Journal of
Data Acquisition and Processing
ISSN: 1004-9037
https://sjcjycl.cn/
DOI: 10.5281/zenodo.7765828

THE MECHANICAL RESPONSE OF AN ORTHOTROPIC LAMINATED REINFORCEMENT IN A SYMMETRICAL STRUCTURE.

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ABSTRACT

An experimental and theoretical investigation was carried out to evaluate the effect of the flexural loads on the stress distribution oriented by " 0, 45, 45,0" laminates of Kevlar-Epoxy composite. The mechanical response of a new advanced composite material was evaluated by comparing the measured and computed deflection values at the mid-point. The results are compared to other composites that have been built. The use of FEM to analyze composite laminates is limited to stacking sequences with symmetry in the mid plane and orientated in the lower half of the laminate, as well as their reflections on the upper half plies. The results of experimental and F E M shows fair agreement.

Key words: laminates, composite , load, deflection, orthotropic, fiber

INTRODUCTION:

One of the most significant developments in the history of materials is the creation of composite materials, along with the associated design and manufacturing processes. Materials that can be customized to fulfill the needs of a certain application include composites, which are multipurpose materials with unheard-of mechanical and physical qualities. Additionally, many composites have strong resistance to abrasion, corrosion, and exposure to high temperatures. Due to these special properties, mechanical engineers have access to design options not available when using traditional monolithic (unreinforced) materials.Additionally, thanks to advancements in composites technology, ceramics, a family of solid materials, can now be used in applications where monolithic versions are ineffective due to their high strength scatter and weak resilience to mechanical and thermal shock. The creation of big, complicated structures can be accomplished using a variety of composite manufacturing technologies, which also allows for the consolidation of parts and lowers manufacturing costs.

A composite material is made up of two separate materials that have different physical and chemical properties. when these elements are mixed, they form a material that is specifically designed to do a specific task.

Composites are significant materials that are now widely used in the aerospace industry as well as a large and growing number of commercial mechanical engineering applications, including internal combustion engines, machine components, thermal management, and electronic packaging, as well as the structural and mechanical elements of cars, trains, and planes, such as brakes, drive shafts, flywheels, tanks, and pressure vessels.

LITERATURE REVIEW:

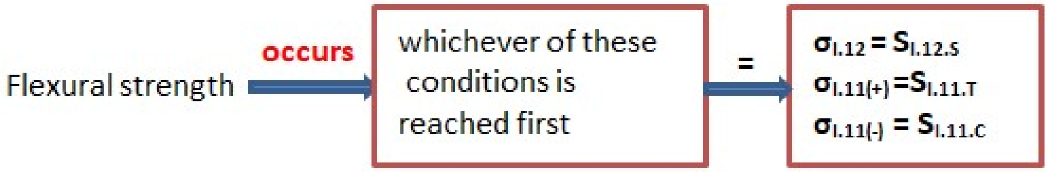
Many researchers presented their research on this field, as follows:

Lawrence J. Broutman, and Richard H. Krock (1974) discussing several ideas about composite strength and fracture, they also discuss time-dependent fracture theory and tests, including both long-term and dynamic fracture. All factors affecting the toughness of brittle and ductile matrix composites are taken into consideration, as well as the fatigue of polymer- and metal-matrix composites.

B. D. Agarwal and L. J. Broutman (1980), The book includes comprehensive coverage of a number of significant subjects, including mechanics, materials, analysis, fabrication, characterization, and performance. In layman's words, fundamental ideas are explained, and the subject is gradually broadened while maintaining a balance between mechanics and materials.

Derek Hull (1981). focused on fiber reinforcing materials that are supported by matrix materials and are used in engineering applications as laminates with multiple layers. He shows that The fundamental benefit of composite materials is their high stiffness-to-weight ratio, which is seen in typicaltechnical applications such as advanced fiber laminated composites like fiberglass, glass epoxy, and Kevlar - epoxy [9].

When unidirectional fiber composites are flexed, they may break due to tension, compression, or shear, or a combination of these factors. [1,2]. Their research revealed a linear relationship between flexure strength and fiber-volume ratio through an experimental study that is related to constituent qualities, assuming that failure occurs when one of the stresses mentioned previously reaches its limit value as follows:



...............(1)

Where;

$\sigma_{1.12}$ = Flexural shear strength.

$\sigma_{1.11(+)}$ =Flexural tensile strength.

$\sigma_{1.11(-)}$ = Flexural compressive strength.

$S_{l.12,s}$ =Longitudinal (interlaminar) shear strength.

$S_{l.11,T}$ = Longitudinal tensile strength.

$S_{l.11,C}$ =Longitudinal compressive strength.

James M. Whitney and Isaac M. Daniel R. Byron (1984),investigate the behavior of a multi-layer material at high strain rate and the damage evolution–propagation inside the specimen were investigated by a combination of experimental and numerical techniques.

The capabilities of an isotropic analysis by FEM were expanded by Thomas et al. (1987) [6] to incorporate orthotropic fracture analysis, stress-intensities and orthotropic stiffness properties. They presented a simple method for the analysis of fracture propagation in orthotropic materials which is shown that isoperimetric quarter-point elements can be used to obtain accurate stress intensity factors using orthotropic displacement correlation equations. An example of fracture propagation analysis in an orthotropic structure is presented and conclusions are drawn with regard to the relative influence of anisotropic strength and orthotropic stiffness properties.

Fuh-Gwo et.al (1990) published a new FE model for laminated composite beams. The model has enough degrees of freedom for each lamina's cross section to deform into a shape that includes up to cubic terms in the thickness coordinate.

Gajbir et.al(1990), investigates the bending of anti-symmetric cross-ply plates using one-term approximations for in-plane and transverse displacements. He used Ray-leigh-Ritz analysis of non-linear bending of anti-symmetric cross-ply laminates, which produces extremely precise results.

Joseph N. Zalameda and Barry T. Smith (1994). They created a nondestructive method for calculating FVF utilizing a dual inspection approach. In a one-dimensional heat flow model where the void volume fraction is calculated using ultrasound, the relationship between thermal diffusivity and fiber, matrix, and void volume fractions is given. In order to quantify thermal diffusivity quantitatively, a phase lag approach is used. The composite plates used for these measurements have different FVFs. With values ranging from.003 to.007 cm^2/sec, diffusivity measurements revealed a nonlinear relationship between FVF and observed diffusivity. Within the region to be destructively tested, frequency dependent relative attenuation ultrasonic measurements were made in addition to the heat data. According to the findings, porosity and attenuation are roughly correlated.

Krishna Kumar Chawla (1998),He shows that the alignment of the fibers is critical in determining the strength of a composite. The strength is highest along a direction parallel to the fibers and lowest along directions perpendicular to it.

Elena Pasternak, Arcady Dyskin (1999). In laminated composite materials, matrix cracking is a topic that they discuss. The factors affecting the start and progression of internal damage under various loadings are discussed. Either a fracture mechanics technique or a probabilistic failure strength theory is used to predict additional cracking. Some researchers use continuum damage mechanics to simulate the behavior of the broken laminate. When a layer delaminates in layered materials, the layer bends and, if the stress is strong enough, can trigger progressive layer breakdown, resulting in a small zone that spreads as a bending fracture. (E. Paternak, A.V. Dyskin) (1999). They found that a disinclination's moment of stress decays according to the inverse square root of the crack's root distance (r).

Wang J, et.al (2002), In this approach, the first-order shear deformation theory (FSDT) is employed and the displacement shape functions are constructed using the reproducing kernel approximation satisfying the consistency conditions. The essential boundary conditions are enforced by a singular kernel method. Numerical examples involving various boundary conditions are solved to demonstrate the validity of the proposed method. Comparison of results with the exact and other known solutions in the literature suggests that the meshless approach yields an effective solution method for laminated composite plates.

Huang, Y. and Q.S. Li (2004),The bending and buckling analysis of antisymmetric thick laminates is done in this study using the moving least square differential quadrature (MLSDQ) method, which is based on the first-order shear deformation theory. Within each region of effect, the centered moving least square (MLS) approximation is used to separately assume the plate's displacement and rotation components. The nodal partial derivatives are computed quickly together with the MLS nodal shape functions, and these two computations result in the weighting coefficients. The accuracy, stability, and convergence of the MLSDQ approach are examined using numerical examples. Investigated are the effects of node irregularity, support

size, and the order of the entire basis functions on numerical accuracy. computed displacements, stresses, and critical buckling loads for various laminated.
Magdi Emissary (2013), in this investigation the fiber and epoxy as lamina are used to form composite laminates with desired directional properties. Mechanical properties for composites are derived starting from properties of fiber and matrix, using the rule of mixtures, and the fibervolumefraction plays a significant role in the determination of the mechanical properties. In this work the value of the fiber volume fraction is determined considering fibrous structure constituent, random fiber, yarns or fabric.

Jawad Kadhim Oleiwi et.al(2014). The purpose of this study is to develop a polymer matrix composite material by hand lay-up, using an unsaturated polyester resin matrix and natural jute fibers of varying volume fractions as reinforcement (3 percent , 4 percent , 5 percent , 6 percent). To investigate the impact of certain jute fiber volume fractions on the bending properties, numerical experiments utilizing the finite element method (Ansys 11 program) were performed. According to the findings of this experimental study, increasing the volume proportion of jute fibers results in an increase in bending modulus. For both experimental and numerical studies, the values of deflection and maximum strain fall while the values of flexural strength and shear stress rise as the volume percent of jute fibers increases.
Vescovini, R.and Dozio L.(2015) The buckling analysis of both thin and thick composite plates under biaxial stresses is presented in this study along with a unified Levy-type solution approach. Two opposite edges of the plates are simply supported, and any combination of simply supported, clamped, and free conditions are applied to the two remaining sides. A variable-kinematic technique is used to formulate the issue, which has the benefit of automatically handling theories of varied orders. Layerwise theories and comparable single layer theories are both taken into account. The governing equilibrium equations are precisely solved using the Lévy-type approach and are analytically derived from the Principle of Virtual Displacements (PVD). Comparisons with results from the literature, including exact 3D solutions, show how accurate the predictions are. A complete set of benchmark outcomes is offered.
Hande S. and Omar B.B (2016)In this work, composites made of four ply jute, carbon, and E-glass fabric reinforcement as well as their hybridized versions are produced. Vacuum infusion technology is used to create nine composite laminates with various stacking arrangements. The fiber weight and volume ratios in the laminate system are first calculated in order to comprehend the structure of the composites. Additionally, to investigate the effect of the amount of fiber content on the void fraction, sample void fractions are calculated using theoretical and experimental densities of the composite samples. The mechanical properties (tensile strength, impact strength) of composite laminates are studied, as well as the effects of hybridizing jute fabric-reinforced polyester composite with E-glass fabric and carbon fabric. The findings of this inquiry indicate that.
19.Sathish S. et al (2017), They investigated the impact of volume fraction on the mechanical and physical characteristics of flax and bamboo fiber reinforced hybrid epoxy composites, including tensile, flexural, impact, interlaminar shear strength, void content, and water absorption. Compression molding techniques have been used to create hybrid composites with flax and bamboo fiber reinforcement. The hybrid composites were created using various fiber

volume fractions. To examine the internal structure of the fractured surfaces and the bonding behavior of the materials, SEM examination of the hybrid composite materials was carried out. By using FTIR measurement, the impact of chemically treating flax and bamboo fibers was confirmed. The results showed that the tensile, impact, flexural and ILSS are maximum for 40:0 (flax: bamboo) hybrid composites. The void content decreased for 20:20 (flax:bamboo) composites due to tightly packed flax fiber and more compatibility towards epoxy resin.

Mohammad Irshad Ali1 and Dr. J. Anjaneyulu (2018) “The primary goal of this work is to determine if unidirectional carbon fiber is suitable for use in the design of a composite suspension system by taking into account the impact of fiber orientation and matrix volume fractions.

Sudad I. Younis et.al. (2018),This study examined how Nano silica particles affected specimen composite material's wear behavior test results for ultimate tensile strength, impact strength, fracture toughness, and shore D hardness. For the manufacture of specimens made from unsaturated polyester resin matrix reinforcement with 4% weight fraction glass fiber (chopped/woven) mat and 1%, 3%, and 5% weight fraction of Nano silica particle, the hand-lay-up method is utilized. The average size of the Nano-silica particles employed in this investigation is (less than 45nm). The outcomes revealed that the specimen's mechanical properties, including ultimate tensile strength, were superior (up +4% woven glass fiber +5% Nano SiO2).

David Müzel S. et.al (2020), They provide finite element approach In order to model composite materials, this effort will focus on the material's qualities, failure criteria, types of elements, and primary application fields.

PROCEDURE:

Five stage was done in the present work to introduce the research in acceptable form which as follows:

1. Advanced composites by lay-up method which include , 4 plies-Kevlar-epoxy (12% V_f , (0,45,45,0), one-ply unidirectional Kevlar-epoxy (12% V_f) , 4-plies woven fabric (cross-ply) , Kevlar –epoxy (12% V_f) and resin made of epoxy without any fiber.
2. Experimental are conducted to study the mechanical flexural response using 3-point test.
3. C-scan image is used to evaluate the failure mode.
4. 3-D FEM by ANSYS and structural analysis program is used to modeling the mechanical response.
5. Finally the experimental results are compared with those obtained from ANSYS.

FIBER-REINFORCED MATERIAL:

These materials are created by embedding a softer or ductile matrix with either continuous or discontinuous fibers of an extremely hard substance. It's possible to think of it as a homogeneous laminated orthotropic material.

A number of plies of unidirectional or woven fabric composites are layered at various angles relative to the laminate's x-axis to form the laminated composite material as shown in Fig.(1-a).

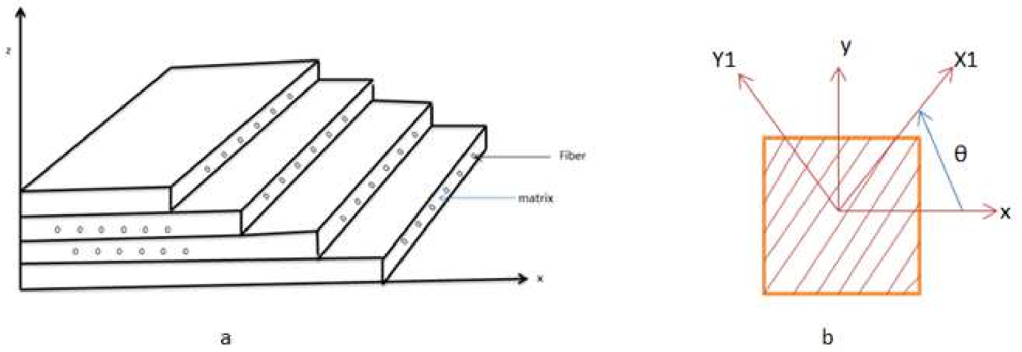


Fig.1: a- fiber reinforced composite (0,45,45,0) b-unidirectional layer

For the case of equally ply thickness , the stacking sequence can be described by simply listing the ply orientation (θ) from the bottom to top. Thesubscript "T" means sequence accounts for the total number of layers such as $[0,45,45,0]_T$.

MAXIMUM FIBER STRESS:

The maximum stress in the outer fibers occurs at the mid-span when a beam of homogeneous elastic material is tested in flexure as a simple beam supported at two locations and loaded at the mid-span.

$\sigma_{max} = \frac{3PL}{2bh^2}$ ……………………………………………(2)

where,

σ_{max}= the stress in outer fibers at the mid span (N/m^2)

P= the load at a certain point on the load deflection curve (N)

L= support span (m)

b= width of the tested beam(m)

h= thickness of the tested beam(m)

However, the flexural strength is equal to the maximum stress in the outer fibers at the moment of break i.e.$\sigma_{flex} = \sigma_{max}$.

After the modules of elasticity, the tangent modules of elasticity is the ratio of stress to corresponding strain inside the elastic limit. It is computed by drawing the load deflection curve's sharpest beginning straight-line part and then applying equation (2) for orthotropic composite. If the shear deformation is ignored [8], yield.

$E_b = \frac{L^3}{4bh^3} M$……………………………………………………(3)

Or,

$E_b = \frac{PL^3}{4bh^3 \delta}$ ……………………………………………………..(4)

Where,

E_b = Modulus of elasticity in bending (N/m^2)

M = Slope of the tangent to the initial straight line portion of the load deflection curve.

δ = Maximum deflection at the mid span (m).

However, if shear deformation is taken into consideration, shear stress will develop between the outer support and the applied load. Therefore the maximum shear stress τ_{max} in case of three point loading [3] is given by:

$\tau_{max} = \frac{b}{2L}\sigma_{max}$……………………………………………………………(5)

THREE POINT BEND TEST:

The load is applied at the center point of the beam in the three-point bend test, and the bending moment (M) increases from the two extremities to the maximum at the center point, as shown in Fig. 2. In this case, the moment might be calculated as:

$M=\frac{PL}{4}$……………………………………………………...(6)

Hence the moment of inertia for rectangular beam is:

$I = \frac{bh^3}{12}$ ……………………………………………………………(7)

Then the maximum stress in outer layer (y=h/2) can be obtained from equation (2) above.

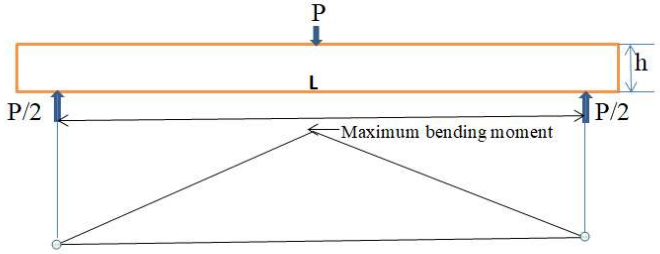


Fig.2 :Application of loads and bending moment diagram for the three point bending

The elastic normal stress distribution through the thickness when the beam is bent could show as in figure 3.

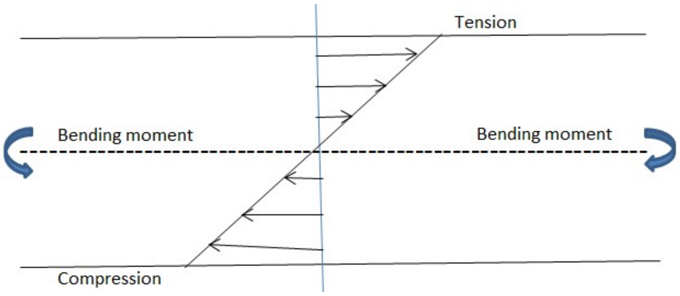


Figure 3- Normal stresses along a section of beam for linearity elastic

EXPERIMENTALWORK:

The following steps are described in the practical section of this work:

1. A special rig are manufactured with 2000 holes of I mm in diameter for the producing up to 4–plies multidirectional reinforcing composite as illustrated in Fig,4.

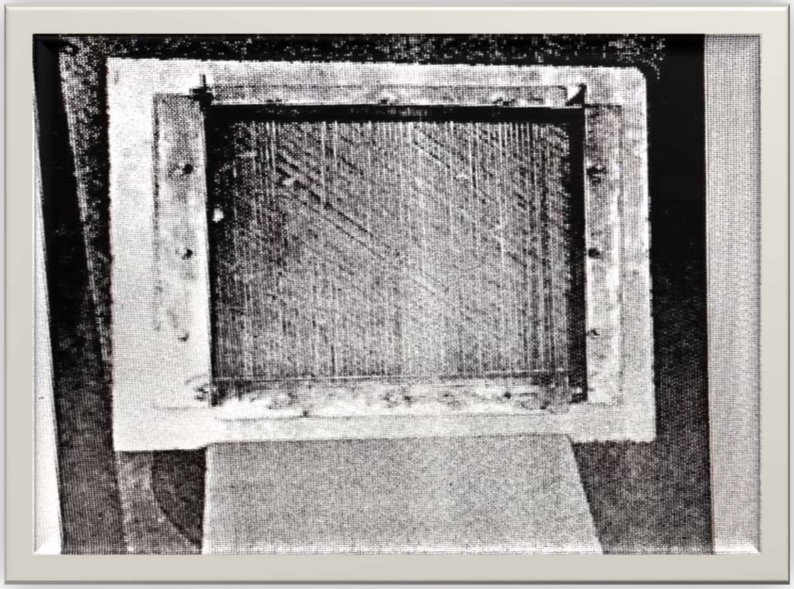


Fig.(4) Rig for unidirectional and multidirectional fiber's packing

The hole are arranged to get rectangular packing with same distance between each pair in the x-direction [2] as illustrated in Fig.5.

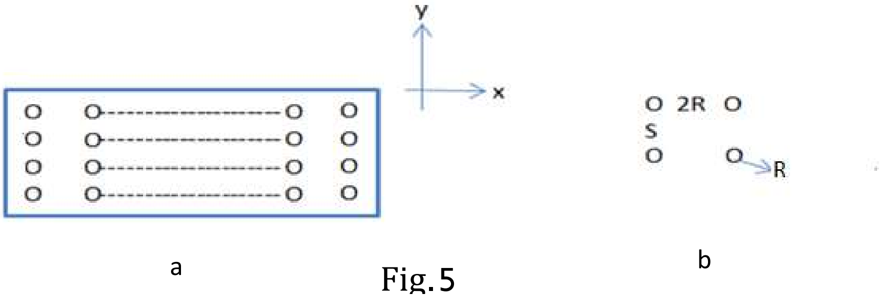


Fig.5

a-one side of rig b- rectangular arrangement

To continue with the experimental activity, volume percentage must be computed because composites are made up of two phases: reinforcement and matrix. The mechanical properties of these composites are determined by the volume proportion of reinforcement and matrix. Reinforcing materials such as fiber, particles, and whiskers can all be employed. The fiber volume fraction may be calculated using the fiber weight fraction, and the other mechanical properties can be calculated using the fiber volume fraction.The stiffness and strength of a composite laminate can be improved by increasing the volume fraction of fibers in the laminate. Because it assumes that the fibers are touching and ignores any voids that may exist in the cured laminate, the maximum volume fraction of fibers is a theoretical estimate. The volume fraction can be determined as follows [2]:

$$V_f = \frac{\pi}{4}\left(\frac{r}{R}\right)^2 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(8)$$

$$S = 2r\ \{\sqrt[2]{\frac{\pi}{4V_f}} - 1\}\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(9)$$

Where “r” is the radius of the fiber

And 2R is the center to center spacing of the fibers

2. Prepare along fibers of Kevlar “49” from woven fiber cloth.
3. Weave 4 plies as (0,45,45,0) as per stacking sequence Fig.6.
4. Mix 3:1 Epoxy Cy223 with hardener Hy 956.
5. Pour the mixture into a rig, then leave it for 24 hrs. at room temperature.
6. Put it in the controlled furnace with 60 C^0 about 16 hrs. and leave it to be cold about 24 hrs. as recommended by MBT company.
7. Prepare speciments for flexural test as per ASTM D790.
8. Flexural strength is obtained and the relation between load and deflection is drawn as a result of three point test at two class.
   -Load bearing on first ply and transfer to other.
   -Load bearing on the four plies directly.
9. Prepare one-ply unidirectional lamina composite from Kevlar-Epoxy V_f =12% following steps 3.5,6,7 and then repeat step 8.
10. Produce another rig to prepare 4-plies cross-ply woven fabric from Kevlar –Epoxy V_f =12% following steps (4, 5 , 6 ,7 ,8) mentioned above.
11. Prepare lamina made from epoxy resin only and repeat the procedure in step 7 and 8.

FINITE ELEMENT METHOD:

The stress and deflection fields are obtained through the use of the ANSYS version 5,4 F.E programs [8].

The material's tensile and flexural properties have been considered orthotropic. From a modeling perspective, composites are more difficult to model than isotropic materials because extra care must be taken in defining the attributes of the orientations of the many layers because each layer may have different orthotropic properties.

When constructing the composite model, focus on the following aspects in the current study.

1. Choosing the suitable element type (solid 46)
2. Defining the layer configuration as in Fig.6.
3. Specifying failure criteria (Von misses).
4. Adherence to modeling and post-processing guidelines.

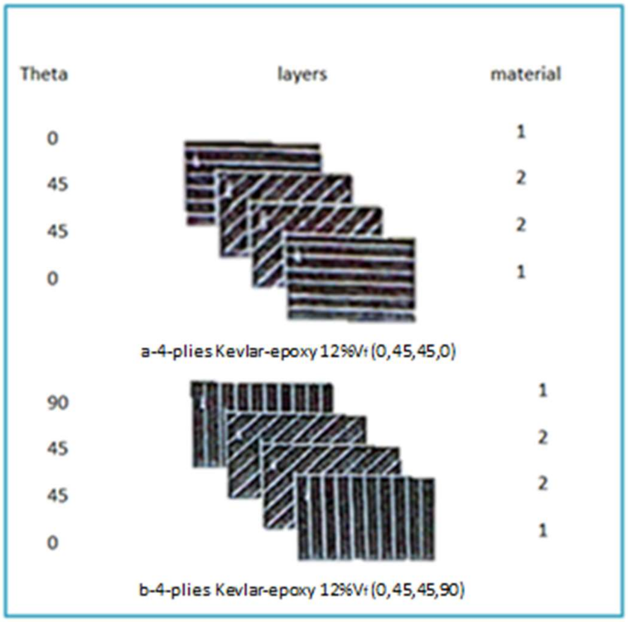


Fig.6: ANSYS lay plot display for symmetric orthotropic material

RESUILTAND DISCUSSION:

Figure 7 shows the load-deflection relationship for two types of flexural loading composites (Kevlar-epoxy 0, 45, and 45,0). The first load was applied laterally (perpendicular to the first ply) to the specimens, whereas the other load was applied perpendicular to the cross section, i.e., to all plies of the arrangement. It also shows a fair agreement between the theoretical (F.E.M results) and practical part.

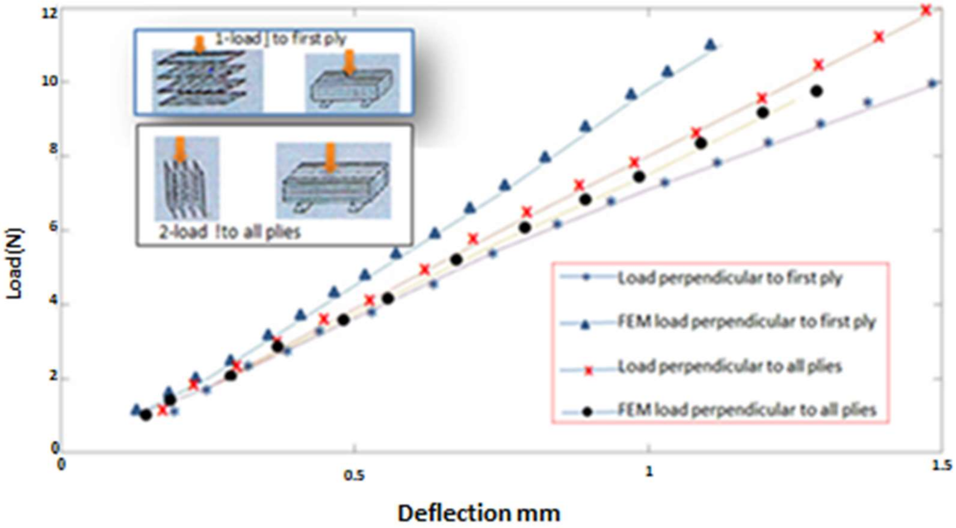


Fig7.load deflection curve Kevlar -49 reinforced epoxy (0,45,45,0) 3-point test

The results of FEM in the first situation, the weight is passed from one layer to the next, whereas in the second case, the load is supported by the material with all layers, as illustrated in Fig.7, resulting in an increase in the carrying load.

The load-deflection relationship for single-layer specimens is shown in Fig.8 (Kevlar- Epoxy - 12 percent V_f). It depicts the nature of the specimen's loading and unloading, as well as the residual strain after the load has been removed, which must be recovered after a period of time.

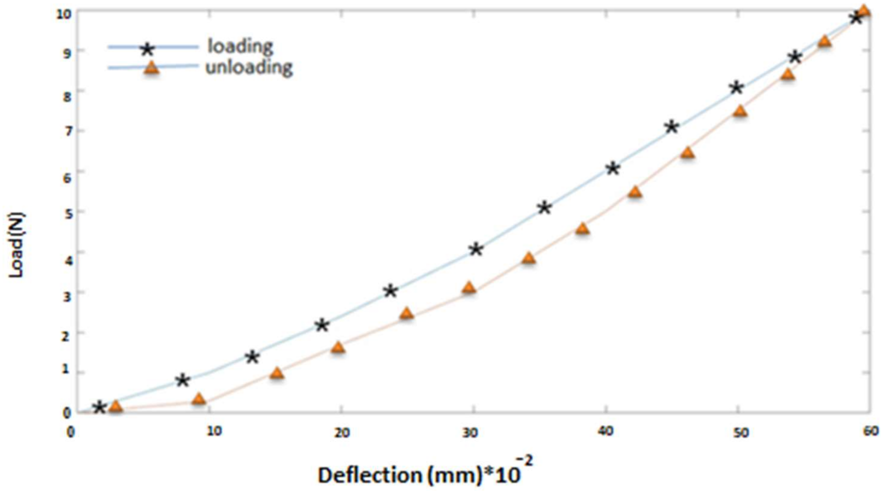


Fig.8:flexural strength and residual strength for one ply composite(Kevlar-epoxy 12%V_f)3-point test-longitudinal load

Fig. 9 shows the same type of the specimen with single layer but the fibers are oriented by 90^0 to the axis of the specimen during loading and unloading with indication of the same residual strain with the higher load, and there is no remarkable differences in the bending performance with indicated load.

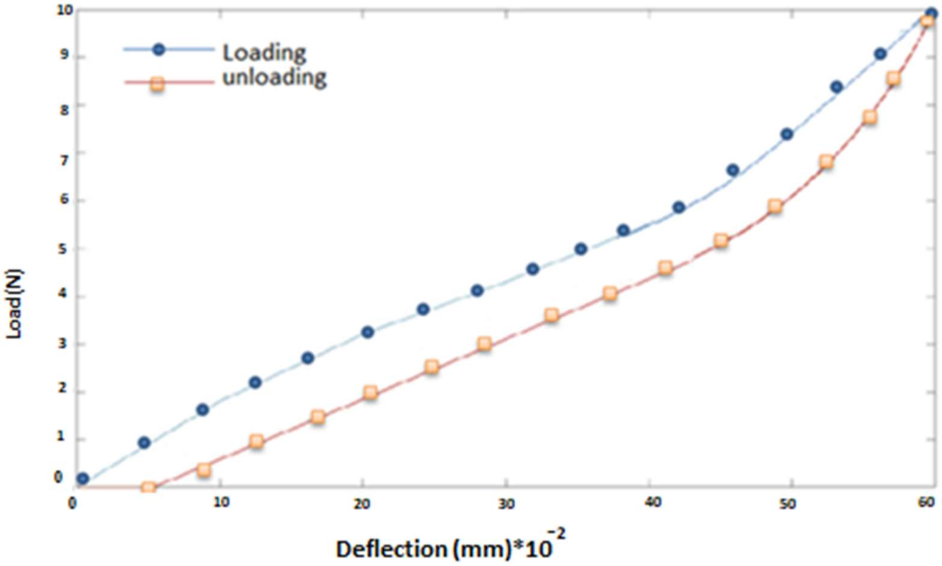


Fig.9:flexural strength and residual strength for one ply composite(Kevlar-epoxy 12%Vf)3-point test-transfer load

Fig.10 shows the load deflection for the specimens made of four layers reinforced with woven (cross ply) Kevlar where the fibers are parallel and at 90^0 which is the same of one layer specimens, higher residual strain was observed after the load removal. The specimen during unloading exhibited distributed unsteady performance resulting in scatter of readings also the behavior differed than the single ply in the relation being non-linear and much lower of deflection values. This is due to higher stiffness of the specimen compared with those of single layer as shown in Table 1.

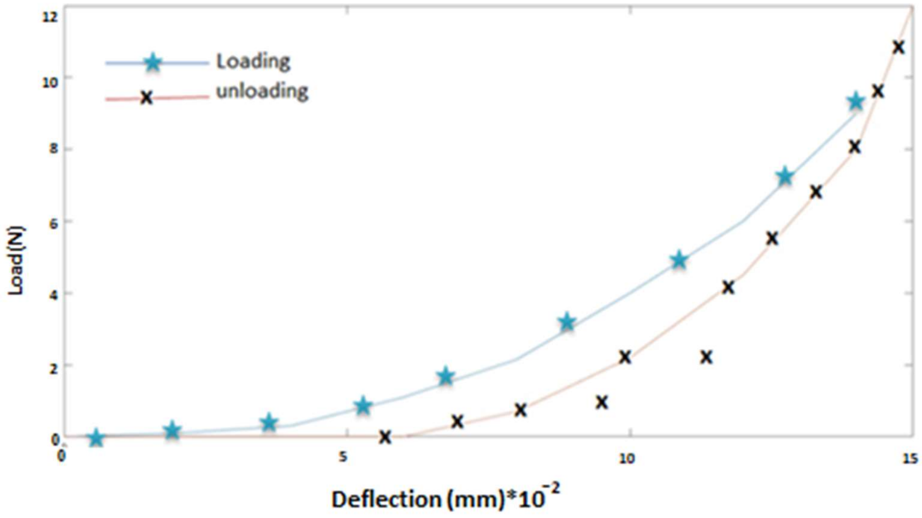


Fig.10:flexural and residual strength for cross ply composite(Kevlar-epoxy 12%Vf) 3-point test

Fig. 11 shows the load deflection for resin only. Higher deflection was noticed as expectedfor the same load and higher residual strain after loadremoval.

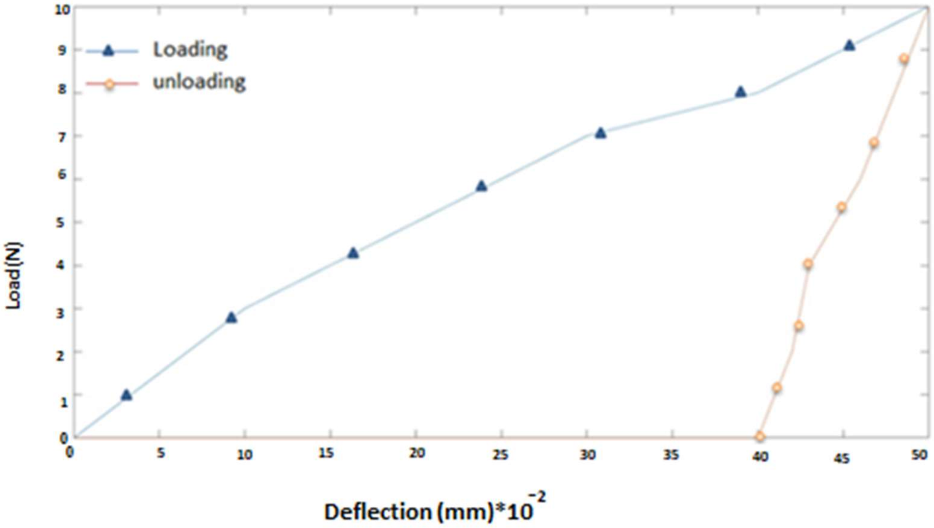


Fig.11:flexural strengthand residual strength for Resin(epoxy cy223+hardner HY 356-3 point test

Fig 12 shows the scanning electron micrograph of the failed nature of the specimen (0,45,45,0) it is clearly shows the failed fiber of the specimen as per the experimental work.

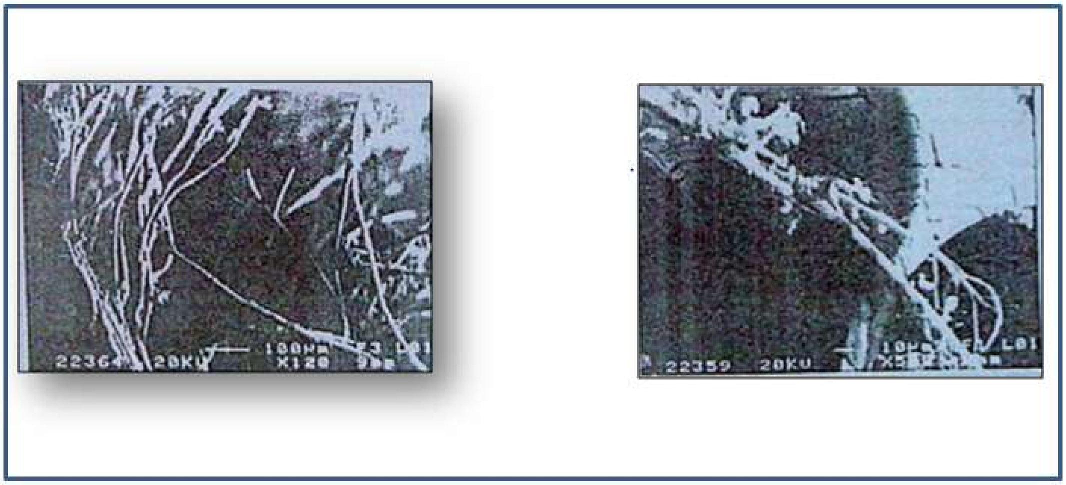


Fig.12: scanning electron micrograph of failed specimen (0,45,45,0) Kevlar 49-epoxy V_f=12%

Table (1)flexural strength and maximum strain for some typical composite and resin.

Type	Failure load N	Max.deflection mm	Max.strain mm/mm	Flexural strength Mpa
Cross-ply (woven)	700	3.4	0.0159	258.460

Resin (Epoxy)	550	3	0.0288	103.125
(0,45,45,0) first case	3000	9.4	0.0202	192.300
(0,45,45,0) second case	3200	9	0.0226	189.140

CONCLUSION

The following conclusions were drawn from the above-mentioned figures and observations made during the experimental study.The behavior of the current material, which is four ply with Kevlar fibers oriented at (0,45,45, 0), differed from that of the other materials reviewed and their outcomes.

1. The current material reaction to the load is not immediate, but it does have a time basis delay.
2. Under the same load, the material has a considerable deflection.
3. As the deflection is passed from one layer to the next, it takes specific pathways that are not always perpendicular to the beam's axis, and the deflection rotates as observed throughout the experiment. This is owing to the fact that force is resolved to each orientated fiber.
4. In the second case (load perpendicular to all plies), the new material failed due to mixed modes of longitudinal-compressive, transverse-compressive, and bending failures, whereas in the first case, the material failed due to compressive at upper layers and tension at lower layers, resulting in hairiness phenomena in the Kevlar (Fig.12).
5. The response of multi-layered multi-directional composites is evaluated as a function of ply fiber orientation and stacking sequence.
6. Longitudinal strain is predicted by FEM. In the first case, lateral loading in a (0,45,45,0) orthotropic construction composite deviates significantly from experimental results, whereas transverse strain in the second case for the same material compares favorably with experimental results, indicating that fiber direction and type of loading play a significant role in the load bearing capacity of a multi-layered multi-directional laminate.
7. Laminate thickness, stacking sequence, lamination structure (number of layers), and nature of loading all affect the amount and variance of deflections of Kevlar reinforcing Epoxy.
8. A significant finding of the current study is that material (0.45,45,0) composite is more sensitive to bending stress than others, as shown in table (1). The [(woven (cross-ply)] stacking is stiffer and has higher flexural strength, failing at a lower strain, whereas the material (0,45,45,0) composite failed at the highest strain and had lower flexural strength.
9. The failure mode is exhibited in specimens with unidirectional fibers in the fiber itself, but failure was limited to the surface layer only in the other types.

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