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# BIAXIAL LOADING ANALYSIS OF LAMINATED POLYMER COMPOSITE MATERIAL

[1]K. Akshitha, [2]Dr. L. Madan Anand Kumar

[1]M.Tech, [2]Associate Professor
Department of Mechanical Engineering, Vidya Jyothi Institute of Technology

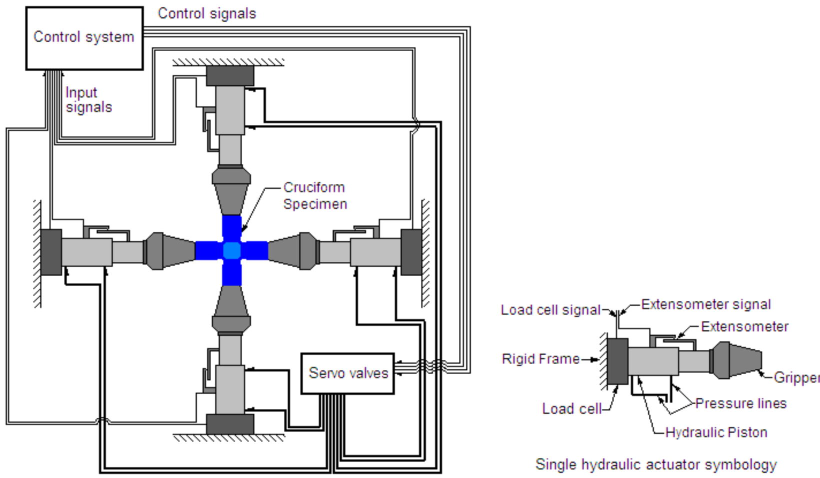
**ABSTRACT**: *The contemporary practice of using uniaxial tests as a source for failure prediction of composite materials which are inhomogeneous and anisotropic under multi-axial loading has witnessed to be inadequate. Therefore, biaxial and multi-axial tests appeared obligatory to improve our understanding the behavior of these complex materials. The present paper is focused on selection of suitable geometry for the test coupons required under biaxial loading.*
*The specimen with: 1. Uniform stress about the gauge section, 2. Failure in the gauge section and 3. Preventing the undesired non-uniform strain distribution due to stress concentration is selected. FEA is implemented on the cross shape (╬) specimen with different undercuts and holes with different stress ratios ranging from ($\sigma_x$:$\sigma_y$) = 1:1, 1:0.5, 1:0.75, 1: -0.25, 1:-0.5, 1:-0.75 are applied on the four edges of the specimen for selection of suitable geometry.*

## I. INTRODUCTION

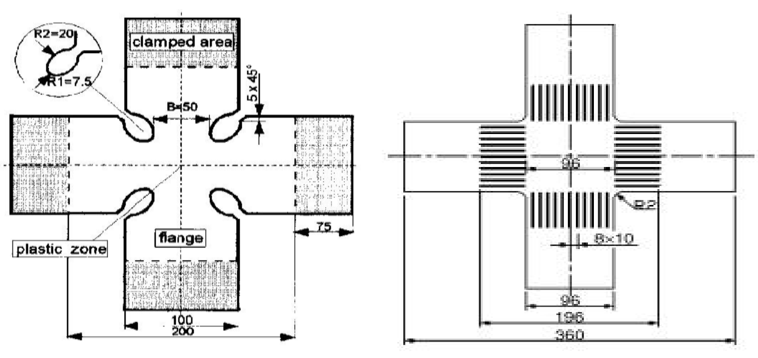
Standard testing to obtain material parameters requires test samples with a well-defined standardized geometry. They commonly generate a uniaxial stress field that allows the identification of one or sometimes two material properties. For orthotropic material properties, different tests are needed to identify all the mechanical properties of the material. Actual structural components manufactured in factory or used in engineering are submitted to complex stress fields and show sometimes other material properties than those obtained by standard testing. In those cases, mixed numerical–experimental methods also called inverse methods for material parameter identification can improve the results. Mixed numerical–experimental methods are based on a finite element model of a complex test geometry. The technique proposed in this paper combines static loading experiments, optimisation techniques, full-field measurement techniques and a numerical finite element model.
A biaxial tensile test is performed on a perforated cruciform specimen made out of glass fibre reinforced epoxy. As the material is supposed to behave homogeneously only one set of material parameters is determined. The responses of the system, i.e., the surface displacements are measured with digital image correlation. Strains are subsequently calculated, based on the measured displacement field. A finite element model of the perforated specimen serves as numerical counterpart for the experimental set-up. The difference between the experimental and numerical strains (ex, ey and ᵞxy) is minimized in a least squares sense by updating the values of the four independent elastic module. The sensitivities used to obtain the parameter updates are determined analytically, using the stress values calculated during the previously converged step. This choice allows a convergence rate that is three times faster than a routine based on finite difference sensitivities. The optimization routine uses a Newton–Raphson algorithm. A recent development is a new failure theory developed at Northwestern University (NU-Daniel theory) which has been proven very successful in predicting yielding and failure of a composite lamina under multi-axial states of stress and varying strain rates. This theory addresses a class of problems where other theories differ the most from each other. The challenge now is to adapt and extend this new theory to the analysis of progressive failure of multi-directional structural laminates under multi-axial static and dynamic loadings and offer easily implemented engineering design tools. The purpose of the present study is to derive a closed-form solution to relate the strength to the fracture load for thin multilayered disks subjected to biaxial flexure tests. First, an analytical model is developed to derive the stress distributions in multilayered disks subjected to biaxial flexure tests. This is achieved by satisfying the continuity condition at the interfaces between layers as well as the force and moment equilibrium conditions for the multilayered system and utilizing the existing closed-form solutions for mono layered discs. Then, an application of the solutions to determine the film modulus for a film/substrate bi layered system using biaxial flexure tests is discussed. Second, the FEA is performed on multilayered disks subjected to ring-on-ring tests. Finally, the comparison between the analytical and the finite element results is made to validate the present closed-form solutions for multilayered systems.
.A large number of researches are grouped according to some important issues such as folding/deploying properties3–6 and axial compression,7–16 torsion8,10 and bending 13–16 strengths as well as biaxial tension–compression behaviour for foldable and deployable thin-walled composite structures/tubes based on experimental databases, analytical models and numerical techniques, etc. carried out a series of tests of filament wound thin-walled CFRP and GFRP composite tubes under axial compressive loading to evaluate the influence of lay-up configuration on elastic strength properties. It showed that the

hoop layers can effectively improve uniaxial compressive strength of composite tubes. Analysis on the buckling of composite tubes subjected to different loading types (e.g., compression, torsion and internal pressure) under free-free and clamped–clamped boundary conditions. New exact equation for predicting buckling load was validated with the existing experiments.




Interaction formula to theoretically analyze the effect of various lay-up on the interactive local/Euler buckling load of composite tubes under axial compression. It showed that the knockdown in buckling load was dependent on the predominant fiber angle of reinforcement and varied from 10% to 30%.The flexural tensile strength is one of the most important parameters used to design concrete structures together with the compressive strength. The flexural tensile strength is not a constant parameter but rather depends on the stress state. We estimated load-strain relationship on the bottom surface of BFT specimens and three different sizes were considered to investigate the effect of the size of specimens.
The SCFs were to be quite sensitive to changes in plate anisotropy and heterogeneity, direction of external tensile force and form of hole in symmetrically laminated anisotropic plates under tension. The remote laser Raman spectroscopy to measure the stress concentration arising in a composite Kevlar 49 fiber/epoxy composite plate containing a circular hole under different strain levels until fracture. Therefore, the main objective of the present research is to perform stress analysis of a finite functionally graded material (FGM) plate with an elliptic hole under uniaxial and biaxial loading conditions. The two-dimensional distributions of stresses near the elliptic hole are analyzed. The sensitivity of the SCFs to FGM properties, such as gradation direction and composition parameter, and the geometric parameters is examined.




The aim in this study is to verify the applicability of our numerical approach to estimate the fatigue crack growth histories of welded joints under biaxial loadings with phase difference from a practical point of view. Metals, and in particular sheet metals, are used in a wide variety of applications in industry, with the main elds of application being packaging (food containers, beverage cans), automotive and aerospace industry. The development of Advanced High Strength Steels that can replace the existing steels is therefore closely followed by the automotive industry. A FE model could be used to determine these forming stresses, but therefore the used material model should accurately describe the material behaviour. For the three-dimensional models, element type shell 8 node 281 was used. Considering symmetry and loading conditions, only a quarter of the cruciform has to be modeled. The used material is glass fiber with a thickness of 5mm, a Young’s modulus of 45 GPa and a Poisson’s ratio of 0.29.

## II.LITERTURE REVIEW

**David Lecompte, Arwen Smits, Hugo Sol,John Vantomme, Danny Van Hemelrijck [1]:** This paper presents a mixed numerical–experimental method for the identification of the four in-plane orthotropic engineering constants of composite plate materials. A biaxial tensile test is performed on a cruciform test specimen. The heterogeneous displacement field is observed. The measured displacement field and the subsequently computed strain field are compared with a finite element simulation of the same experiment. The four independent engineering constants are unknown parameters in the finite element model. Starting from an initial value, these parameters are updated till the computed strain field matches the experimental strain field. Two specimen geometries are used: one with a centered hole to increase the strain heterogeneity and one without a hole. It is found that the non-perforated specimen yields the most accurate results.

## III. PROBLEM FORMULATION

The conception of a material's capability to safely sustain a load, before breaking has been of prime importance ever since structures were first built. The strength of an isotropic material could be judged by knowing its tensile behavior, but this is not valid in the case of FRP materials are anisotropic in nature.
There have been many test configuration proposed for the study of biaxial behavior, which have been classified into two type based on the loading system. The configuration in loading the system may use a single loading system or loading system comprising of two or more loading configuration. In the first configuration the biaxial stress ratio depends on the geometry of the specimen or the loading fixture. This type of configuration has some limitations such as:

1. Each stress ratios requires a specific shape of plate and does not allow a variable loading ratio to be applied.
2. A stress gradient appears in the thickness of the specimen and the stress field is non homogeneous.

ANSYS 14 has been implemented for the analysis of the cruciform specimen. Layered element is selected for the analysis and the material properties have been selected from the literature available. The cruciform specimen is fixed at both ends and the load is applied on the other two arms. The load in the X – direction is maintained constant of about 1848 N/mm2 and load in the Y – direction is varied from +1848 to – 1848. The ratio of load being applied is varied from -1 to +1 with a variance of 0.25. The buckling effect in the laminated composite is considered when the compressive load is applied.
In the present work a cruciform specimen with and without a corner radius is studied. The cruciform specimen without corner radius is a 300mm long and the arm of 25mm wide, 5 mm thickness. The cruciform specimen has a corner radius of 12.5mm and the arm width 25mm the arm thickness of 5mm as per ASME.
The cruciform specimen is fixed at both ends and the load is applied on the other two arms. The load in the X – direction is maintained constant of about 1848 N/mm2 and load in the Y – direction is varied from +1848 to – 1848. The ratio of load being applied is varied from -1 to +1 with a variance of 0.25.
As when the load is applied on the specimen without corner radius the stress concentration is less. So the specimen which is designed with corner radius has more stress concentration compared with the normal specimen. The deformation takes place at the corners so that we are performing on the specimen with corner radius.

## IV. EXPERIMENTATION AND ANALYSIS

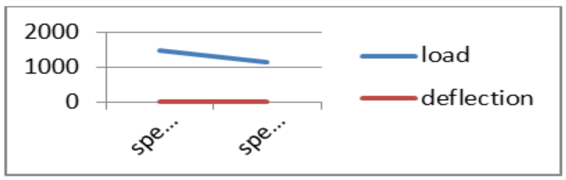
In the present work after cutting the laminate of $(0\text{-}90^0)$ orientation composite specimens are tested in various operations. Tensile and bending tests were conducted on various sandwich specimens. Both the testing procedures were discussed below.

Fig 1.0 Specimen-1 held in the Bi-axial Testing Machine

The load is applied on the specimen-1 is 1474 KN and the deflection occurred is 7mm. the stress concentration is less compared with the specimen which is discussed in the problem formulation and load bearing capacity is more the specimen which as no curvature.

The load applied on the specimen -2 is 1146 KN and the deflection is 11mm. the load carrying capacity is less compared with specimen-1, where the tapered shape is gradually decreasing to its centre so the deformation is more. The deflection occurred in the tapered cruciform at the guage length.

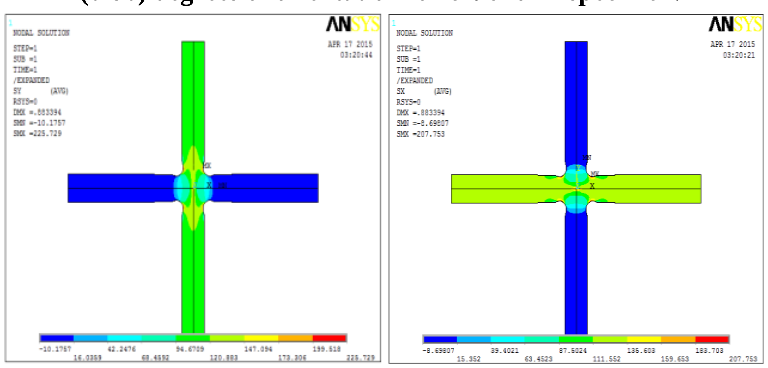
| | specimen-1 | specimen-2 |
|---|---|---|
| Load(KN) | 1474 | 1146 |
| Deflection(mm) | 7 | 11 |

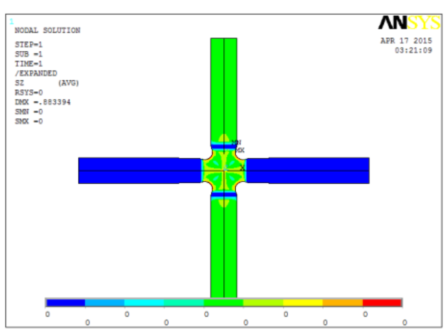



Graph-1 the testing on bi axial machine load vs deflection

**FEA implementation to laminate polymer glass fibre:**
The FEA is implemented considering polymer glass fibre laminate the analysis is carried out considering the whole laminate structure as 3D shell 281 element and with orthotropic properties.
The respective properties of laminates are derived from laminate design software made from Classical laminate theory the software provides the orthotropic properties of the laminates of orientation of sequence of stacking considered for this experiment. The laminate design software output data related to the material properties are directly used in FEA analysis.The simulation was carried out using ansys 14 with skin as 3D shell 281 element and core as linear elastic orthotropic element with orientation and same load has been applied. The maximum stress, maximum strain, maximum deflection in all the X, Y, Z directions is as follows.

**(0-90) degrees of orientation for cruciform specimen:**



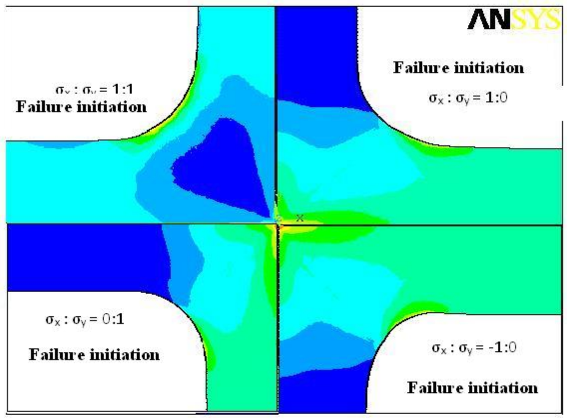


Applying the load of 1848 N on the cruciform laminate along the X, Y, and Z direction the maximum stress obtained are 207.753 N/mm$^2$, 225.729 N/mm$^2$, 0 N/mm$^2$.

## V.RESULTS AND DISCUSSIONS

For the model with a corner radius, the initiation of stress is observed at the fillet radius and prevails to the center region for the case of stress ratio $\sigma_x/\sigma_y$ = 1:1, for both T-T and C-C where as for all the other cases the stress initiation is at the center of the gauge section.
The model with a spline cut and a taper arm stress concentration or stress initiation is observed at the corner of the gauge section that is at the spline cut for all the stress ratios other than the $\sigma_x/\sigma_y$ = 1:0, for both T-T and T-C.
The model with a spline cut and straight arm showed a uniform stress distribution at gauge section and the high stress is observed at the central region for all the loading cases. A stress reliving zone is observed for the three models.




## VI.CONCLUSIONS

- Modifying the specimen's geometry, one can increase the uniformity of strain in the bi-axially stressed gauge section and/or contemplate failure in this same region.
- Three geometries (i) Cruciform geometry with a round corner at the center, (ii) Cruciform with a spline cut and taper arm and (iii) Cruciform with a spline cut and straight arm were under consideration. For the first two geometries under all the loading cases the stress concentration was not at the center of the gauge section but for the later in all the loading cases the stress at the center of the gauge section was high and it is predicted that the failure would be initiated at the center.
- A uniform strain field was observed for only the third geometry and the other two showed a non uniform strain field on the specimen gauge section. The geometry with a spline cut and straight arm should be selected for the successful prediction of the behavior of FRP under biaxial loading case. More over it enables extension for the study on effect of stacking sequence and correlation with the experimental data.

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