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Three Dimensional Finite Element Analysis of Layered Composite Plate with Elastic Pin under External Uniaxial Loading

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ABSTRACT: Stress analysis plays important role in the structural integrity and optimization. Prior stress estimation helps in better design of the products. Composites find wide usage in the industrial and home applications due to its strength to weight ratio. Especially in the air craft industry, the usage of composites is more due to its advantages over the conventional materials. Composites are mainly made of orthotropic materials having unequal strength in the different directions. Composite materials has the drawback of delamination and debonding due to the weaker bond materials compared to the parent materials. So proper analysis should be done to the composite joints before using it in the practical conditions. In the present work, a composite plate with elastic pin is considered for analysis using finite element software Ansys.

Initially the geometry is built using Ansys software using top down approach with different Boolean operations. The modeled object is meshed with 3 dimensional layered element solid46 for composite plate and structural three dimensional solid element Solid45 for pin material. Various combinations are considered to find the strength of the composite joint under uniaxial loading conditions. Due to symmetry of the problem, only quarter geometry is built and results are presented for full model using Ansys expansion options. The results show effect of pin diameter on the joint strength. Here the deflection and load sharing of the pin is increasing and other parameters like overall stress, pin stress and contact pressure is reducing due to lesser load on the plate material. Further material effect shows, higher young modulus material has little deflection, but other parameters are increasing. Interference analysis shows increasing of overall stress, pin stress, contact stress along with pin bearing load. This increase should be understood properly for increasing the load carrying capacity of the joint. Generally every structure is preloaded to increase the compressive stress in the joint to increase the load carrying capacity. But the stress increase should be properly analysed for composite due to its delamination and debonding effects due to failure of the bond materials. When results for an isotropic combination is compared with composite joint, isotropic joint shows uniformity of the results with lesser values for all parameters. This is mainly due to applied layer angle combinations. All the results are represented with necessasary pictorial plots.

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KEYWORDS: Displacement, Bearing force, Frictional force, Finite Element Analysis, Ansys and 3 dimensional.

I. INTRODUCTION

In this section, we examine the problem of composite laminates with an elastically pinned circular hole. The effects of friction and bearing load on the stress redistribution are studied in detail, based on the infinite plate configuration. The issues of practical interest, such as the loading-history and cycling dependencies of stress state due to the presence of friction, are addressed. The material properties and the numerical meshes used in the simulation are described below. The laminate plate contains seven plies of identical orthotropic material with the stacking sequence $(0/\pm45/\bar{90})s$. The orthotropic material represents a unidirectional fiber-reinforced composite plate. With the fibers lying in the horizontal plane (Lubin, 1982). The number in the stacking sequence indicates the in-plane rotation angle of each ply relative to the reference 0^o-ply where the fibers lie in the 0^o direction. The elastic constants are given by E_1=138 GPa, E_2 = E3 =14.5 GPa, $\mu_{23=}$ $\mu_{13=}$ $\mu_{12=}$5.86 GPa, and $\nu_{23}=\nu_{13}=\nu_{12}$=0.21. Meanwhile, the isotropic pin is made of Ti–6Al–4V, and the

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elastic constants are given by Ef =110 GPa, and ν=0.31. The hole radius R is taken to be the normalization length scale. The plate thickness H = 1.4R, i.e., ply thickness = 0.2R. The length of the pin is 2R.

Note that the elements and nodes on the hole surface match with those on the vertical surface of the pin. The nodes on the hole surface and those on the pin surface are numbered separately.The mesh used in the simulation is described as follows. The hole surface is discretized with equal divisions in the thickness direction (i.e., six vertical divisions per ply). The elements are of the constant type, assuming uniform fields in each element and with a single node located at the center. The vertical surface of the pin is discretized, among these elements, those between the plate surfaces are in one-to-one correspondence with those on the hole surface. The top and bottom surfaces of the pin are discretized with same pattern.

II. LITERATURE REVIEW

Chen et al. [1] analyzed 3D contact stress in the mechanical joints of symmetric composite material layers by numerical method. Their results were accomplished using local contact between pin and hole, considering 3D friction and clearance.

Kadivar and Shahi [2] calculated contact surfaces between pin and hole along thickness of multiple layers by 3D finite element model with ANSYS software. They assumed solid pin. Considering appropriate boundary conditions, they also modeled pin-hole effect and checked geometry effect on contact region and stress distribution.

Tayfun Gulem et.al.[3] carried out a study to deal with the bearing strength, failure mode and failure load in a woven laminated glass vinyl ester composite plate with circular hole subjected to a traction force by a rigid pin. They investigated for two variables; the distance from the free edge of the plate to- the diameter of the hole (E/D) ratio and the width of rectangular plate-to-the diameter of the hole (W/D) ratio numerically and experimentally.

McCarthi et al. [4] investigated clearance effects on stress distribution for multiple pin joint, by use of FEM and MARC software. Yavari and Kadivar [5] studied the effects of contact surface between pin and shell in mechanical single edge “composite” materials by use of ABAQUS software. In this research, they considered 3D joint behavior and also friction effect. Wimmer and Pettermann [6] numerically simulated separation in composite plates. In his study, he used combination of critical and failure loadings. Alenfaie [7] modeled composite plates with internal separation plates by use of finite element method. He used a 3D model and calculated natural frequency and displacement in various cases.

Yang et al. [8] defined exact numerical method for mechanical behavior of composite plates with elastic joints. They assumed isotropic joints and also considered friction in contact surface between joints and plates. In their analysis, plates were assumed symmetric. Hyer and Liu (1984) investigated effect of pin elasticity, clearance and friction on radial and tangential stress distribution around hole in mechanical joints of orthotropic plates by numerical method. Their model was 2D and constituted of two symmetric layers to investigate aforementioned parameters.

III. EXPERIMENTAL PROCEDURE

Steps carried out for Modeling
Step 1: Mesh the plate with circular hole of radius 5mm, without any triangular element at the circular region.
Step 2: Now create the laminate of desired thickness, by dragging the elements along Z directions with required number of layers along the ply thickness (Ex: 6 layers/ Ply).
Step 3: Create 7 ply’s of same thickness, by dragging it along Z direction, as shown in Fig 1.
Step 4: Create separate collector with desired name for each ply, and move those elements to newly created collector.
Step 5: Create mesh at the top of the pin face, and project those elements to top of the ply plane, then create elements by drag option. While creating pin elements nodes on circumference of pin should match with those nodes on the ply hole face and extend the elements of pin to the desired length on either sides
Step 6: Create a rigid at one end of the composite plate by selecting all the nodes to apply a single point load on it.

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Step 7: Create constrain (all degrees fixed) at the other end of the composite plate and at top and bottom of the pin, as shown in Fig.2.
Step 8: Create material property for Composite plate and Pin.
Step 9: Create property for each ply with desired ply orientations along with the thickness and assign to respective ply.
Step 10: Apply desired load on the centre node of the rigid.
Step 11: Define contact between pin and composite plate interface with the frictional value of 0.3, by selecting nodes on plate hole face and pin surface at the contact region.
Step 12: Submit the run in Ansys and post process the result.

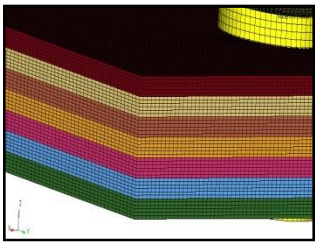

Fig.1. Elements created to represent composite plate of 7 ply's

Above figure shows Elements creation to represent composite plate of 7 ply's by mesh the plate with circular hole of radius 5mm, without any triangular element at the circular region. Now create the laminate of desired thickness, by dragging the elements along Z directions with required number of layers along the ply thickness (Ex: 7layers/ Ply).

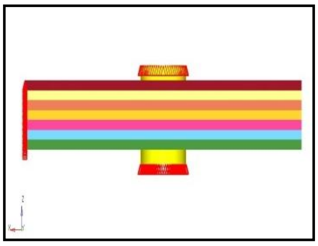

Fig.2. Boundary condition applied on one side of plate, by constraining all degree of freedom.

Above shown image describe the complete model with 7 layers of laminates and a pin

IV. PROBLEM DEFINITION

Analysis has been carried out for different load cases. The analysis is very important as the pin joints are used in many structures. Any improvement in the stress reduction helps in fatigue life improvement of the machine components and joints. So an finite element analysis is carried out to find the joint behaviour under various conditions of the pin for the composite plate. The following cases of analysis are carried out.
Case 1: Diameter effect on stress generation
Case 2: Pin material effect on the stress generation
Case 3: Comparison for Isotropic and composite joint

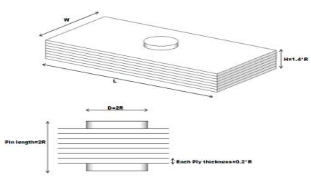

Fig.3. Modelling dimensions

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1. <u>Modeled for R5mm</u>
   If R=5mm
   H=1.4*5
   H=7mm
   W=30mm (Assumed)
   L= 60mm (Assumed)
   Each Ply thickness = 0.2*5 = 1mm
   Pin length=2*5 =10mm

V. EXPERIMENTAL RESULTS

Case 1: Diameter effect (Results for 5mm)

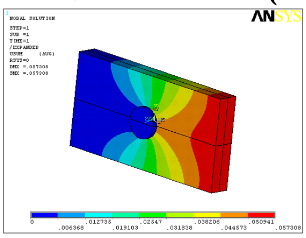

Fig 4(a)

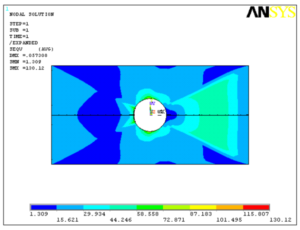

Fig 4(b)

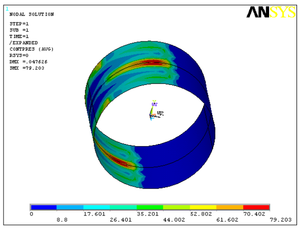

Fig 4(c)

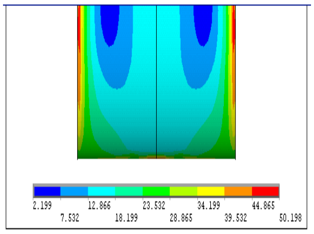

Fig 4(d)

Fig 4(a): Displacement contour, (b): Vonmises Stress, (c): Contact pressure, (d): Bearing load on pin

Above results are carried out for Pin diameter of 5mm, the results are captured for Displacement, Plate stress, contact pressure and Bearing load of Pin. And the same experiments are carried out on 6mm and 7mm diameter pin and the results are tabulated below.

Pin Diameter	Overall Deformation(mm)	Plate Stress (Mpa)	Pin Stress (Mpa)	Contact Pressure (Mpa)	Bearing Load on the pin(N)
5	0.0573	130.12	50.198	79.203	614.98
6	0.0634	124.761	46.209	71.128	626.36
7	0.0705	121.423	42.123	64.189	636.21

Table 1: Results for Change in Pin diameter

Case 2: Pin material effect on the stress generation

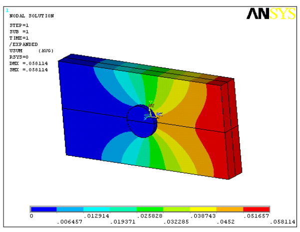

Fig 5(a)

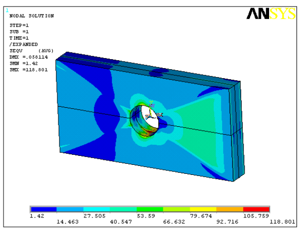

Fig 5(b)

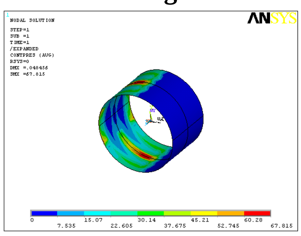

Fig 5(c)

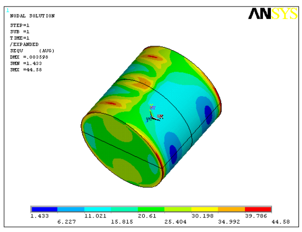

Fig 5(d)

Fig 5(a): Displacement contour, (b): Vonmises Stress, (c): Contact pressure, (d): Stress on Pin

Above results are carried out for Aluminium material on Pin diameter of 5mm, the results are captured for Displacement, Plate stress, contact pressure and Stress on Pin. And the same experiments are carried out for Steel and the results are tabulated below.

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Pin Diameter	E (Gpa)	Overall Deformation (mm)	Plate Stress (Mpa)	Pin Stress (Mpa)	Contact Pressure (Mpa)	Bearing Load on the pin(N)
Aluminium	70	0.0581	118.80	44.58	67.815	571.86
Titanium	110	0.0573	130.12	50.19	79.203	614.98
Steel	200	0.0566	139.48	57.96	89.844	644.69

Table 2: Results for Change in Material for Pin

Case 3: Comparison for Isotropic and composite joint

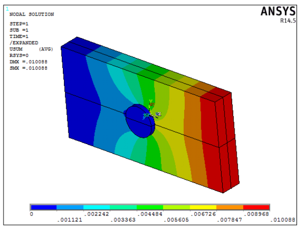

Fig 6(a)

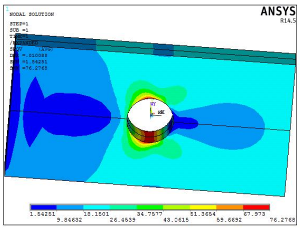

Fig 6(b)

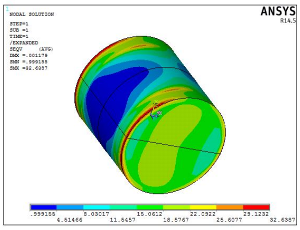

Fig 6(c)

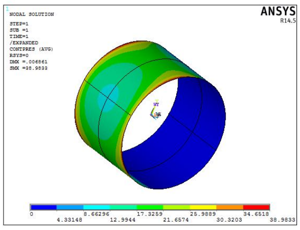

Fig 6(d)

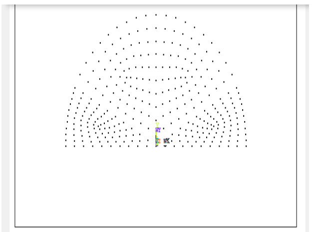

Fig 6(e)

Fig 6(a): Displacement contour, (b): Vonmises Stress, (c): Stress on Pin, (d): Contact pressure, (e): Bearing load

Above results are carried out for Isotropic material for both Pin and Plate of Pin diameter 5mm, the results are captured for Displacement, Plate stress, contact pressure, Bearing Load of Pin and Stress on Pin. Results are tabulated below.

Details	Overall Deformation(mm)	Plate Stress (Mpa)	Pin Stress (Mpa)	Contact Pressure (Mpa)	Bearing Load on the pin(N)
Composite	0.0573	130.12	50.198	79.203	614.98
Isotropic	0.01	76.27	32.63	38.98	425.08

Table 3: Comparison of composite to Isotropic Joints

VI. CONCLUSION

We have proposed an efficient and accurate analytical method for analyzing the mechanical behavior of a composite laminate plate with an elastically pinned circular hole under a bearing force on the pin. The composite laminates are considered to be generally Orthotropic and the pin to be isotropic. The plies are assumed to be perfectly bonded. The contact interaction between the composite and pin is followed by a Eulirian algorithm. The overall summary of the analysis is as follows.

Initially Modeling is done using Ansys preprocessor. Initially blocks are built and copied to the required size to ease brick meshing of the problem. Boolean operations are used to build hole in the solid blocks. Contacts are defined between plate and the pin after selecting target and contact regions using Targe170 and Contac174 elements. Standard

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contact algorithms are selected for better accuracy. After application of boundary conditions, the analysis is carried out for various load cases.

Initially analysis is carried out to find the effect of pin diameter on joint behaviour. The pin diameters are changed from 5mm to 7mm with increment of 1mm. The results are captured for Deformation, overall stress, pin stress, contact pressure and pin bearing load. The results shows increase of deformation and bearing load with increase in the diameter along with reduction of stress in both plate and pin materials. Also contact pressure is dropping with the increase in the diameter. This can be mainly attributed to increased contact area which reduces the stresses in the overall joint.

Further analysis is carried out with variation of materials (Young's Modulus 'E') and results are captured for deformation, Vonmises stress, contact pressure, pin stress and bearing loads. The results shows higher effect of young's modulus on the behaviour of the joint. Increase in the young's modulus is increasing all the design parameters excepting the deformation. This can be mainly attributed to increased stiffness with the higher young's modulus materials. Higher stresses are not desirable in the composite plates, as they are potential sources of stress concentration and possible sources for delamination debonding effects.

Final analysis with isotropic combination shows better load distribution with compared to the composite material. For the same external load, all the values (Deformation, overall Vonmises stress, pin stress, contact pressure and pin bearing load) are less compared to the composite plate. The aim of the project is not to show the advantages or strength of composite over the isotropic combinations, but to analyze the composite plate with elastic pin interface conditions for overall stress and load distribution conditions.

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