EFFECT OF FRICTION AT THE PIN PLATE INTERFACE IN COMPOSITE LAMINATED STRUCTURE USING FEM/ANSYS

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Abstract: Mechanically fastened joints are widely used in composite aerospace structures. Among various methods of joining, fastener (bolted) joints are preferred in applications, which require periodic assembly and disassembly. The mechanics of load transfer has been extensively studied earlier for the case of such joints in metallic structures. With the advent of composite structures in the recent past, there is a renewed interest in these problems from the viewpoints of both the stress analysis and the strength prediction. An understanding of the process of load transfer at connections like pin joints in composite materials are essential to achieve a level of confidence in analysis and design of composite structures. This is necessary to expand the range of application of composite materials in primary structures. In view of recent advances in the field of computers and the development of Finite Element Methods to handle complex practical problems, attempts to study the pin-plate problem of composites could be very fruitful. The present work is an effort in this direction and has achieved success in two-dimensional plane-stress analysis of pin joints with round pin in a hole in a composite plate using commercial software ANSYS (Analysis System) as a tool for finite element analysis. Both inverse and iterative approaches are employed as required in the analysis.
The pin loading and uniform tension on rectangular plate were carried out for various hole eccentricity to hole diameter and plate width to hole diameter ratios.

The contact stress problem at the pin-plate interface can be analyzed by iterative or inverse methods of approach. In iterative approach, the extents of contact/separation are determined iteratively for a given load level. Inverse technique determines the load level required for various extents of contact/separation.
Finally the article presents the analysis of pin joints considering the effect of friction on pin plate interface. The effect of friction on load contact behavior and maximum stresses is successfully demonstrated using ANSYS software for finite element analysis.

Index Terms – Pin joints, composite laminated structure, FEM, ANSYS

I. INTRODUCTION

All mechanical fasteners using rivets, bolts, hinges, etc incorporate a basic load transfer mechanism, namely a round pin in a round hole. Load transfer process is a function of several parameters such as material properties, dimensions of pin and plate, interfacial conditions of contact, friction and compliance.

In the present work we study the phenomenon of load transfer through a study of an idealized combination of a round rigid pin in a circular hole in a unit thickness (Plane Stress) composite laminate subjected to plate loading of a square plate for different radius to width ratios, pin loading in a rectangular plate with an eccentrically located pin, uniaxial tension for the same by varying the eccentric to hole diameter ratios and width to diameter ratios. The hole and the pin diameters are taken as 2a and $2a(1+\lambda)$, where λ is the proportional interference.

The basic configuration of a pin in a plate could be clearance, push or interference fit. The hole in the plate of radius' a' is filled with a pin of radius a $(1+\lambda)$, where λ is the proportional interference, i.e. clearance fit if $\lambda < 0$, push fit if $\lambda = 0$ and interference fit if $\lambda > 0$. The pin is assumed to be rigid. To obtain clarity of phenomena with relatively simple analysis, we first assumed the pin-plate to be perfectly smooth (interfacial friction coefficient $\mu \to 0$), for the stress analysis, this allows free relative moment in the tangential direction between the pin and plate, and thus no shear stress will develop along the interference. Thereafter we examine the implication of slip due to finite friction. Composite laminate consists of number of layers with fibre orientation in each layer being denoted by α as shown in fig 1.1.

The finite laminated composite plate considered is of length L, and width 2W with a hole located in such a way as to retain certain axis / axes of symmetry for the sake of simplicity in the analysis. Hole at the center retains two axes of symmetry as shown in fig1.2. Eccentric location of the pin generally on the X-axis retains at least one axis of symmetry. The center of the hole is at distances e and H from the edges of the plate as shown in fig1.3. Both pin load and plate load cases are considered for the analysis. The configuration of pin joint with pin and plate load conditions is shown in fig 1.4. The orthotropic properties of each lamina are define by four elastic constants E L, E T ν LT and GLT. The combined properties of the laminate are determined using classical laminate theory and the total laminate could have orthotropic/ anisotropic properties depending on the layup.

It will be our endeavor in the present work to examine the forgoing aspects of pin joints.

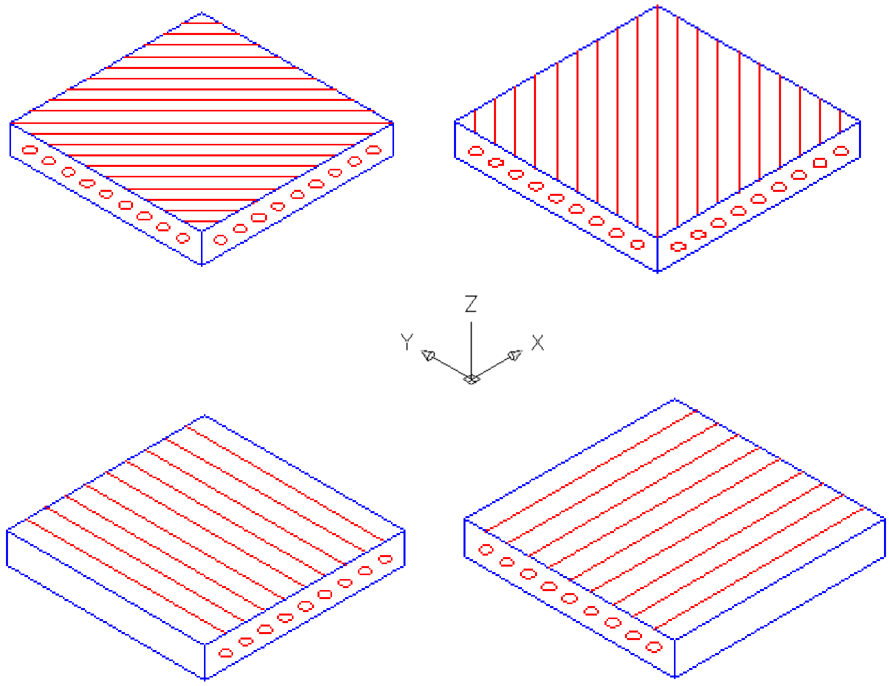

Fig 1.1 Laminate Construction

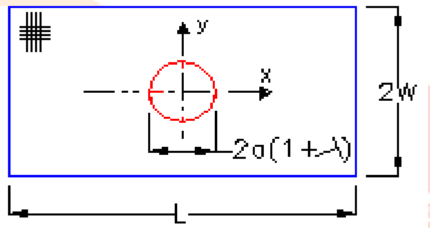

Fig. 1.2 Plate with central pin in a laminated composite plate

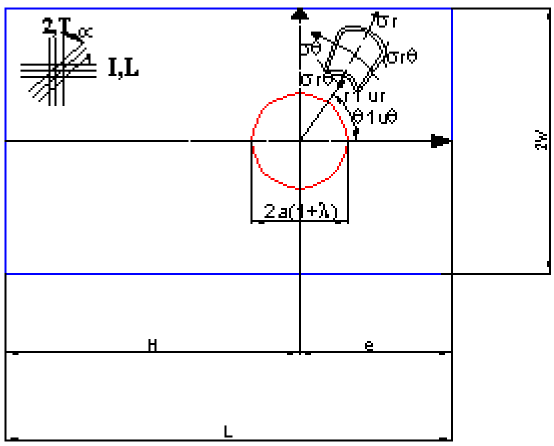

Fig. 1.3 Laminated composite plate with eccentric pin

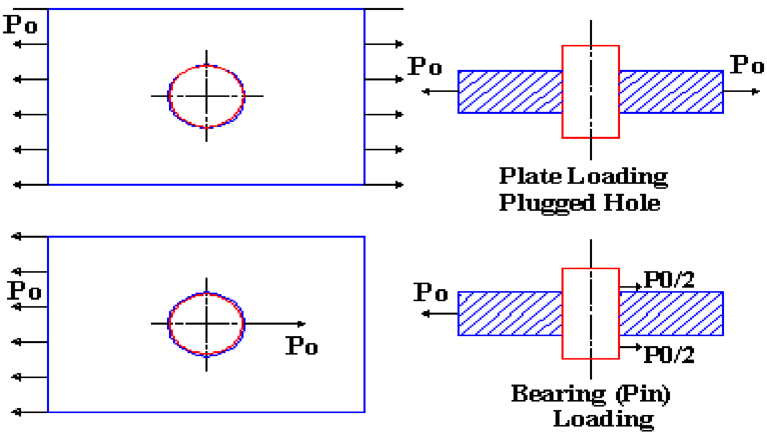

Fig 1.4 Load cases in Pin joints

II. PROPOSED METHOD OF ANALYSIS

The finite element method has become a powerful tool for the numerical solution of a wide range of Engineering problems. Applications range from determination and stress analysis of automotive, aircraft, buildings and bridge structures to field analysis of heat flux, fluid flow, magnetic flux, space and other flow problems. With the advance in computer technology and CAD systems, complex problems can be modelled with relative ease. Several alternative configurations can be tried out on a computer before final modelling.
The finite element method (FEM) is a numerical technique in which an assemblage of sub-divisions called finite elements represents a structure. These elements are considered inter- connected at joints, which are called nodes or nodal points. Solutions are formulated for each consequent unit and combined to obtain the solution for the original structure. In the present work, ANSYS software for finite element analysis is used which can handle the non-linear contact stress problem under consideration. The problem of pin-joints was handled by specially developed software using finite element method, inverse technique is adopted for the solution of problems. In the present work, an attempt is made to use the commercial software for finite element analysis ANSYS for the problem of pin-joints for the first time. In many cases, it is possible to use inverse method of analysis and this will be employed for most of the cases. In other cases, an iterative method of analysis will be used along with the ANSYS software.
The major capabilities of ANSYS software includes linear and non-linear static, dynamic, buckling and heat transfer analysis. A comprehensive library of elements is available. This includes 2-D and 3-D point masses, springs, spars and beams, 2-D plane and axi-symmetric solid elements, 3-D solid elements, axi-symmetric 3-D shell elements, 3-D layered composite solid and sandwich shell elements, gap elements and axi-symmetric shell and solid elements with no axi-symmetric loading.
In the present study for composite structures, 3-D laminated composite general shell element is used; quadrilateral four nodded and eight nodded elements are used for the analysis ANSYS software is capable of considering finite friction using gap and friction elements in contact stress problems. This capability of ANSYS is utilized in the present work to consider finite friction in the analysis of pin-joints.

Table 1.1 Material system used in the present study

Material designation	Material system	EL GPa	ET GPa	GLT GPa	VLT
M1	Aluminium	72	72	27.7	0.3
M2	T300/5208	181	10.9	7.17	0.28
M3	Boron-epoxy (30% epoxy by volumes)	276	55	32	0.22
M4	T300/SP286	130	8.274	5.011	0.3
M5	Boron-epoxy (60% epoxy by volumes)	159	21.875	15.26	0.26
M6	E-glass-epoxy (30% epoxy by volumes)	49.56	18	9.11	0.2466
M7	Nearly isotropic	68.95	68.95	26.2	0.3

III. RESULTS & DISCUSSION

Finite Square Plate subjected to Uniaxial Plate Tension

Here analysis was done on a finite square plate subjected to uni-axial plate tension. For an interference fit the separation initiates at A and B ($\theta = 0$ and $\theta = 180$) corresponding to point E on the curve and increases progressively as the load is increased and later reaches an asymptotic value . It is seen that as the a/w ratio increases the maximum angle of separation decreases quite considerably and also the applied stress value decreases right from the initiation of separation to the maximum degree of separation. As the a/w ratio increases the Load will increase as shown in fig 2.1.a. The load parameter will be maximum at 0 degree of separation for different a/w ratios as shown in fig 2.1.b. The effect of finite width on computed pressure and load parameter required for various angles of separation in interference fit pin joint is shown in fig 2.1.c & 2.1.d respectively.

Plots of Square plate subjected to tension

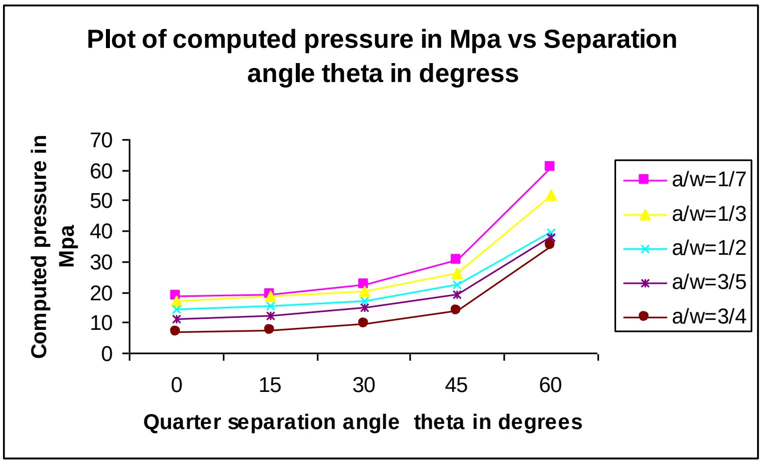

Fig 2.1a

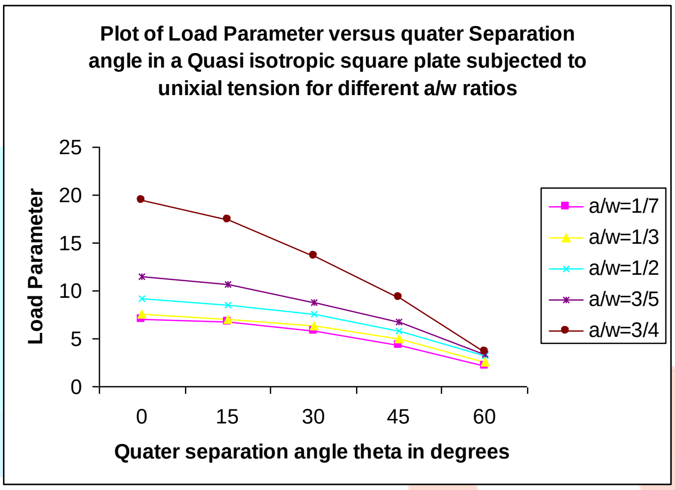

Fig 2.1b

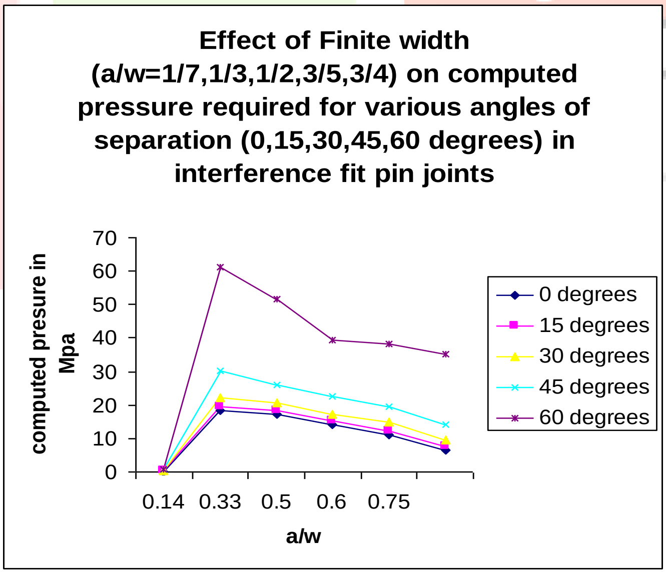

Fig 2.1c

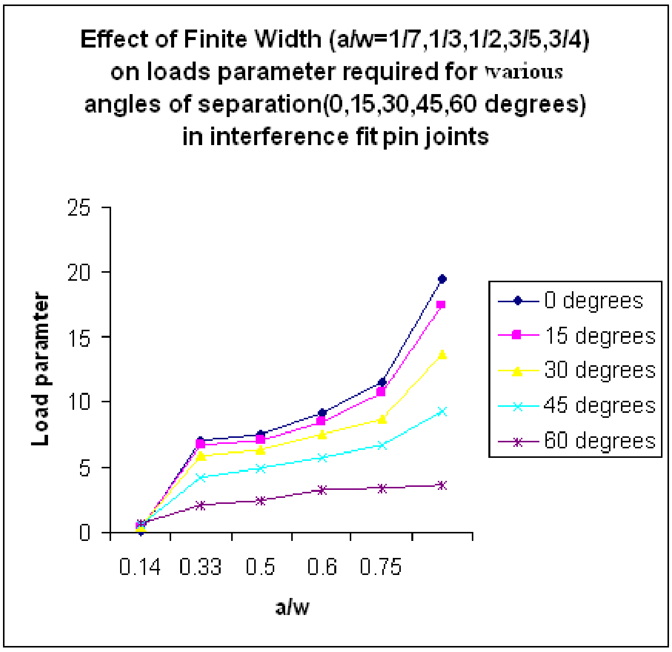

Fig 2.1d

The results are tabulated in Table 2.1a, 2.1b, 2.1c, 2.1d.

Table2.1: Uniaxial Plate Tension of Quasi-isotropic square plate

a) a/w=1/7 & λ=0.001

θs, Separation angle	Computed Pressure σx in Mpa	Load Parameter ELλ/σx
0	18.518	7.02
15	19.40	6.7
30	22.224	5.85
45	30.23	4.3
60	61.15	2.12
73	∞	0

b) a/w=1/3 & λ=0.001

θs, Separation angle	Computed Pressure σx in Mpa	Load Parameter ELλ/σx
0	17.24	7.541
15	18.51	7.023
30	20.534	6.331
45	26	5
60	51.73	2.513
70	∞	0

c) a/w=1/2 & λ=0.001

θs, Separation angle	Computed Pressure σx in Mpa	Load Parameter ELλ/σx
0	14.18	9.17
15	15.3	8.5
30	17.2	7.56
45	22.6	5.752
60	39.4	3.3
69	∞	0

d) a/w=3/5 & λ=0.001

θs, Separation angle	Computed Pressure σx in Mpa	Load Parameter ELλ/σx
0	11.26	11.55
15	12.15	10.7
30	14.834	8.764
45	19.403	6.7
60	38.1	3.41
69	∞	0

e) a/w=3/4 & λ=0.001

θs, Separation angle	Computed Pressure σx in Mpa	Load Parameter ELλ/σx
0	6.68	19.46
15	7.47	17.403
30	9.49	13.7
45	13.98	9.3
60	35.303	3.6825
66	∞	0

IV. CONCLUSIONS

This Research work presents the use of commercial software ANSYS as a tool for Finite Element Analysis for contact stress problems and their use in the analysis of pin joints in composite plates. Especially with the increasing use of fibre reinforced composites in high technology structures such as Aerospace, and the inevitable requirements to join various sub-components of any major structure. The results presented in this thesis could be of immediate value to practical problems.

We have introduced our analysis of pin joints in composites by first studying the load transfer trough a basic configuration of a circular and eccentrically located pin in a circular hole in a finite orthotropic plate by varying the width of the plate to diameter of the hole ratio and varying the eccentricity to diameter of the hole ratio in order to understand the effect of geometry on the load contact relations.

As the a/w ratio increases the maximum angle of separation decreases quite considerably and also the applied stress value decreases right from the initiation of separation to the maximum degree of separation.

The effect of eccentricity on the load contact variation in a graphite epoxy composite plate (T300/SP286) with (0±45/90)s lay-up is also studied. It is also concluded that in the case of interference fit(λ=0.004), the separation initiated at A (0degree) at Eλ/σx=11.362 and initiates at B(180 degrees) at Eλ/σx=10.843 when e/d=.75. As e/d is increased, the initiation of separation occurs at higher loads or lower values of Eλ/σx. The study is conducted by varying e/d (0.75, 1.5, and 2.0) and keeping b/d constant at 3.

The variation of tangential displacement along the hole boundary for different loads.. The variation of stress ratio σr / σθ along the hole boundary for different loads. The effect of friction at the pin plate interface is studied in this thesis for the using finite element analysis (ANSYS).

Composite materials can be designed to provide desired strength and stiffness in the required directions in any particular region of the structure to achieve better performance

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