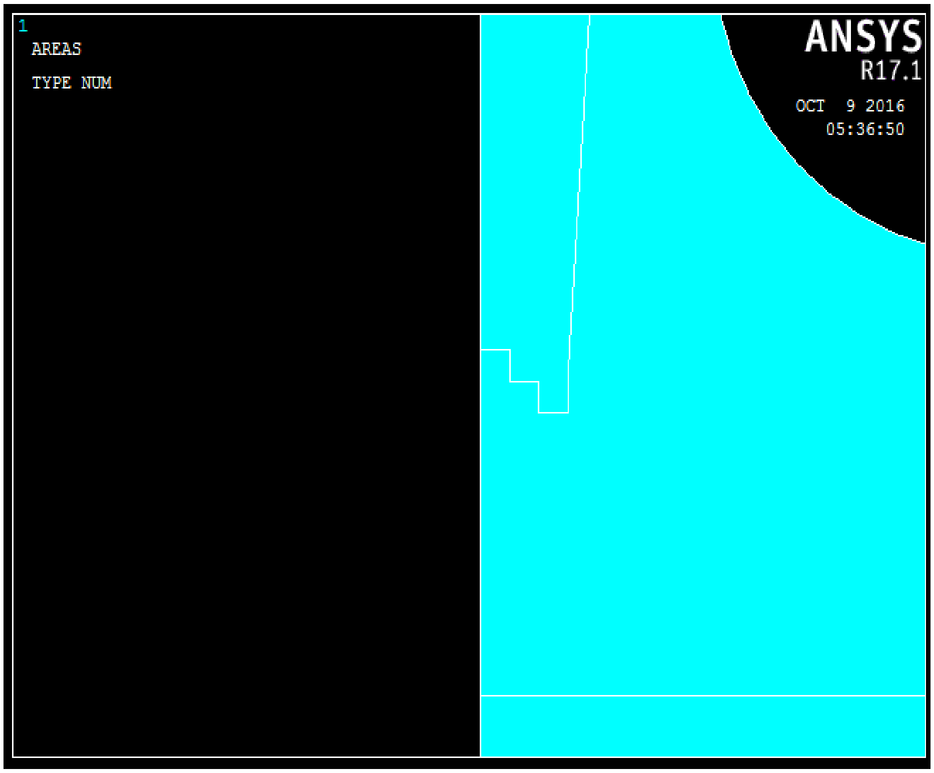


Figure 10A,B: 2-Dimensional topology of double notched lap joint

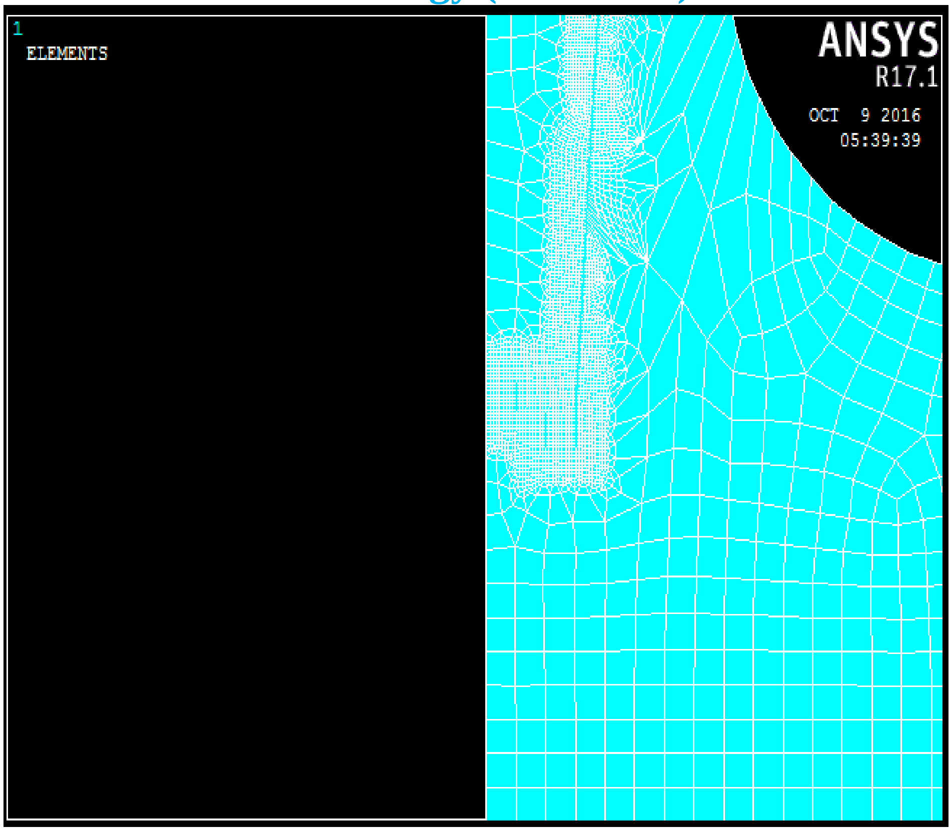


Figure 11: Meshed view of the 2-Dimensional topology of double notched lap joint

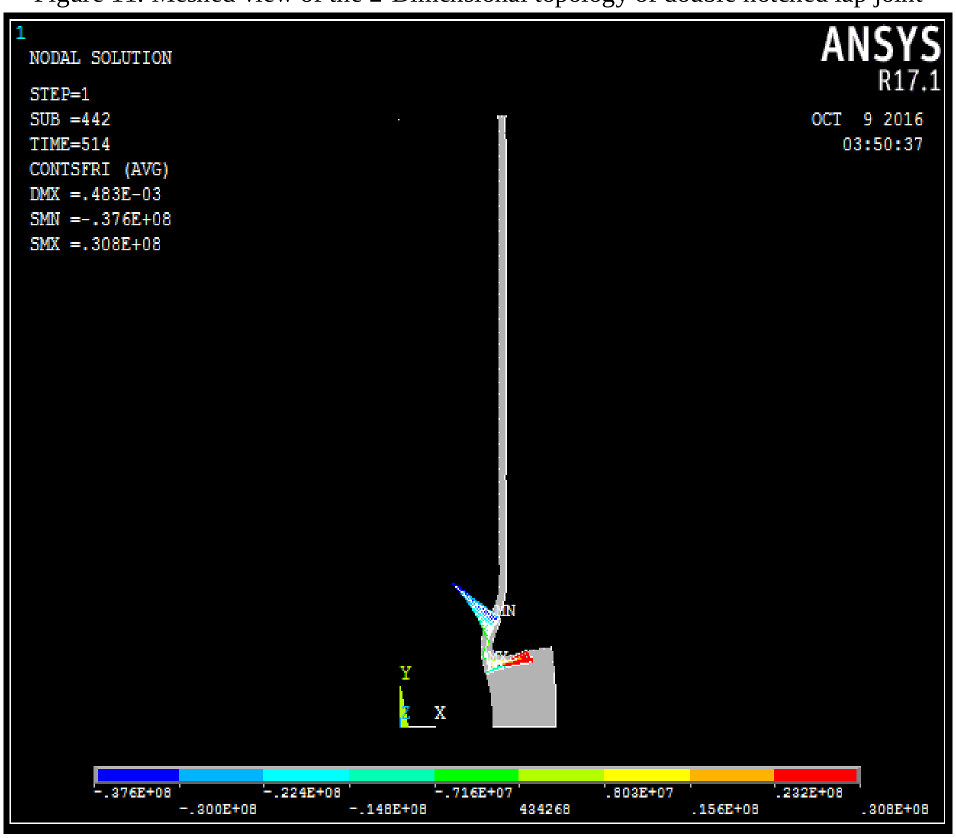


Figure 12: Contact stress distribution of the double notched lap joint

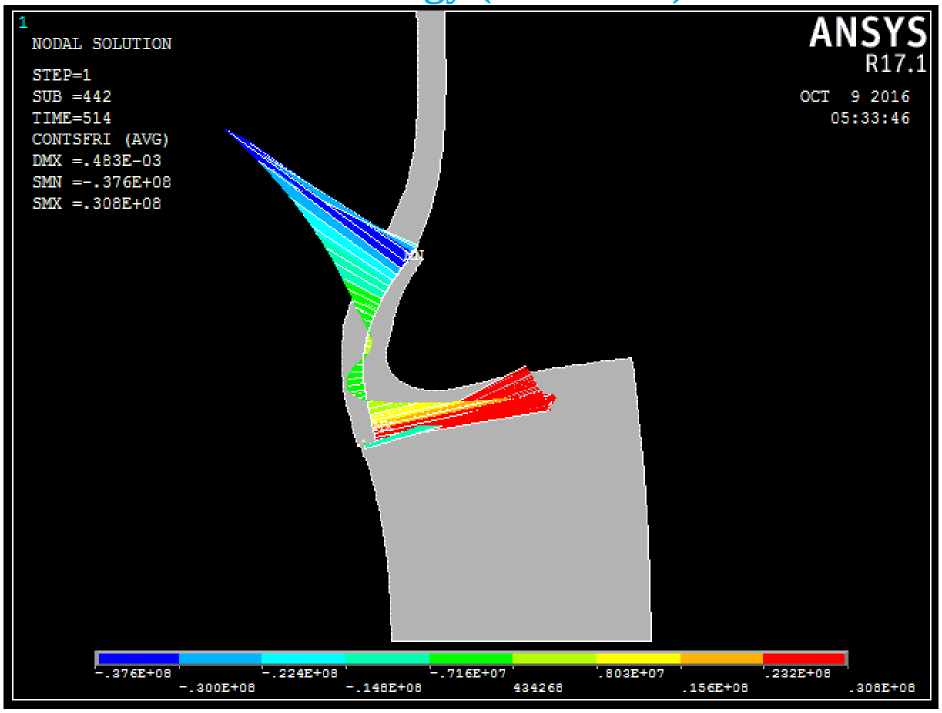


Figure 13: Enlarged view of Contact stress distribution of the double notched lap joint

V. CONCLUSIONS AND FUTURE SCOPE

From the above result it is clearly depicted that notches in the lap joint always bear more bending and shear load. But it is also true at the same time that to create the tiny notches in the composite pipe is very difficult to machine. At the same time there is a huge scope in the optimization of the dimensions of the notches and its shape which will generate maximum contact stress with minimum difficulties in manufacturing the notches.

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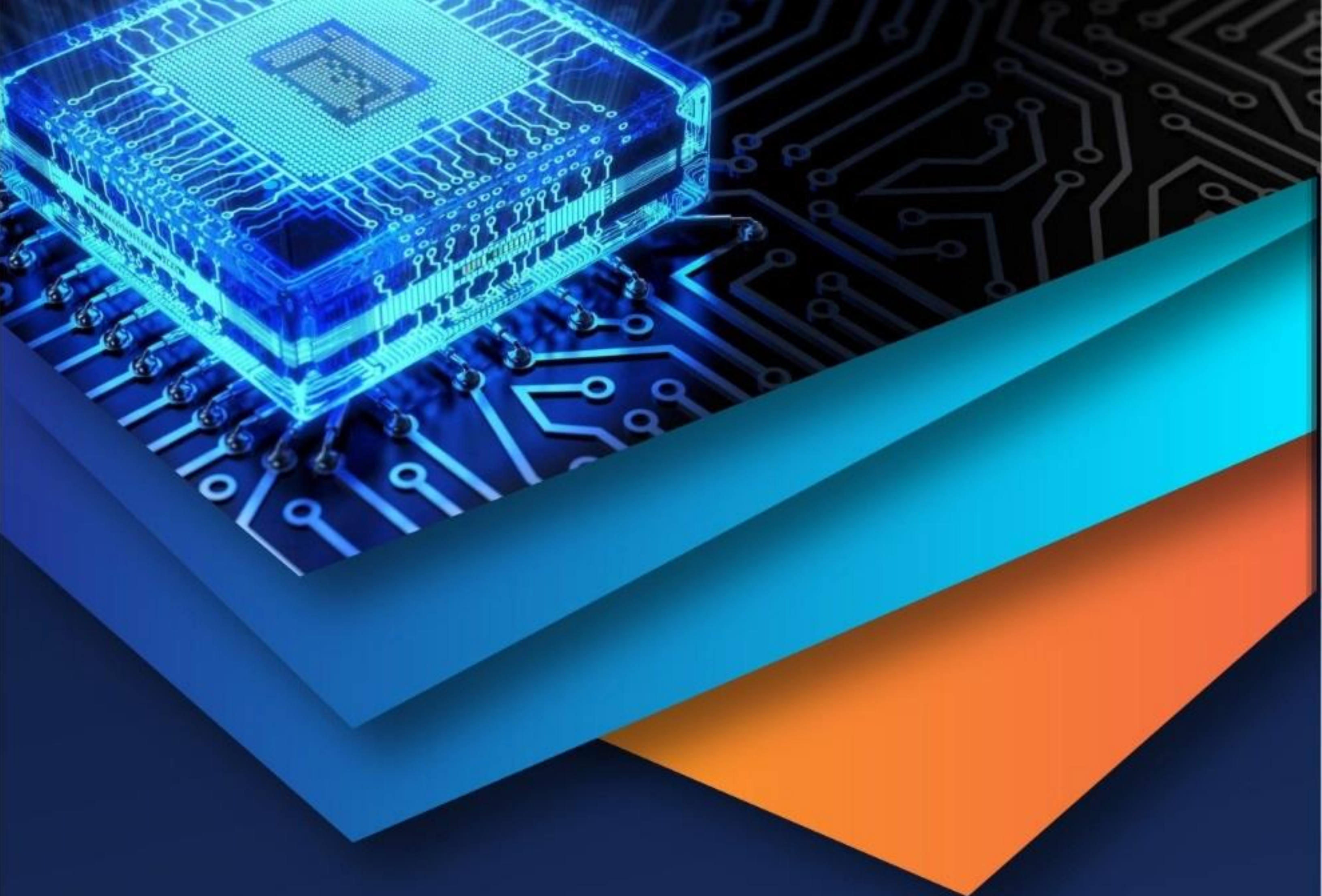

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