Deformation studies of polymer matrix composites reinforced with jute fibres: A continuum modelling approach

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Deformation studies of polymer matrix composites reinforced with jute fibre: A continuum modelling approach

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By

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May 2016

National Institute of Technology
Rourkela

CERTIFICATE

This is to certify that the project report entitled "**Deformation studies of polymer matrix composites reinforced with jute fibres: A continuum modelling approach**" being submitted by **Yelumarthy Lakshmi Sriram** (214MM1336) in the partial fulfilment of the requirements of **Master of Technology degree** in **Metallurgical and Materials engineering** is a bonafide thesis work done by him under my supervision during the academic year 2015-2016 in the Department of Metallurgical and Materials engineering, National Institute of Technology Rourkela, India.

To the best of my knowledge, the matter embodied in the thesis has not been submitted to any other University / Institute for the award of any Degree or Diploma.

Date: May 26, 2016

Place: Rourkela

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DECLARATION OF ORIGINALITY

I, Yelumarthy Lakshmi Sriram, Roll Number *214MM1336* hereby declare that this thesis entitled **“Deformation studies of polymer matrix composites reinforced with jute fibres: A continuum modelling approach’’** represents my original work carried out as a postgraduate student of NIT Rourkela and, to the best of my knowledge, it contains no material previously published or written by another person, nor any material presented for the award of any other degree or diploma of NIT Rourkela or any other institution. Any contribution made to this research by others, with whom I have worked at NIT Rourkela or elsewhere, is explicitly acknowledged in the thesis. Works of other authors cited in this thesis have been duly acknowledged under the section "Bibliography". I have also submitted my original research records to the scrutiny committee for evaluation of my thesis.

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May 26, 2016 *Yelumarthy Lakshmi Sriram*

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ABSTRACT

The present project work deals with the deformation studies of polymer matrix composites reinforced with jute fibres, utilizing continuum modelling approach. Jute Fibre reinforced polymer matrix composite consists of better mechanical properties such as high stiffness and high strength due to low density, corrosion resistance, electrical insulation, these advanced composites replaced the metals. The composite strength mainly depends upon volume/weight of reinforcement, Length/ diameter ratio of fibres, orientation angles and other aspects. In the current analysis using ANSYS simulation software designed a composite model with respective Jute fibre reinforcement polymer matrix, subjected it to longitudinal, transverse loading (Depends on Fibre orientation). From that investigated the mechanical properties and stress strain behaviour of composite material. Designed a Six ply composite (Jute 60 wt % + polymer 40 wt %) with and without crack, subjected it to three point bending test, from that analysed the deformed shape of the body, stress-strain distribution at each layer, and calculated flexural stress and strain, von misses yield criterion, maximum shear stress theory, simulation results are giving more accurate after comparing with literature values. And also calculated stress intensity factor (Mode I) for six ply jute fibre reinforced polymer composite with introducing a crack, analysed that stress intensity factor by variation of crack length and applied stress.

Keywords: Jute fibre, polymer matrix, ANSYS, Three point bending, stress intensity factor

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CHAPTER 1

INTRODUCTION

Improvement of advanced polymer composite materials gives a quality mechanical properties that created a new development in the engineering field. Advantages those are electrical insulation, corrosion resistivity, , easy process ability at practically less energy requirement in tooling and cost of assembly, have higher stiffness and greater strength, fatigue resistance and lower weight than metals, suitable in structural application made by jute fibre polymer composite[1]. The supposed advanced composites have changed metals because it has excellent mechanical properties and due to low density giving them greater specific stiffness and specific strength. Weight savings are extremely needed for applications in aerospace industry to transportation to decrease weight and fuel consumption. Another discrete advantage is their ability to be planned by proper fibre orientation placing in different layers of the laminated structure to get the properties in different directions [2].

Composite properties always depends on the properties of the constituent materials i.e. Fibres and resins used. The stiffness and strength of the composites are directly as a function of the reinforcing fibre properties which transmit most of the load and their volume content. The resin supports to maintain the relative position of the fibres within the composite and, more significantly,

Properties are also important and have a vital effect on composite properties including toughness and transverse fracture stress. To fabricate greater strength composites, all three factors namely fibre properties, resin properties as well as fibre/resin interface features are critical. By the continuum modelling approach study the deformation behaviours of a composites and to analyse the stress distributions at every point.

1.1 BACKGROUND AND IMPORTANCE

Generally Carbon, glass, boron such fibres are used as reinforcing materials in fibre reinforced polymers. In structural and non-structural applications these are commonly used as materials [3].By comparing with conventional materials fibre reinforced plastics FRP have greater specific modulus, greater stiffness/weight ratio and greater strength/weight ratio when. Though, usage of conventional materials are very expensive and it is used in aerospace applications. Hence, by using of natural fibres such as, cotton, banana, sisal, coir and jute are helped the scientists for presentation in various applications. It is observed that the natural fibre composites have taken place superior corrosion resistance and electrical, high thermal and insulating properties and greater resistance to failure. From the all the natural fibre materials jute looks as a favourable material because it is very economical and largely obtainable everywhere in the essential form. Which has greater strength, stiffness and higher modulus than the plastics [4] for conventional fibres in many conditions it is a good substitute. Though, the jute fibre has a collection of micro fibrils, multicellular structure and it cross-section is mainly non-uniform. The mechanical and physical properties are extremely inconsistent so that it depends on geographic origin, climatic development conditions and processing methods.

1.2JUTE FIBRE

Jute appears as the most capable natural fibres so that it has a higher specific strength and specific stiffness and also greater strength to cost ratio.it is available in Asian region, Jute fibres also be grown anywhere and it can be imported from many countries at a very low price.

Table 1 shows the jute fibre Chemical configuration

Composition	Percentage %
Cellulose content	65.2
Hemi-Cellulose content	22.2
Lignin content	12.5
Water soluble Matter content	1.5
Fat and wax content	0.6

Figure 1.1 Jute fibre

The untreated jute fibres were obtained directly from plants. We will get Untreated Jute fibre samples. It has golden colour with an average length and diameter of 1.5 m and 0.07mm as shown figure. From the process “retting,” remove the fibre from plants, so the plant is immersed in water some time. The “reeds” which are formed from plants are coarse aggregates. The fibres are segregated when the dried reeds are spread, thinner fibre structures are called “strands.”[5] A strand appears like a separate fibre, but in reality, it was composed of a number of true separate fibres, called as filaments or fibrils, By means of the natural binder lignin that intensely adhere longitudinally to each other. It was very tough to separate true filaments from the strand because the filaments are very thin and insistently stick to one each other. To separate the distinct filaments from the bundle, it has to use the finger and nails; in this method, the filaments are separating not only unevenly also its weakened because they are simply damaged.

1.3 POLYMER

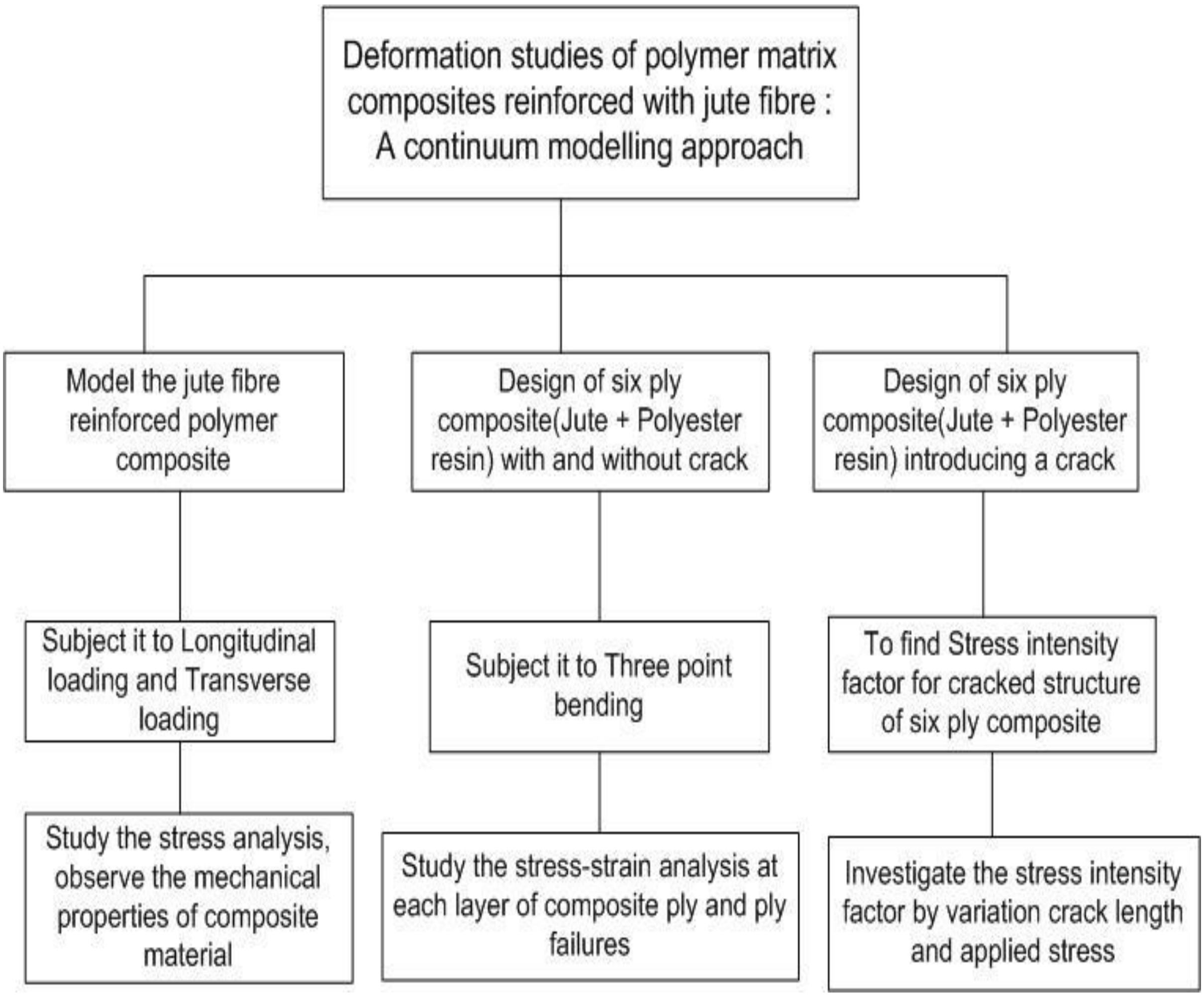
Over the past years, we observed that the polymers are exchanged several conventional metals/materials in many applications. It is because of the benefits polymers more than the conventional materials [6].So by using polymers most important advantages are, productivity, processing and cost reduction. In many applications, the polymers properties are changed using fillers and fibres to ensemble the higher strength/higher modulus requirements. Comparing to conventional materials the fibre-reinforced polymers deal profits over other, when specific properties are matched. These polymer composites are discover the applications in diverse fields from utilizations to spacecraft’s.

The long chain linear polymers having a many carbon double bonds which are called as unsaturated polyesters. These are made by any moisture build-up or condensation reaction amongst any by using glycol which are consists of wethylene, propylene, diethylene to create polyester resin by moisture build up or condensation reactions. Unsaturated dibasic acid solutions laterally used. The monomer for sample styrene is polymerizable (reactive), Generally carbon double bonds take place by its addition, Simply joining and adjoining of polyester matters on a unsaturated features it operates like a cross linking. The addition of monomer properties, then it works like a diluent, decreases in viscosity, from which it is a helpful for the method. Selecting of any compound it begins the cross-linking technique, taking as example of better aliphatic azo ingredient such natural and organic peroxide. It was observed that there is no by-product in this effect, treating is done also linked with enhanced temperature. By the components of maleic acid solution along with diethylene glycol particular reaction polyester resin forms. Reaction shown in below.

$$HOOC\text{-}CH{=}CHCOOH + [HOCH2CH2OCH2OH] \longrightarrow OH\text{-}[CH2CH2OCH2CH2OC\text{-}OCH{=}COHCO]\ n\text{-}H{+}H2O$$

Figure 1.2 Shows Polyester resin

1.4 WORK PLAN


Deformation studies of polymer matrix composites reinforced with jute fibre : A continuum modelling approach
Model the jute fibre reinforced polymer composite
Design of six ply composite(Jute + Polyester resin) with and without crack
Design of six ply composite(Jute + Polyester resin) introducing a crack
Subject it to Longitudinal loading and Transverse loading
Subject it to Three point bending
To find Stress intensity factor for cracked structure of six ply composite
Study the stress analysis, observe the mechanical properties of composite material
Study the stress-strain analysis at each layer of composite ply and ply failures
Investigate the stress intensity factor by variation crack length and applied stress

CHAPTER 2

LITERATURE SURVEY

2.1 COMPOSITE

Composite is a multiphase material which shows an important proportion of the properties of both the phases, it will give a better mixture of properties. Better properties combinations are produced by practical mixture of two or more different materials from the principal of combined action, [7].

Most of the composites are created to increase the mechanical characteristics such as greater stiffness, toughness, and greater strength.

We have taken two phase composite which consists one is matrix phase acts as a binder for the other phase and also it is continuous and surrounded by other.

Any composites properties are always depends on the component constituent phases, composites also depends on dispersed phase properties are in required amount, and the geometry of disperse phase which means that the particles shape and particle size, , orientation angles and distribution. Composite materials are classified as given below

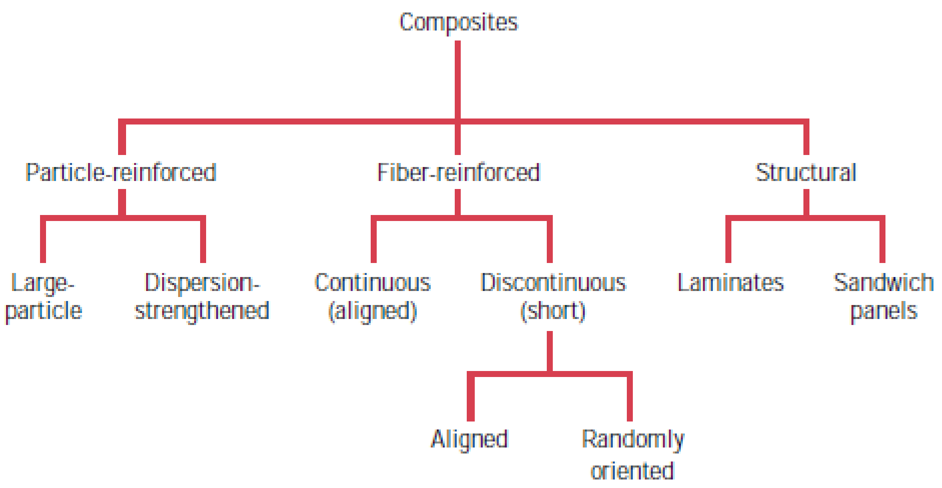


Figure 2.1. Different types of composite materials [7].

2.2 RULE OF MIXTURES

To calculate the properties of the composite materials by using rule of mixture, so that elastic modulus which fall between an upper bound. The mathematical expression formulated that elastic modulus depends on the volume fraction of the constituent phases for a two-phase composite. From this equations calculate the elastic modulus of composite.

$$\boldsymbol{E_c\ (u) = E_m V_m + E_p V_p}$$

2.3 FIBRE REINFORCED COMPOSITES (FRC)

Most of the composites have the fibres are in the dispersed phase. To design a fibre reinforced composite main objectives are that include high stiffness and greater strength on a weight basis. Specific strength and specific modulus are the parameters of FRC [7].

The ratio of tensile strength to specific gravity is called as specific strength

The ratio of modulus of elasticity to specific gravity is called as specific modulus

Due to the low-density fibre and matrix materials, fibre reinforced composites have mainly high specific strengths and modulus.

2.4 EFFECT OF FIBRE LENGTH IN COMPOSITE

Fibre reinforced composite not only depends the properties of the fibre, it also depends on the load which is applied, so that matrix will transform load to the fibre. Significant to that transformation of load is the degree of the interfacial bond between the fibres - matrix phases. At the end of fibres, the bond between fibre and matrix terminates, by the applied stress. The deformation pattern of matrix as shown in

2.4.1 Critical fibre length

The critical fibre length is essential for any composite material, it gives better stiffening and strengthening. The critical length which is denoted by ***lc*** is depends on tensile strength σ_f and the fibre diameter *d*, and on the interfacial bond strength of fibre matrix, shear strength of the matrix phase) τ_c

$$l_c = \frac{\sigma_f\ d}{2\,\tau_c}$$

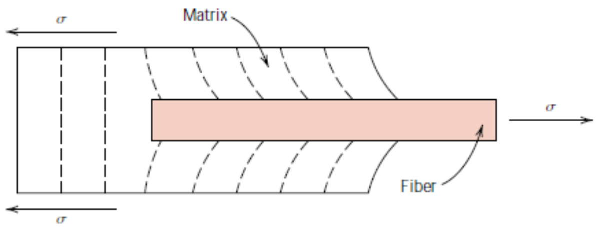


Figure 2.2. It shows the deformation of matrix and fibre when it subjected to tensile load [7].

If the stress equal to σ_f and it is applied to a fibre that having the critical length, the stress position as shown in figure 2.3*a* so that, at the axial centre of fibre the maximum fibre load is reached. Once the fibre reinforcement becomes more effective, if the fibre length *l* increases; it is shown in Figure 2.3*b*, if the applied stress is equal to the fibre strength then a stress axial position outline *l* > *lc*. Figure 2.3*c* shows that the stress position for

l < *lc* .If the fibres have *l* >> *lc* (generally *l* > 15*lc*) are termed as continuous fibres. Fibres have lengths shorter than critical length *lc* for the short or discontinuous.

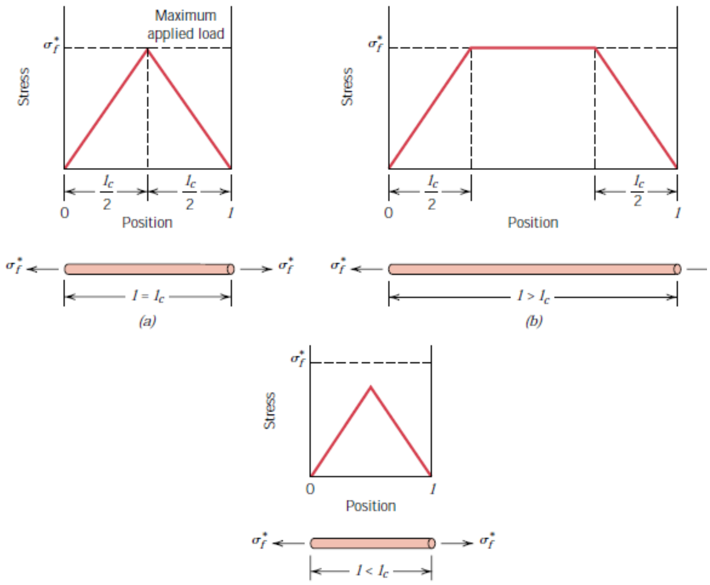


Figure 2.3. It shows the position of stress (a) fibre length equal to lc, (b) Fibre length greater than lc (c) Fibre length is less than lc it is subjected to a tensile stress [7].

When the matrix deforms around the fibre, so that there is no stresses transfer and the slight reinforcement by the fibre, if the fibres are continuous.it will improve the strength of the composite

2.5 EFFECT OF FIBRE ORIENTATION IN COMPOSITE

Fibre orientation and arrangements in composites plays an important role. The major influence of strength and other properties of fibre reinforced composites mainly depends on the fibre concentration and its distribution in composite. By the fibre orientation, classified as (1) The alignment of fibre in a parallel single direction along the longitudinal axis, (2) Fibre alignment totally random. Fibres are aligned Continuous as shown Figure 2.4*a*, and fibres are also aligned in discontinuous as Shown Figure 2.4*b*, Fibre orientation in random as shown Figure 2.4*c*, and oriented partially. Better composite properties are obtained when the fibres are distributed in uniform manner.

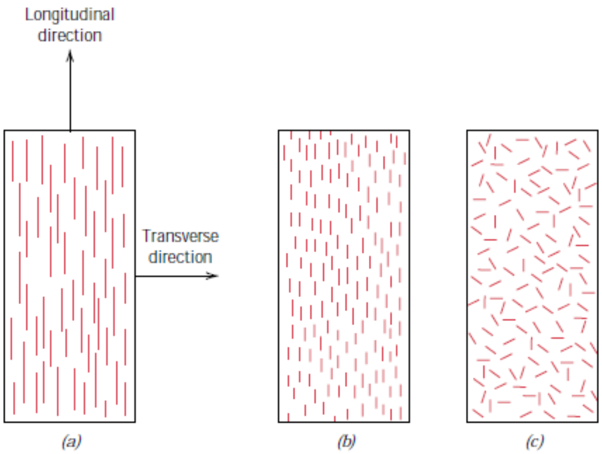


Figure 2.4. Shows that the (a) continuous fibres (b) discontinuous fibres (c) randomly oriented of a fibre reinforced composites (FRC) [13].

2.6 Tensile Stress–Strain Behaviour—Longitudinal Loading

Composites are mainly depend on some factors which influence on the stress ,strain behaviours of fibre , matrix phases, fibre volume fraction, and the applied load in the direction. Moreover, the alignment of fibres in the composite and its properties are extremely anisotropic, so that, it's totally dependence on the direction in which they are going to measure. The stress or load which applied along the direction of fibre alignment, such that longitudinal direction**,** from that study the stress–strain behaviour for the situation which direction is specified as shown in Figure 2.5*a*

Observe the stress versus strain behaviours for fibre and matrix phases that are characterised as shown in Figure 2.5*a*, here we have taken fibre as to be totally brittle materials and the matrix phase is to be basically ductile in nature. The strength of fracture in tension for fibre and matrix, σ_f and σ_m, respectively are specified in that figure, and also fracture strains, ϵ_f and ϵ_m respectively, it shows that $\epsilon_f > \epsilon_m$ [7].

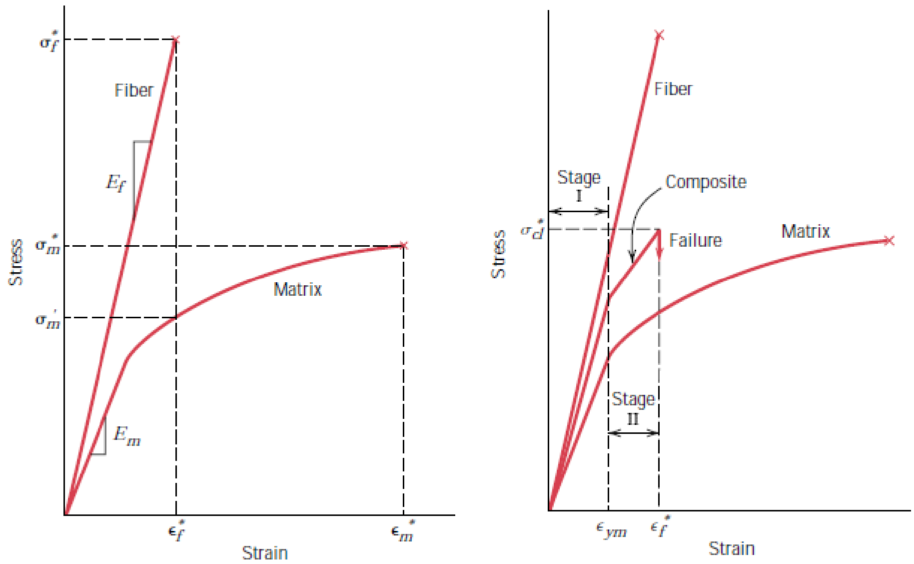


Figure 2.5. (a) The stress vs strain curve for the fibre and matrix materials. (b) Shows the stress vs strain curve for fibre reinforced composite, in the direction of fibre alignment uniaxial stress is applied [7].

In the fibre reinforced composite consists of a fibre and matrix materials which shows the stress–strain response as shown in Figure 2.5*b*, the behaviour of fibre and matrix from Figure 2.5*a*. At Stage I deform elastically both fibres and matrix, up to this portion the curve is linear. Naturally, this type of composite the matrix yields and also deforms plastically at ϵ_{ym} as shown in figure 2.5*b* while coming to the fibres are those stretch elastically, fibres tensile strength is greater than the yield strength of the matrix. Moreover, changing the curve from Stage I to Stage II, The applied load which is allowed by the fibres increases proportionally. When the fibres are ready to fracture, the failure of composite begins, so that the corresponds strain nearly ϵ_f as shown in figure 2.5*b*, the matrix is complete still, even failure of fibre, as $\epsilon_f < \epsilon_m$. So that, these fractured fibres are shorter when compared with the original fibres, these fibres are still connected completely with the matrix, fibres have capable of resist the diminished load when the matrix deform plastically.

2.7 LONGITUDINAL LOADING

The load which is applied in the direction of fibre alignment to an elastic behaviour of a continuous and oriented fibre composite. It was observed that the fibre matrix interfacial bond is very good, so that deformation of both matrix and fibres are in the same direction (isostrain). In this conditions, the total load which carried by the composite *Fc* is equal to the loads carried by the respective phases such as *Fm*, and *Ff*

$$\boldsymbol{F_c = F_m + F_f} \qquad \textbf{(1)}$$

Stress we can write as, *F* =σ*A*, forces are *Fc*, *Fm*, and *Ff* have respective stresses σ_c, σ_m and σ_f.

And cross-sectional areas of constituents *Ac*, *Am*, and *Af*.

$$\sigma_c A_c = \sigma_m A_m + \sigma_f A_f$$

Divide the above equation with total cross section area of composite

$$\sigma_c = \sigma_m \frac{A_m}{A_c} + \sigma_f \frac{A_f}{A_c}$$

The area fractions of the matrix and fibre phases, *Am*/*Ac* and *Af* /*Ac* are respectively. If the length of composite, matrix, and fibre phase are all equal, so that area fractions of the matrix a equivalent to the volume fraction of the matrix, *Vm*, in the same way for fibres, *Vf* = *Af* /*Ac.*

$$\sigma_c = \sigma_m V_m + \sigma_f V_f$$

In isostrain condition, strains of all phases are equal

$$\epsilon_c = \epsilon_m = \epsilon_f$$

From that we get

$$\frac{\sigma_c}{\epsilon_c} = \frac{\sigma_m}{\epsilon_m} V_m + \frac{\sigma_f}{\epsilon_f} V_f$$

The composite, matrix, and fibre phases all are deforms elastically, such that $\frac{\sigma_c}{\epsilon_c}$ =*Ec*, $\frac{\sigma_m}{\epsilon_m}$ =*Em*, and $\frac{\sigma_f}{\epsilon_f}$ =*Ef*, the *E*'s is the young's modulus for all phases. The expression for the Young's modulus for a continuous and aligned fibres composite [7].

$$E_{cl} = E_m V_m + E_f V_f$$

The composite have only the matrix and fibre phases, such that, *Vm+Vf* =1.

2.8 TRANSVERSE LOADING

The load which is applied in the direction perpendicular to fibre alignment to a continuous and oriented fibre reinforced composite. As shown in figure 2.4*a*. In this condition the stress acting on composite as well as both fibre matrix phases are equal.

$$\sigma_c = \sigma_m = \sigma_f = \sigma$$

It is called as *iso stress* state. The deformation on the entire composite expressed as below

$$\epsilon_c = \epsilon_m V_m + \epsilon_f V_f$$

Strain $\in = \frac{\sigma}{E}$,

$$\frac{\sigma}{E_{ct}} = \frac{\sigma}{E_m} V_m + \frac{\sigma}{E_f} V_f$$

Young’s modulus acting in the transverse direction. From that [7]

$$\frac{1}{E_{ct}} = \frac{V_m}{E_m} + \frac{V_f}{E_f}$$

2.9 LAMINAR STRUCTURED COMPOSITE

These structured type of composites have two-dimensional sheets or layers it has a high strength direction so that they are found usually in wood and continuous and aligned fibre-reinforced plastics [7]. The layers are arranged and after combined together so that the orientation of the high strength direction varies with the each successive layers as shown in figure.2.6

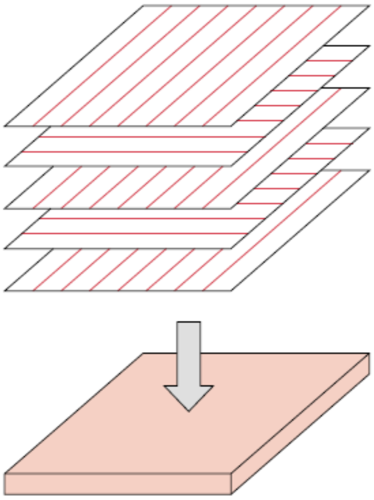


Figure 2.6 Shows the arrangement of successive layers oriented of fibre reinforced laminar composite [13].

2.9.1 Fabrication of ply composite

Jute fibres in non-treated and conditions were used for fabrication of six-ply composites. The jute fibre reinforced polymer composite sheets are fabricated by using the technique called hand lay-up.

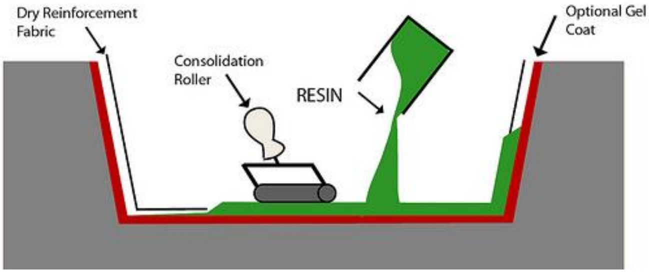


Figure2.7. Fabrication of composite ply by using Hand-Layup method [13].

The composites are prepared by using 60 weight % jute fibre (non-treated) and 40 weight % unsaturated polyester resin (containing the additives like resin, hardener and accelerator in a ratio of 100:2.6:2 by weight).

From that green composite sheets were subjected to rolling for evenly distribute and allow the penetration of resin to every corner of composite. And also, removal of air bubbles occurs from the above process. Then the composite sheets are afterward subjected to a pressure for a period of 10 min. It will enhance the resin penetration and enable the removal of remaining air bubbles from the composite after that curing of the composite was done at 30°C for 48 h maintaining a pressure of 0.3 N/mm^2. The cured sheets were cut into 92 mm long (span length = 70 mm), 12.7 mm wide and 4.5 mm thick specimens following ASTM D790 standard for flexural test.

2.10 PROPERTIES OF FRP

2.10.1 Tensile Test

According to literature, tensile tests are performed on fabric of a jute and yarn and jute fibre reinforced polymer composite, It has a gauge length of 200 mm and cross-head speed of 1.3 mm/min from that plotted the stress vs strain curves, tensile strength and modulus of elasticity. The yarn has a circular cross-section area, to measure the diameter of the slightly stretched yarn. By multiplication of the number of yarns per inch of fabric, so that cross-sectional area of fabric is achieved. Tensile tests are also perform on polyester resin and composite which gives a define tensile strength, young's modulus and Poisson's ratio [3]

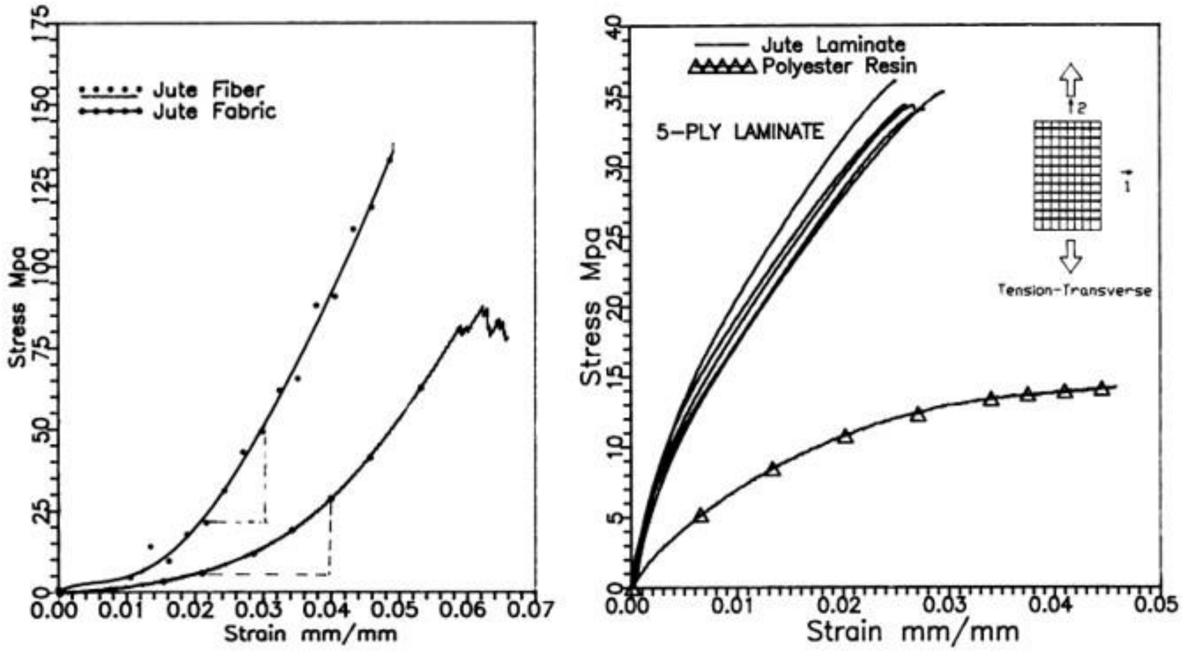


Figure 2.8. (a) Shows Stress-strain curve of jute (b) shows the stress-strain curve of jute fibre reinforced polymer composite [3]

2.10.2 Flexural Test

Flexural test of as received fabric JFRP composites (environmental conditioned and non-conditioned) were done as per ASTM D790 standard for flexural test using Instron1195. The tests were conducted at crosshead velocities of 0.5, 1, 5, 10, 50, 100, and 500 mm/min. The load-displacement plots generated by the machine were used to estimate ILSS using the following relation (Chawla 2009) [3]:

ILSS=3/4 (P_{max} / b×h).

Where P_{max} = maximum load, b= Sample width and h= sample thickness.

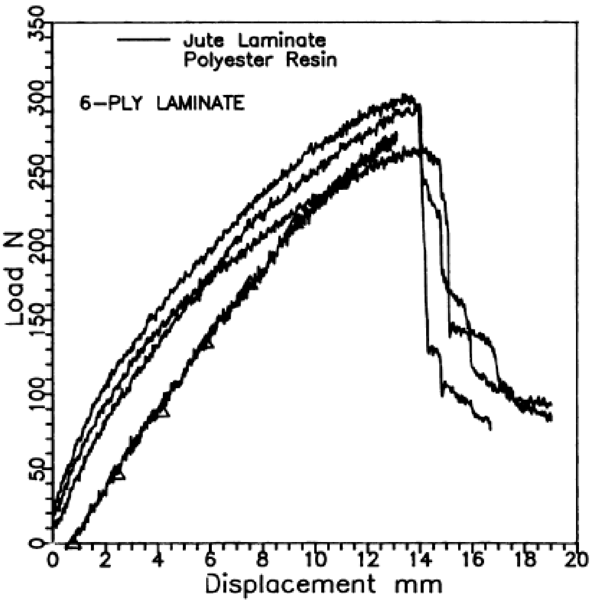


Figure 2.9. Shows the load vs displacement curve of jute fibre reinforced polyester composites [3].

2.11 FRACTURE MECHANICS

It deals with the studies of the crack propagation and defects in a structure when it is subjected to an external or practical loads. It will link the analytical prediction of a crack and failure propagation with the experimental values. Calculating the fracture parameters, those are stress intensity factors in the region of crack. To calculate the crack growth rate, the crack length increases, normally with the application of applied loads [8].

Stress intensity factor is used to predict the state of stress near the crack tip when acting applied loads and residual stress.

Fracture parameters are given below

- Stress intensity factors which are classified in three different modes of fracture

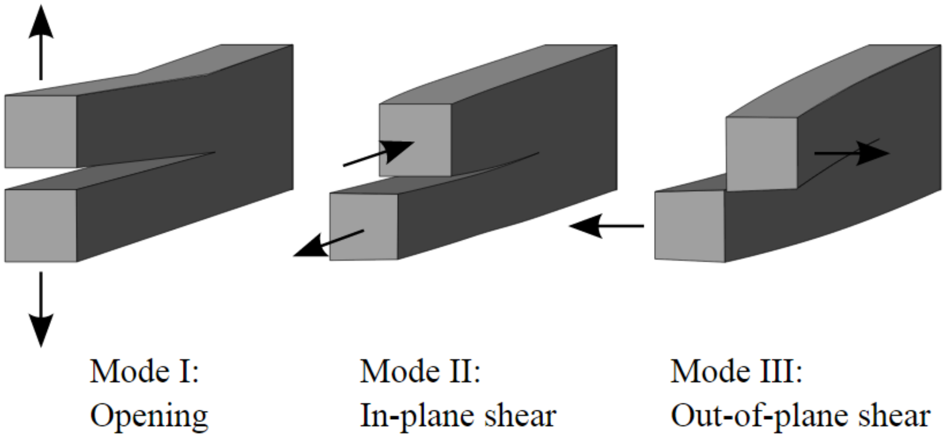


Figure 2.10. Shows different types fractures [8].

- To measure that the strength of the particular stresses and strain near a crack tip region by J- Integral is the type.
- The amount of work released at a crack opening and closure calculated by Energy release rate G,

2.11.1 Stress Intensity factor (SIF)

This factor is used in facture mechanics to study the stress intensity factor near the tip of crack propagation by the repeated loads or applied stresses. The factors which are depends on the SIF are geometry, the size of the crack and location of the crack, and the magnitude and the modal circulation of loads on the material.

$$K_{\mathrm{I}} = \sigma\sqrt{\pi a}$$

σ = Applied stresses, a = Crack length

2.12 LITERATURE VIEWS ON JUTE FIBRE-REINFORCED POLYMER COMPOSITE

If we observe failure of any laminated composite the factors of failure appears like fibre rupture, debonding of fibre, matrix interface, composite ply delamination and crack in a matrix [15]. Mainly these failures occur on any composite ply laminate, the weakest ply fails first so that it called as the first ply failure (FPF). The propagation of this failure continue until the last ply fails and it breaks totally. We could analyse of individual ply failure because result from first ply failure, and it is also greatly depends on to find last ply failure [16].It is very economical and cost to perform an any Physical tests on composite structures, from the last ply failure of the laminates structure we will get the strength values[17]. So that by using computer software's to analyse the structure failure which gives better and acceptable results. Other analyses like computational and mathematical analysis are somewhat lengthy approach which require many iterations to calculate the problems with variation of loads, geometry and properties of materials [18]. So that finite element analyses approach is used by many researchers to get the accurate results while comparing it with theoretical values [17, 18]. By using of programming code, language and tools to develop a model on the computers [19].It requires more research to get accuracy and acceptable results when using finite element analysis to investigate the failure of laminated composite with comparing experimental results. Laminated type of composites are to be analysed by many software packages like ANSYS APDEL is available to provide better solutions to the various computational problems [6]. According to the literature, ANSYS software developer has started the finite element models and created a First-order shear deformation theory for free vibration analysis and also the earlier assumption was removed because of accurate deformation [4]. HSDT is a complex programming so it cannot be used for ANSYS and also more time consumption..

And also some researchers are investigated the process variables such as curing temperature and time on the mechanical properties of jute fibres Bhattacharya[9].A reasonable work on jute fibre in epoxy polyester resins are performed by the Scientists of the National Aerospace Laboratory (Bangalore) and Vikram Sarabhai Space Centre (Trivendrum).. Verma et al. [10] and Mohan et al. [11] they investigated mechanical properties of jute-glass hybrid composites with epoxy resin and polyester resin and Chawla and Bastos [12] are investigated the untreated jute fibres in unsaturated polyester resin developed by the leaky mould technique from that observed the result of the volume fraction of on Young's modulus, maximum strength and impact strength. Winfield [13, 14] they have investigated the jute reinforced various applications.

2.13 OBJECTIVE OF MY PRESENT WORK

- To study the deformation behaviour of jute fibre reinforced polymer matrix composite. With a continuum modelling approach.
  - To create a jute fibre reinforced polymer composite model and subject it to longitudinal and transverse loading by variation of fibre orientation.
  - To design jute fibre reinforced 6 ply composite model and subject it to three point bending test to find stress distribution at each layer.
  - To design jute fibre reinforced 6 ply composite model with a crack and subject it to three point bending test to find stress distribution at each layer.
  - To design jute fibre reinforced 6 ply composite model and calculate stress intensity factor by introducing a crack.

CHAPTER 3

CONTINUUM MODELLING DETAILS

3.1 WHAT IS CONTINUUM MODELLING?

It is a branch of mechanics that investigates the mechanical behaviour of materials modelled from a discrete particles to continuous mass. If any object modelled as a continuum it will accepts that the matter of the object which totally fills the space as it occupies [20]
Continuum mechanics deals with physical properties of solids and fluids which are self-governing of any specific system in which they are observed.

3.2 WHAT IS SIMULATION?

It defined as imitate the operation of real world process over a particular time. If u simulates a something first we need to develop a model, from that model we observed the behaviour and functions of the selected physical system or a process. Whereas as the simulation indicates the operation of the process over particular time, and the model which indicates the process itself,

3.3 FINITE ELEMENT ANALYSIS

Finite element method is used to produce solutions for the boundary value problems and it is a numerical method which consist of partial differential equations. It is also called as finite element analysis. The main advantage of finite element method that subdivides a big problem into a finer, parts, and simpler, which defined as finite elements. Any simple equations that are model by the finite elements then it is assembled to a greater system of equations which models the entire problem.
Structural integrity of a design model could be analysed by using a finite element analysis software is ANSYS**,** using with this software to design a model it can be verified and tested theoretically before the prototype is produced, it will save the cost and time. The research community are focusing more attention on FEA method to observe the stress strain analysis on various types of composite models such as composite ply and also it is a numerical tool for many applications, such that it analyse the post-buckled delamination failure in the composite

laminate [21]. In the fibre reinforced composite model the fatigue damage [22]. The finite element method depends on the input factors which are, loading, constraints, and mechanical properties are helps the correct estimation for the structural strength of the composite. The mechanical properties of a jute fibre reinforced composite material are generally calculated with help of three-point bending so that a specimen is made from the composite material. The non-homogeneity present in the composite material so that the results of a test are not repeated to different test of specimens. Presence of internal defects, those are presence of voids, delamination, and moisture content, will affect the measured properties of composite material. To predict the finite element method by using experimental means in that case it is essential. This type of studies carried by the many researchers [23–25].

Fibre reinforced composite consists of fibre and matrix phases, by the fibre, matrix properties, which observed the mechanical behaviour of the composites. Significant proportion to determining the mechanical properties are also depends on as fibre shape, fibre array and the fibre volume fraction. To calculate the properties which are start with the intrinsic properties and their constituents phases, from this model have given a clear idea that fibre strength is not employed from the results of fibre length and poor fibre matrix interfacial adhesion.

To model the composite material with the help of using assumption. By the finite element method software (ANSYS) used to analyse the mechanical properties.

Unidirectional composite properties that are given below.

Analysis of work have been grouped by some of assumptions

1. Fibres should not be porous
2. Fibres should have uniform with diameter.
3. Good Interface bonding is to maintain between fibres and matrix.
4. The bond should maintain between fibre and matrix is perfect, without slippage.
5. Arrangement of fibres in unidirectional manner, aligned perfectly
6. Composite material have without voids.

Model the behaviour of a composite material by the finite element method in the origin of micromechanical level. The model was a rectangular section of beam and it is an isotropic material. The elements which consist of isotropic property and will be located corresponding to the fibres, and the mesh regions are coarsely meshed.

The composite material contains of fibres aligned in unidirectional way and modelled as a rectangular uniform arrangement. This model expected that the fibre is a perfect cylinder of length *l* and diameter *d* (0.07mm) in matrix.

The model is treated as a linear isotropic problems. The FEA model is created of SOLID 95 elements, used for fibre matrix structure. The model involved the fibre, matrix, and fibre-matrix interface. The fibres with surrounding matrix were selected for stress analysis in this model. These regions were modelled by means of the coarse mesh.

3.4 ANSYS

ANSYS is the finite element software that used to solve the huge scale of problems. And also solve a wide variety of problems which are linear and nonlinear structural response, modal analysis, full harmonic response, buckling, heat transfer, transient and dynamic response electromagnetic and fluid flow problems. ANSYS offers a large verity of library of elements the simplest (1-D elastic bar element) to the very complicated (3-D nonlinear elasto-plastic element). Facts about these elements and the type of analysis available in ANSYS can be found in various sources and manuals. Help is also offered interactively within ANSYS.

The ANSYS is a structural analysis software that allows you to solve complex engineering and structural problems, it gives better and faster design decisions. With the help of finite element analysis (FEA) tools, Parameterize them to analyse multiple design situations, if we modify and automate our simulations. Structural Mechanics ANSYS software easily connects to other physics analysis tools, providing even greater practicality in predicting the behaviour and performance of complex products.

3.5 MODELLING OF JUTE FIBRE REINFORCED POLYMER MATRIX COMPOSITE SUBJECTED TO LONGITUDINAL AND TRANSVERSE LOADING

3.5.1 Materials and their properties used for modelling

- Untreated Jute fibre used as a reinforcement and its mechanical properties are [3]
  Density: 1.3 (g/cm^3)
  Young's Modulus: Longitudinal direction 7 (GPa)
  Transverse direction 3.5 (Gpa)
  Shear Modulus: 2.2 (Gpa)
  Poisson's ratio: 0.25
- Polyester resin used as a matrix and its mechanical properties are [3]
  Density: 1.22 (g/cm^3)
  Young's Modulus: Longitudinal direction 1.4 (Gpa)
  Shear Modulus: 1.2 (Gpa)
  Poisson's ratio: 0.38

3.5.2 Simulation using ANSYS

To create the jute fibre reinforced polymer matrix composite model with help of using Ansys Work bench. So before going to design a model we have to select an element type and then need give material properties as an input to the material models. After that in modelling create a rectangular area with respective dimensions 40×40×50 mm and add a reinforcement jute fibre dia of (0.07mm) to that rectangular area, then extrude that area, so that rectangular solid with reinforcement generated as show in figure.3.1 .

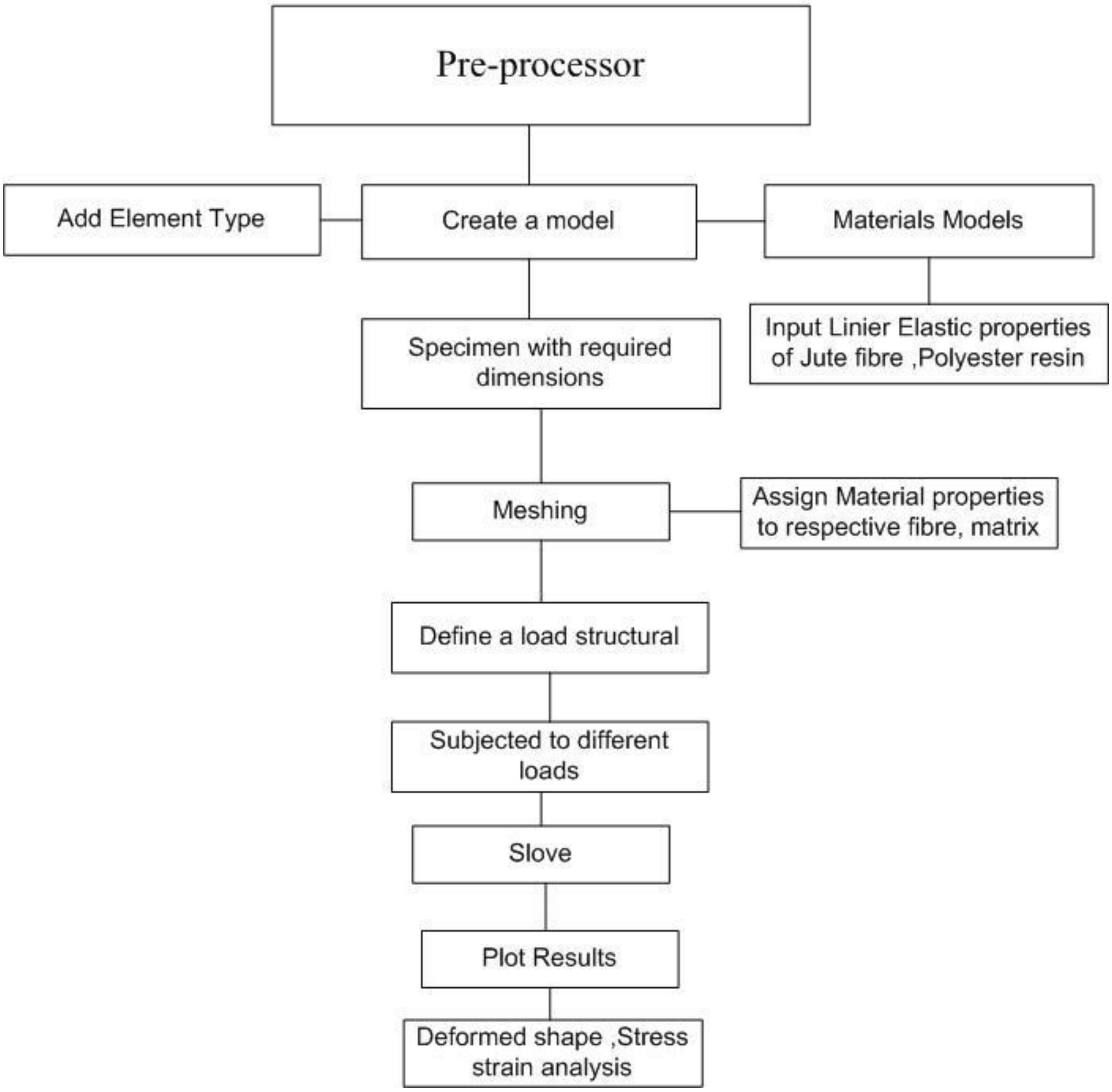


Figure 3.1. Flow chart showing sequence of process in modelling through ANSYS.

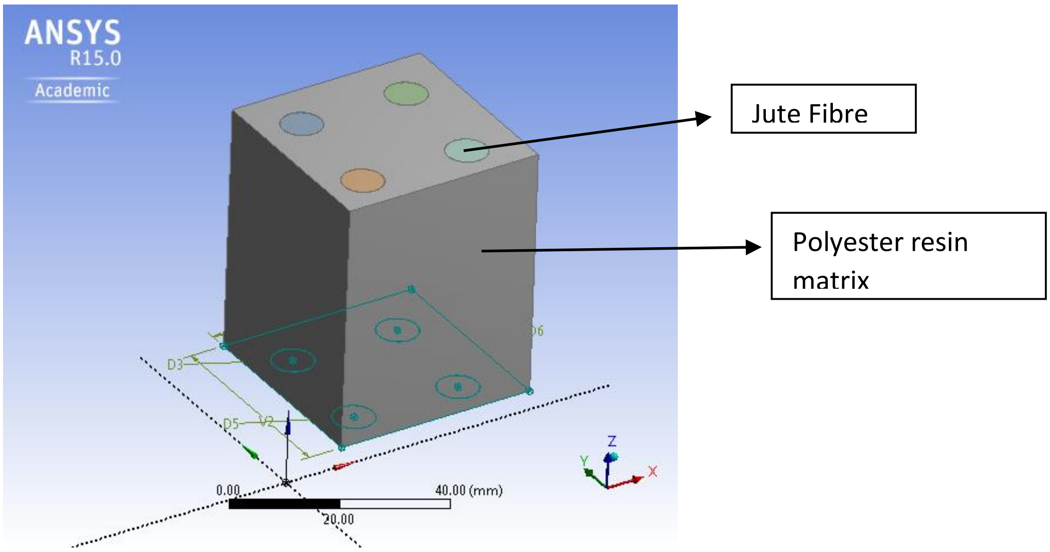


Figure 3.2. Model of jute fibre reinforced polymer composite with respective dimensions 40×40×50 mm and fibre diameter 0.007mm.

After creating a model subject it to a longitudinal loading in the direction of fibre alignment and transvrese loading in the direction perpendicular to fibre alignment as shown below figures after sloving plot the results and find stress analysis

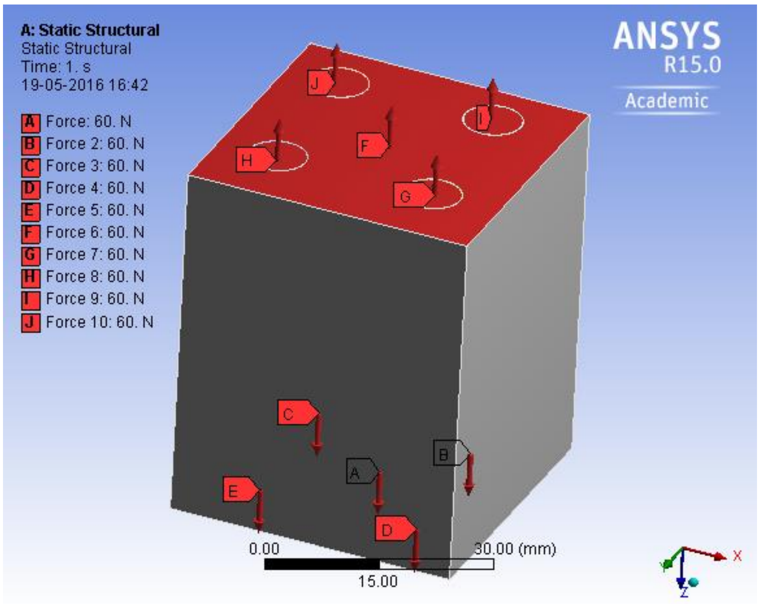


Figure 3.3.Shows longitudinal loading of jute fibre reinforced polymer composite

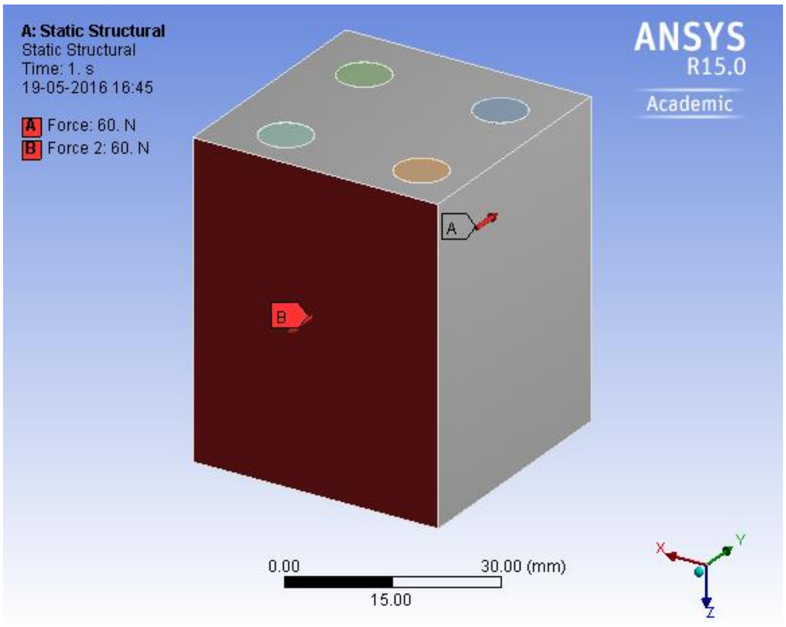


Figure 3.4.Shows Transverse loading of jute fibre reinforced polymer composite

3.6 DESIGN OF SIX PLY COMPOSITE (JUTE FIBRE + POLYESTER RESIN)

To Design a Jute fibre reinforced six ply composite. The composites were prepared using 60 weight % jute fibre (non-treated) and 40 weight % unsaturated polyester resin (containing resin, hardener and accelerator in a ratio of 100:2.6:2 by weight).

The composite ply defined as the semi-finished product of reinforced fibre and resin, it is two dimensional (2D) thin layer type structure.

- Matrix with a unidirectional layer of fibres
- Matrix with a woven fabric in nature
- Matrix with a layer of mat

3.6.1 Mass Fraction of fibre and matrix

Mass fraction of Fibre is

$$M_f = \frac{Mass\ of\ fibre}{Total\ mass} = 0.6$$

Mass fraction of matrix is

$$M_m = \frac{Mass\ of\ matrix}{Total\ mass} = 0.4$$

Such that

$$M_m = 1 - M_f$$

3.6.2 Volume Fraction of Fibre and matrix

Volume fraction of Fibre defined as

$$V_f = \frac{\text{Volume of fiber}}{\text{Total volume}}$$

$$V_f = \frac{\frac{M_f}{\rho_f}}{\frac{M_f}{\rho_f} + \frac{M_m}{\rho_m}} = 0.584$$

And the matrix volume fraction is defined as

$$V_m = \frac{\text{Volume of matrix}}{\text{Total volume}}$$

Such that

$$V_m = 1 - V_f = 0.416$$

3.6.3 Ply mass density

Ply mass density calculated by

$$\rho = \frac{\text{Total mass}}{\text{Total volume}}$$

From that,

$$\rho = \frac{\text{Mass of fiber}}{\text{Total volume}} + \frac{\text{Mass of matrix}}{\text{Total volume}}$$

$$= \frac{\text{Volume of fiber}}{\text{Total volume}} \rho_f + \frac{\text{Volume of matrix}}{\text{Total volume}} \rho_m$$

$$\rho = \rho_f V_f + \rho_m V_m \qquad \textbf{[7]}$$

$$\rho = 1.266 \quad {}^{g}/_{cm^3}$$

3.6.4 Thickness of a Ply

Thickness of a ply depends on the weight per unit area of fibre. Thickness of a ply denoted by *h*, and grammage denoted by m_{of}

$$h \times 1\,(\text{m}^2) = \text{Total volume} = \text{Total volume} \times \frac{m_{of}}{\text{Fiber volume} \times \rho_f}$$

Ply thickness expressed in mass fraction when compared to volume fraction [7]

$$h = m_{of}\left[\frac{1}{\rho_f} + \frac{1}{\rho_m}\left(\frac{1 - M_f}{M_f}\right)\right]$$

3.6.5 Ply properties in Unidirectional

The mechanical characteristics of the fibre/matrix mixture can be estimated from the characteristics of each of the properties of each constituents phase are used to estimate fibre-matrix mechanical characteristics. The literature provides a number of theoretical or semi By using many empirical or theoretical relations to get the results so that those results not always connect with the values derived from the tests. Fibres are in anisotropy nature.

- Along the fibre direction, Modulus of elasticity E_l [7]

$$E_\ell = E_f V_f + E_m V_m$$

$$E_l = 4.6704\ (GPa)$$

- Along the transverse direction to the fibre axis, modulus of elasticity E_t

  Below equation shows that, perpendicular to the fibre that is along the fibre in the direction, elastic modulus E_{ft} [7]

$$E_t = E_m \left[\frac{1}{(1 - V_f) + \frac{E_m}{E_{ft}} V_f} \right]$$

$$E_t = 2.155\ (GPa)$$

- **Modulus of shear, G_{lt}**

The shear modulus of the fibre, represent by G_{flt} [7]

$$G_{\ell t} = G_m \left[\frac{1}{(1 - V_f) + \frac{G_m}{G_{f\ell t}} V_f} \right]$$

$$G_{lt} = 1.79\ (\text{GPa})$$

- **Poisson Ratio of composite ply**

A composite ply is subjected to tensile loading that is in the longitudinal direction ℓ so that contraction occurs in the transverse direction t. [7]

$$\upsilon_{\ell t} = \upsilon_f V_f + \upsilon_m V_m$$

$$\upsilon_{lt} = 0.3$$

3.6.6 Modelling of 6 ply composite

Select an element type SHELL 4node181 and give ply liner orthotropic material properties as an input to material models as shown in given table.

Table 2 Liner orthotropic material properties of jute fibre reinforced polymer composite ply.

Elastic Modulus (E)	Shear Modulus(G)	Poisson's Ratio (υ)
$E_x = \;$ *4.67 GPa*	G_x = 1.79 GPa	υ_x = 0.3
$E_y = \; \mathbf{2.15\ GPa}$	G_y = 1.5 GPa	υ_y = 0.3
$E_z = \; \mathbf{2.15\ GPa}$	G_z = 1.5 GPa	υ_y = 0.3

Modelling the jute fibre reinforced polymer matrix of six-ply composite with help of Ansys APDL. Fibre orientation of each ply taken as 0 and 90 degrees alternatively as shown in figure.3.5

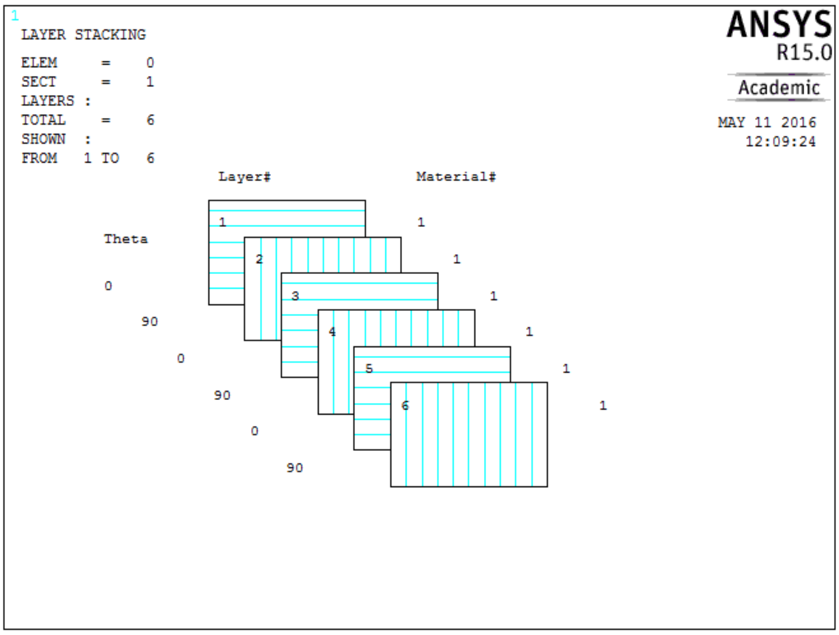


Figure 3.5. Jute fibre orientation of each ply taken as 0 and 90 degree.

Create a rectangular specimen with respective dimensions 92×12.7×4.5mm as shown figure.3.6 which consist of 6 ply composite layers and meshing should be done.

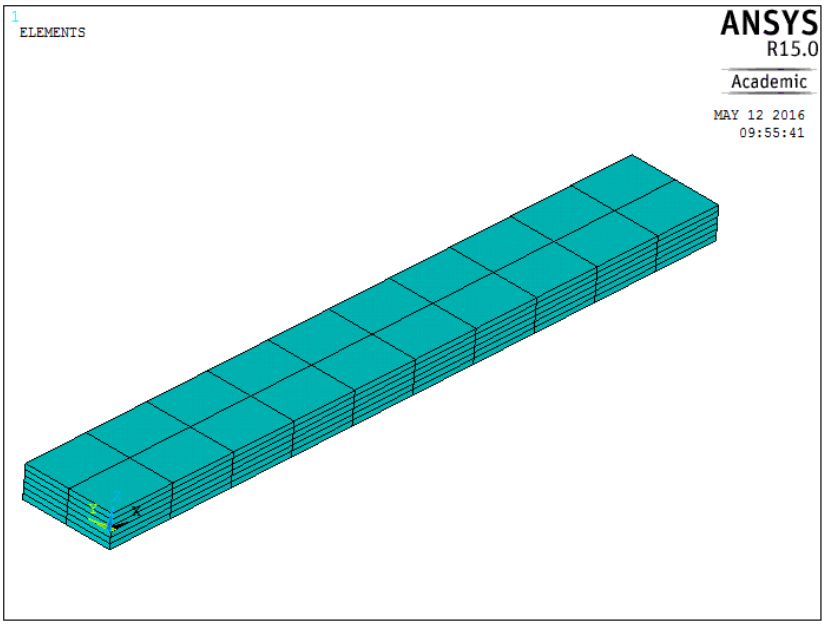


Figure 3.6.Shows Design model of Jute fibre reinforced six ply composite

After creating a model subject it to three point bending test to find deformed shape of the composite ply and stress distribution at each layer, same operation has to perform to create a model of 6 ply composite with introducing crack.

3.6.7 Three Point bending (Flexural test)

By applying the three point bending test to calculate the various mechanical properties of a composite materials such as Young's modulus E_f and Flexural stress σ_f, and Flexural strain ε_f. From the Universal testing machine UTM three point bending or flexural test conducted for the jute fibre reinforced composite ply according to ASTM D790 specimens were prepared. The rectangular beam length L, placed on the two supports and it is applied to a load P at its centre from top, at crosshead velocities of 0.5, 1, 5, 10, 50, 100, and 500 mm/min. The load-displacement plots generated by the machine were used to estimate ILSS. Plotting values from experimental graphs.

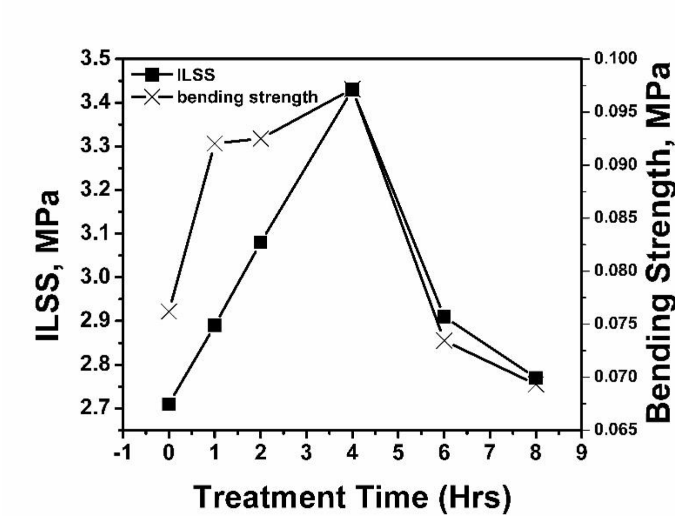


Figure 3.7.Graph between ILSS and Treatment Time of six ply composite [26]

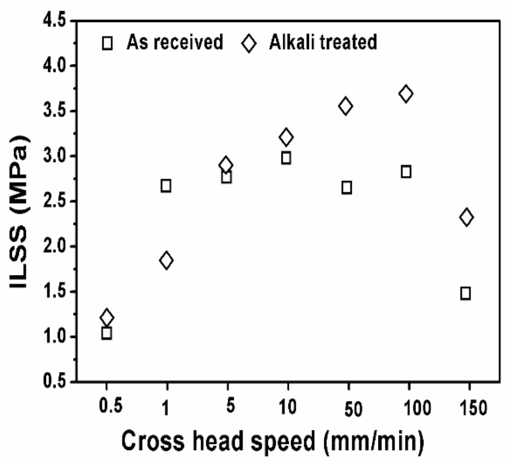


Figure 3.8. Graph between ILSS and Cross head speed of six ply composite [26]

3.6.7.1 Interlaminar shear strength (ILSS)

It is important to identify the delamination failure of laminated composite

ILSS = $\frac{3\,P_{max}}{4\,b \times h}$ P_{max}= Maximum Load, b = with of the sample, h= height of the sample

ILSS value taken from graphs = 3.429 MPa

From this we calculated P_{max} = 261.2N.

3.6.7.2 Composite ply subjected to three point bending

Six ply composite model subjected to three point bending, giving the support to both ends of specimen and the load 261.28N (calculated from ILSS) is applied at the centre of the specimen from the top as shown in figure.3.9.

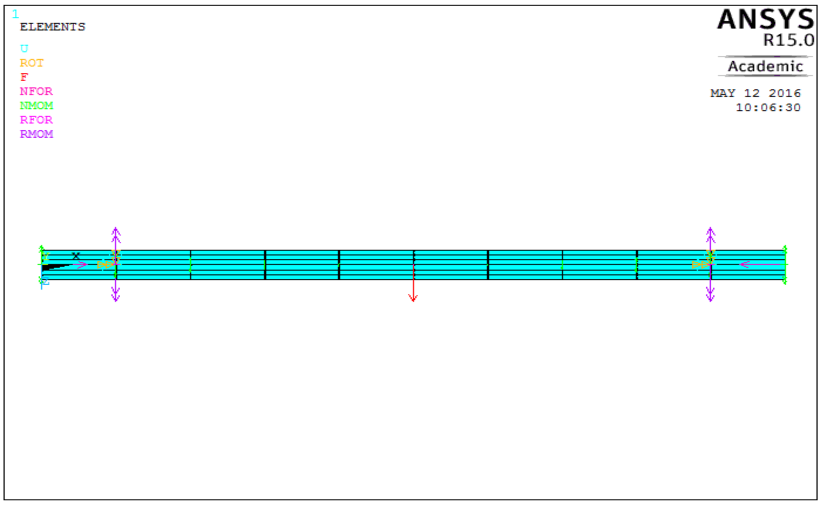


Figure 3.9. Support to both ends of specimen and load applied at centre from the top

3.6.7.3 Calculation of Flexural strength

It is a Modulus of rupture, fracture strength or bend strength, the highest stress acting in the material at the moment of rupture or also called as at the moment of rupture it has highest bearing capacity.

$$\text{Flexural strength 6 ply of composite,} \quad \sigma_f = \frac{3FL}{2bd^2} = 140 \text{ MPa}$$

Where,

F= Concentrated load N, L= specimen length.

b= specimen width, d= specimen thickness.

Flexural strain = $\frac{6sd}{L^2}$

S=deflection, d = rectangular specimen thickness

L =distance between the two supports.

Flexural strain = $\frac{6 \times 5.2 \times 4.5}{92^2}$ = 0.016 for 6 ply composite

Flexural modulus = $\frac{L^3 m}{4bd^3}$ = 2.2 GPa

m= slope at load deflection curve.

Flexural modulus = 2.2 GPa for 6 ply composite.

3.7 CALCULATING STRESS INTENSITY (MODE I) FACTOR BY INTRODUCING A CRACK ON 6 PLY COMPOSITE

The crack length and material properties of matrix disturb the stress intensity factor and these factors are studied to recognize the crack growth and fracture mechanism in composite material. The stress intensity factor values depends on the position of crack tip in additional to the matrix properties of fibre and matrix. In brittle material the crack behaviour can be considered as a single factor known as the stress intensity factor. once a critical level of the stress intensity factor reached the crack become unsteady and calculating of stress intensity factor it is very important to do analysis of cracked structure at a given geometry and loading.

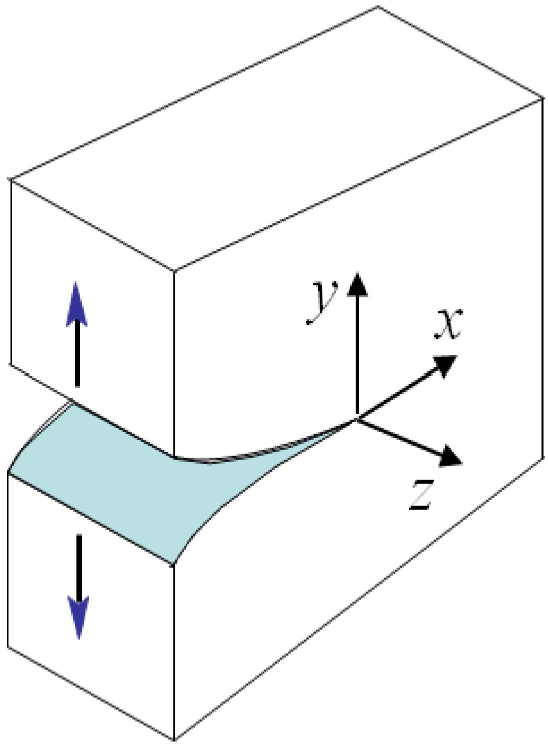


Figure 3.10 Shows (Mode I) opening, displacement of surface of crack is perpendicular to plane of crack

3.7.1 Finding SIF through ANSYS

In modelling input the material properties of the composite ply to material models and giving crack length at edge of the specimen, after that place displacement zero at respective position and apply tensile loading on top of the specimen .So deformed shaped occurs, so that calculate stress intensity factor at crack tip, so repeat this procedure with changing crack length and loads up to yield stress, finally plot the FEM element values and compare with the theoretical calculated values.

A cracked sheet is loaded in tension (Figure 3.10). Because of double symmetry, we can use one-quarter for the analysis with symmetry conditions on the edges x = 0 and y = 0 as given in Figure 3.10. The SIF will be determined by the crack opening method. In non-dimensional units: E = 2.2 GPa, ν = 0.3.

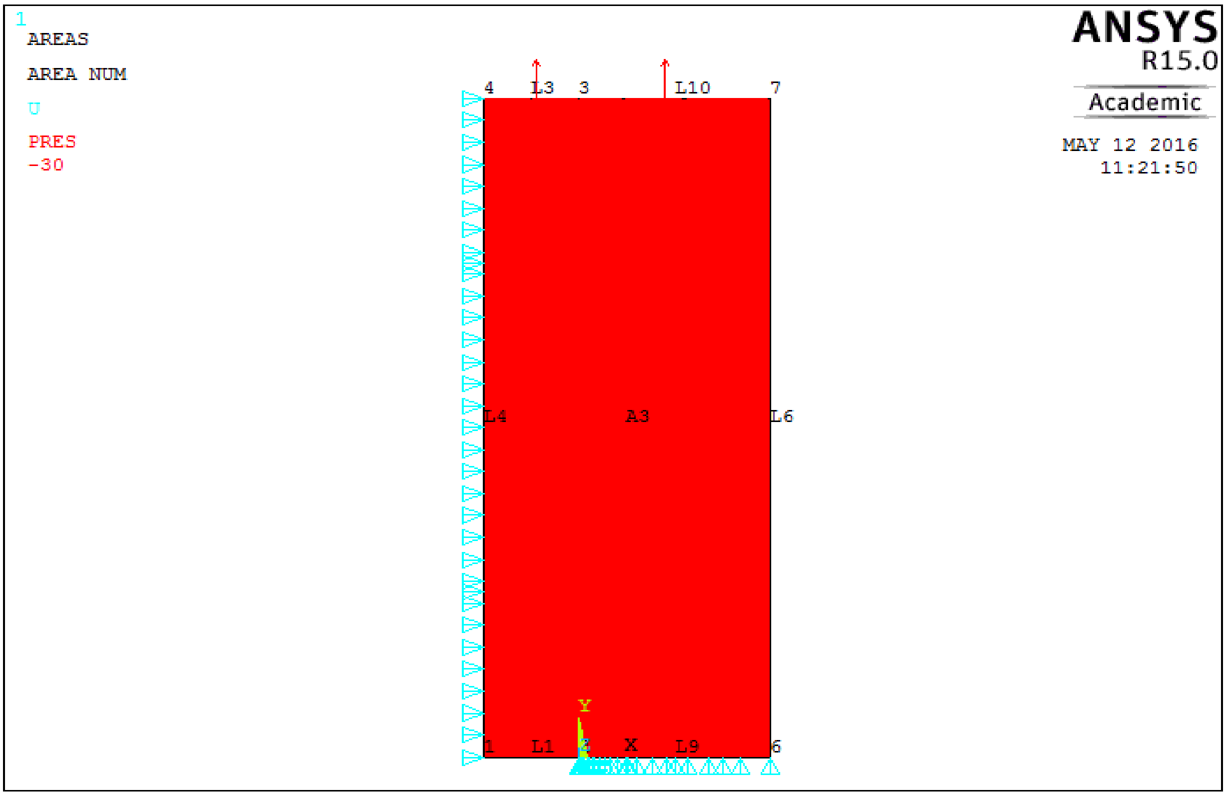


Figure 3.11 a jute fibre reinforced six ply composite cracked sheet is loaded in tension.

CHAPTER 4

RESULTS AND DISCUSSION

Based on the continuum modelling approach designed the different types of composite models using Simulation software ANSYS and subjected it to Longitudinal loading, transverse loading, Three point bending test and stress intensity factor calculation by introducing crack. Different types of analysis have been carried out and presented below with respective problem specification.

4.1 ANALYSIS OF JUTE FIBRE REINFORCED POLYMER MATRIX COMPOSITE SUBJECTED TO LONGITUDINAL AND TRANSVERSE LOADING

4.1.1 Composite subjected to longitudinal loading

The tensile load (P=60N) is applied longitudinally in the direction along the fibre alignment so that deformed shape and stress, strain distributions as shown in below figure. In this case the fibre + matrix have good interfacial bond, such that both matrix and fibres deforms is in the same direction that we can observed from figure 4.1.

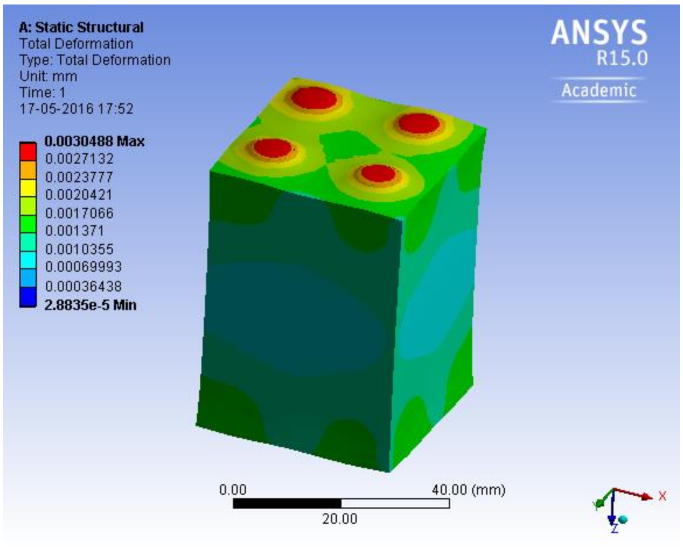


Figure 4.1. Shows deformed shape of jute fibre reinforced polymer composite by longitudinal loading.

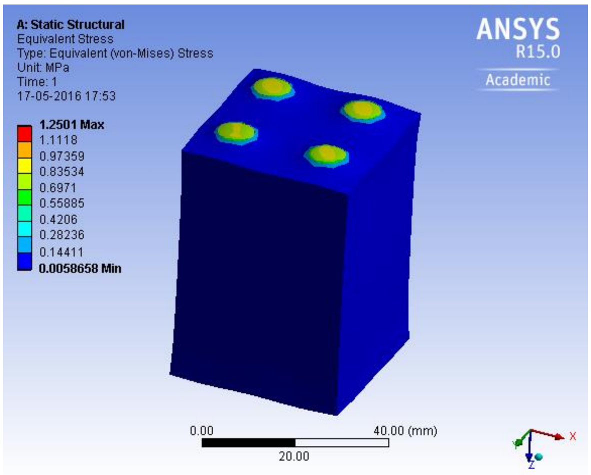


Figure 4.2. Shows Von misses stress of jute fibre reinforced polymer composite in longitudinal loading

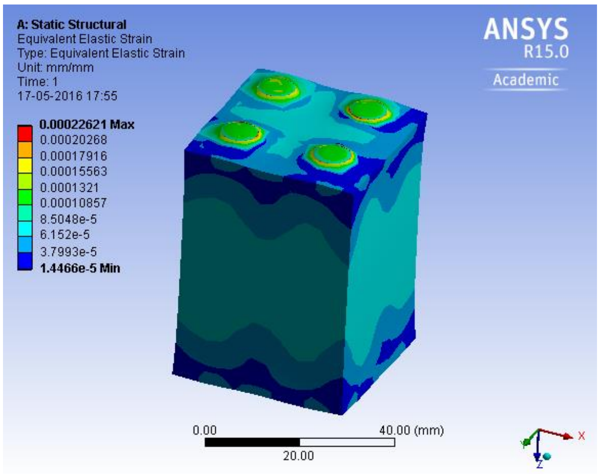


Figure 4.3. Shows equivalent elastic strain of jute fibre reinforced polymer composite in longitudinal loading

From the results analysed the stress strain distribution and von misses stress strain of jute fibre reinforce composite at longitudinal loading, it is observed that from ANSYS results both the fibre and matrix deforms in same direction and longitudinal loading of fibre reinforced composite has good mechanical properties because it has a high strength and interfacial bond is very good.

4.1.2 Composite subjected to transverse loading

The tensile load (P= 60N) is applied in the direction perpendicular to fibre alignment so that deformed shape and stress distribution as shown in below figures. Here the interfacial bond of Fibre + Matrix is weak, so that deformation of matrix and fibre is in the different direction. So that the voids presents at interface of jute and matrix which can observe from the figure 4.4

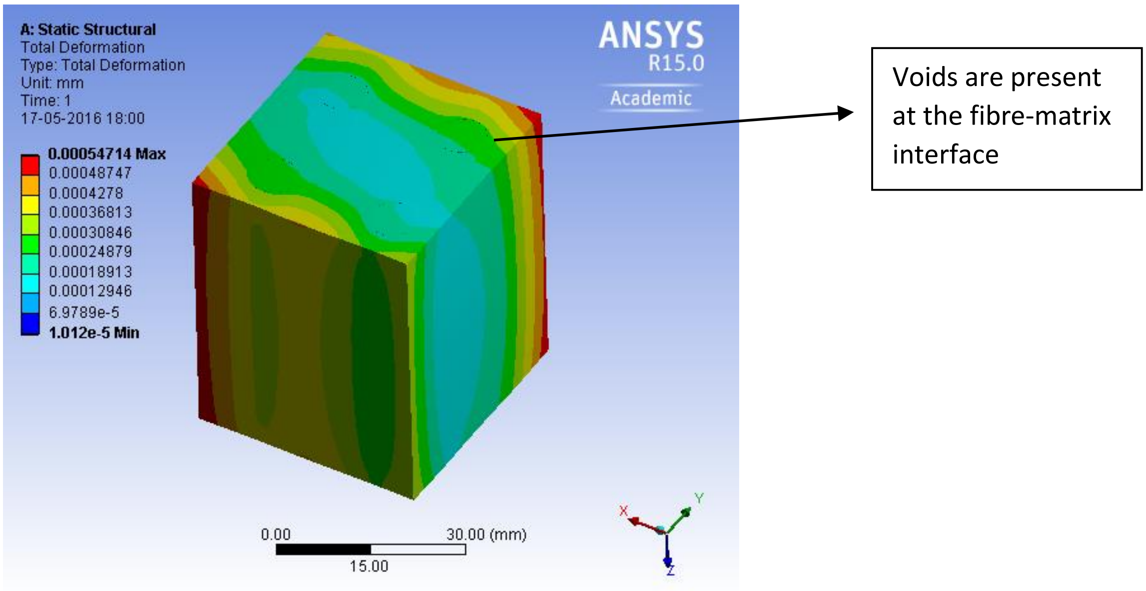


Figure 4.4. Shows the deformed shape of jute fibre reinforced polymer composite by transverse loading

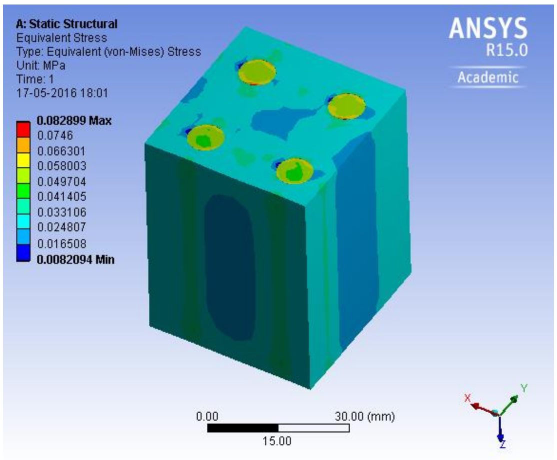


Figure 4.5. Shows von misses stress of jute fibre reinforced polymer composite in transverse loading

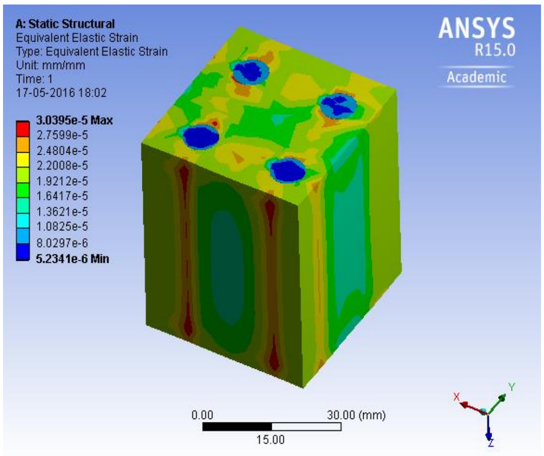


Figure 4.6. Shows von misses strain of jute fibre reinforced polymer composite in transverse loading.

From the ANSYS results observed that the both fibre and matrix deforms in different direction and also voids presents at the interface of fibre matrix, so that transverse loading have poor mechanical properties comparing with the longitudinal loading. These results also showing von misses stress strain distributions under the elastic load in the fibre reinforced composite.

4.2 Analysis of Six ply composite subjected three point bending test

4.2.1 Six ply composite without crack

After subjecting six ply composite to three point bending, plot the results. The deformed shape of the composite and stress strain distributions with in the material can be studied and analysed as shown in below figures.

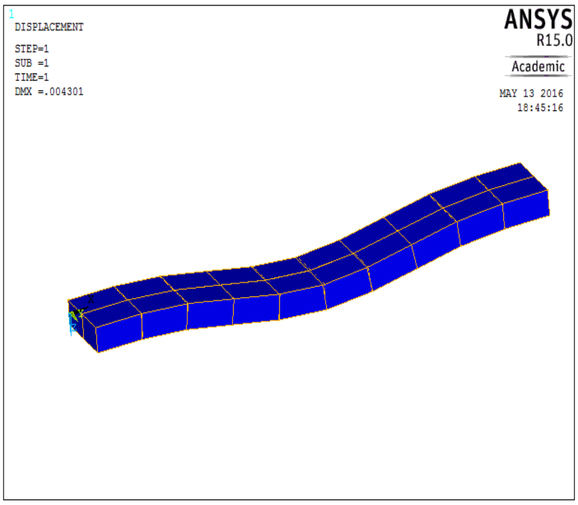
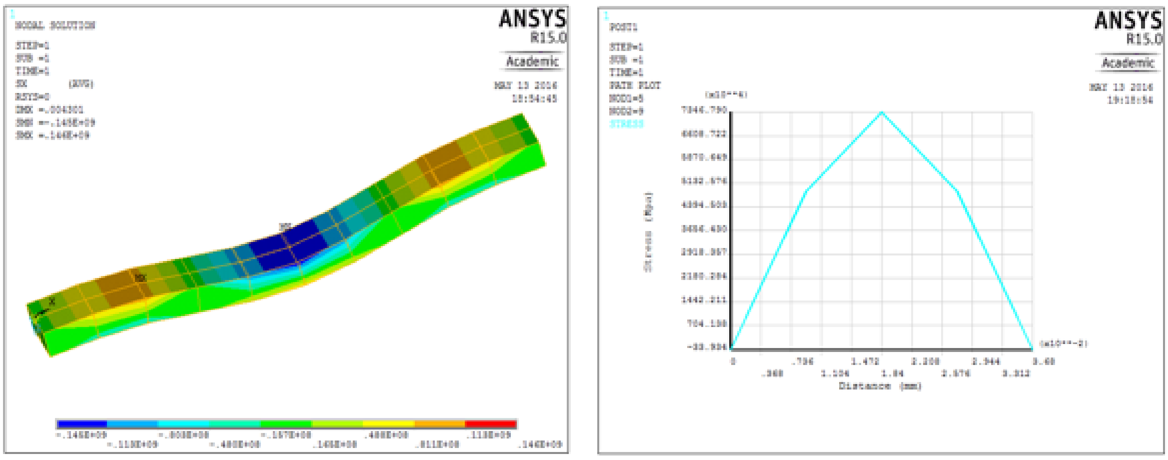
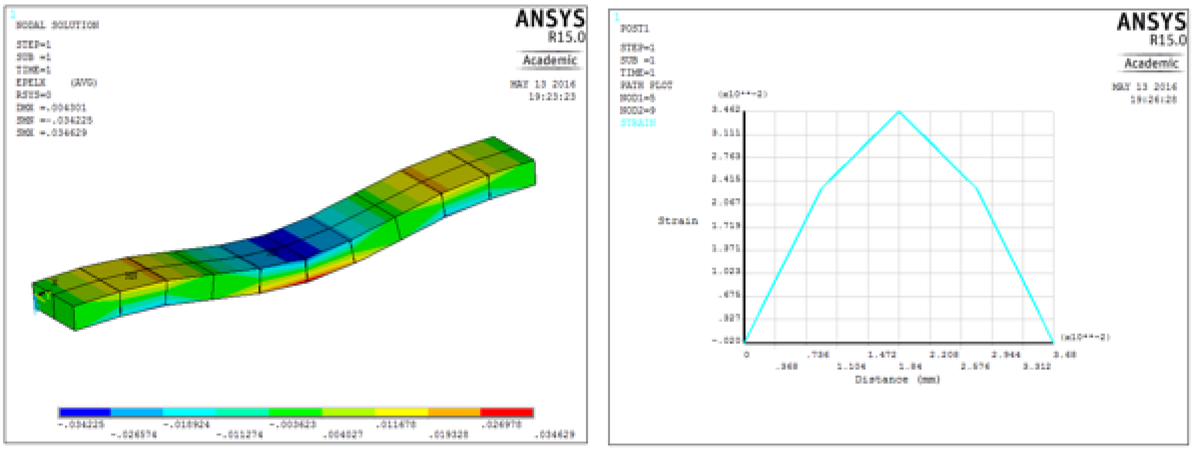


Figure. 4.7 Shows Deformed Shape of a six ply composite without crack



(a) (b)

Figure 4.8 .Shows Von misses stress of a six ply composite (b) Shows strain distribution curve for a six ply composite without crack.



(a) (b)

Figure 4.9 (a) Shows elastic strain of a six ply composite (b) Shows strain distribution curve for a six ply composite without crack

From the above results calculated stress and strain distribution at each layer of six ply composite as shown in given table. The max stress and strain acting at bottom layer 1 which crack tends to propagate first and minimum stress and strain acting at top layer 6.

Table 3 Shows stress distribution values at each layer of six ply composite

From Bottom	Stress	Strain
At Layer 1	140 MPa	0.0346
At Layer 2	123 MPa	0.0269
At Layer 3	115 MPa	0.0193
At Layer 4	109MPa	0.0116
At Layer 5	103MPa	0.0040
At Layer 6	95MPa	-0.03422

4.2.2 Von Mises or Distortion-Energy criterion

It is the stress used to check whether the design model can withstand a given load condition., If the Von Mises stress induced in the material is maximum which implies more than strength of the material ,then the design model will going to fail. For the shape deformation of a material this energy is needed. In pure distortion, volume of the material does not change but shape changes.

4.2.3 Six ply composite with crack

Six ply composite specimen with crack is subjected to three point bending load plot the results. The deformed shape of the composite ply and stress strain distributions with in the material can be studied and analysed as shown in below figures.

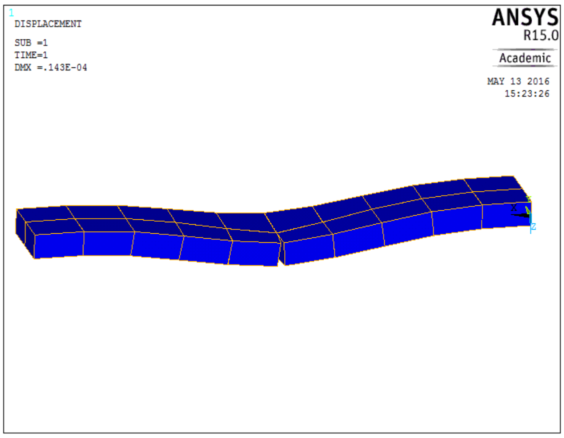
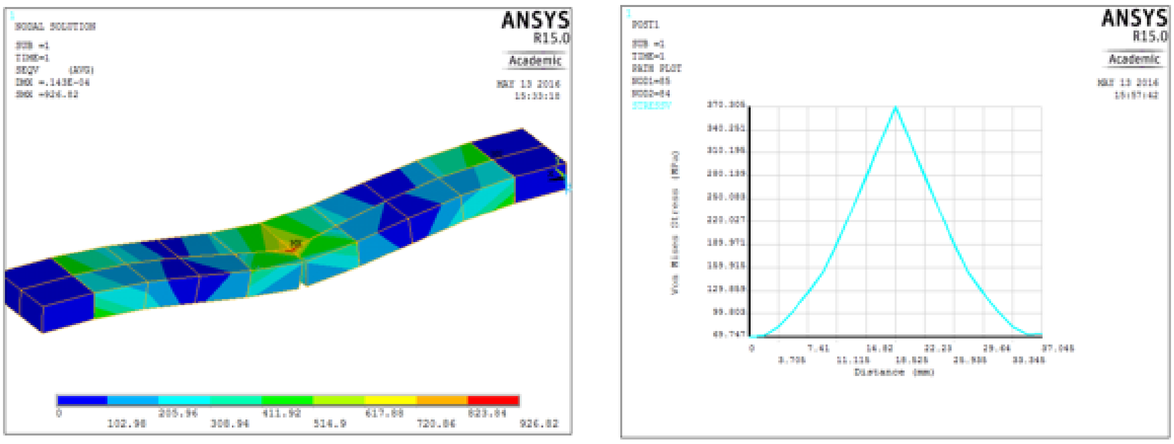
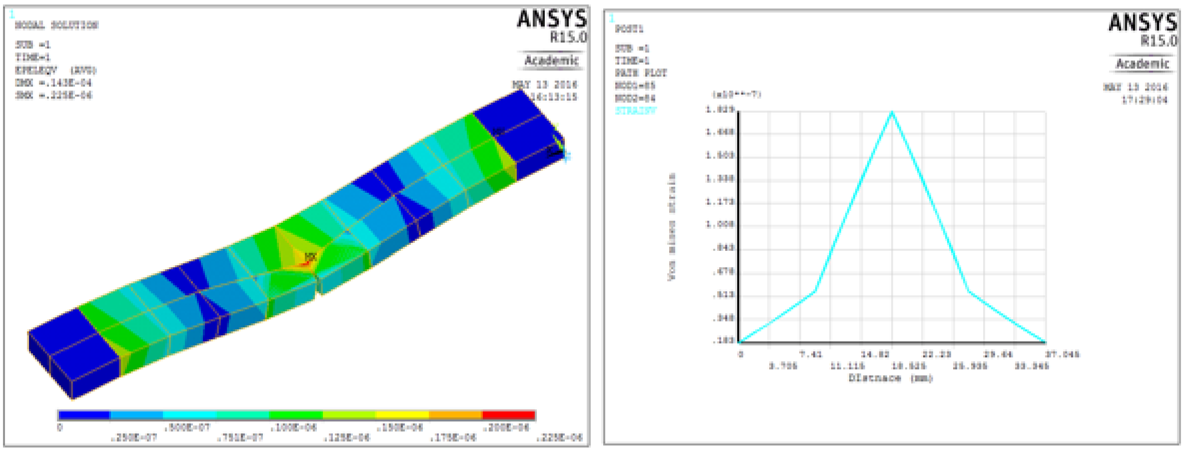


Figure 4.10 Shows Deformed Shape of a six ply composite with crack



(a) (b)

Figure 4.11 Shows Von misses stress of a six ply composite with crack (b) Shows stress distribution curve for six ply composite with crack



(a) (b)

Figure 4.12 (a) Shows elastic strain of a six ply composite (b) Shows strain distribution curve for a six ply composite with crack

From the above results calculated stress and strain distribution at each layer of six ply composite with crack as shown in given table and also it is observed that the maximum stress acted at the crack tip of composite materials

Table 4 Stress strain distribution values at each layers of six ply composite with crack

From top	Stress	Strain
At Layer 1	926.82 MPa	0.22×10^{-6}
At Layer 2	720.86 MPa	0.20×10^{-6}
At Layer 3	514.9 MPa	0.17×10^{-6}
At Layer 4	411.92 MPa	0.12×10^{-6}
At Layer 5	308.94 MPa	0.10×10^{-6}
At Layer 6	102.98 MPa	0.75×10^{-7}

4.3 ANALYSIS OF STRESS INTENSITY FACTOR (MODE I) CALCULATING BY INTRODUCING A CRACK

Mode I- Displacement of the crack surface is perpendicular to the plane of crack

From the modelling, variation of crack length with constant tensile stress to calculate stress intensity factors of a six ply composite and compare it with theoretical stress intensity factor values. In the same way variation of tensile stress (up to yield stress) with constant crack length to calculate stress intensity factor of composite and compare it with theoretical stress intensity factor values. Stress distribution as shown in figure 4.13

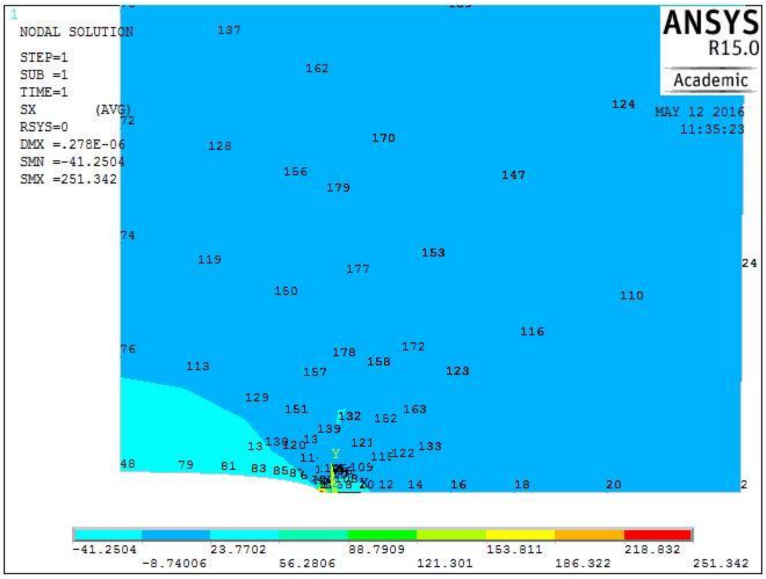


Figure 4.13. Stress in a cracked structure of jute fibre reinforced six ply composite

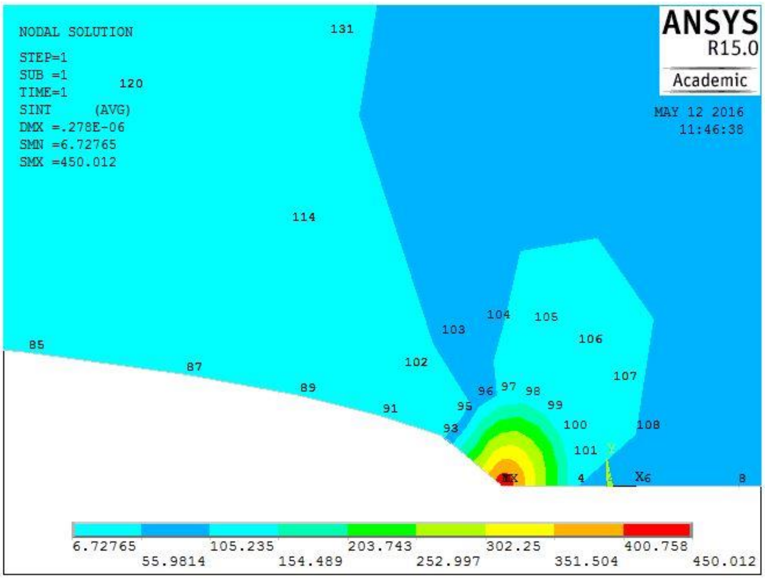


Figure 4.14 Stress intensity in a cracked structure of jute fibre reinforced six ply composite

Theoretical formula for SIF Mode I $K_I = \sigma\sqrt{\pi a}$

σ = Stress applied, a = length of the crack

- Stress Intensity Factor changes by varying crack length(σ = 30 MPa)

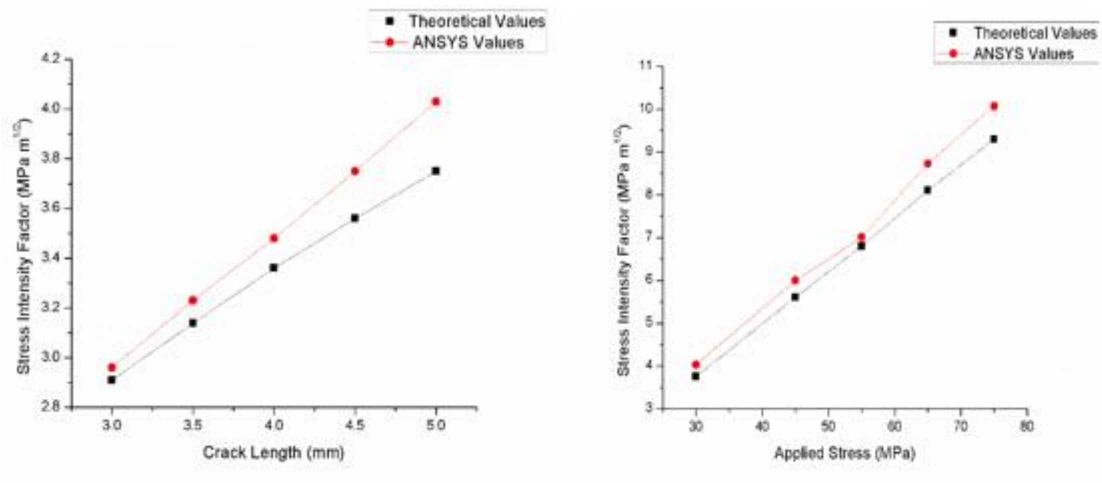
Table 5 Stress intensity values by variation of crack length of a six ply composite

Crack Length (mm)	SIF values(Theoretical) (MPa $m^{1/2}$) $K_I = \sigma\sqrt{\pi a}$	SIF values(Ansys) (MPa $m^{1/2}$)
5	3.75	4.03
4.5	3.56	3.75
4	3.36	3.48
3.5	3.14	3.23
3	2.91	2.96

- Stress Intensity Factor changes by varying Applied stress

Table 6 Stress intensity values by variation applied stress of a six ply composite

Applied stress(MPa)	Crack Length (mm)	SIF values(Theoretical) (MPa $m^{1/2}$) $K_I = \sigma\sqrt{\pi a}$	SIF values(Ansys) (MPa $m^{1/2}$)
30	5	3.75	4.03
45	5	5.6	6.0
55	5	6.8	7.01
65	5	8.1	8.73
75	5	9.3	10.07



(a) (b)

Figure 4.15. Graphs between (a) SIF vs Crack length (b) SIF vs applied stress of six ply composite

From the above results observed that the stress intensity factor (SIF) of jute fibre polymer composite depends on the crack length and applied stress, so decreasing crack length stress intensity factor decreasing and increasing applied stress, stress intensity factor increasing .Also observed modelling through ANSYS the SIF values compared with theoretical SIF values, so we can easily predict when crack will start in a structure. How Stress intensity factor changes with respect to crack length and applied stress.

CHAPTER 5

CONCLUSION

From the continuum modelling approach, by the application of numerical analysis software ANSYS is used to designed a various composite models and subjected to different loadings, studied the deformation behaviour of jute fibre-reinforced polymer composite.

1. Jute fibre-reinforced polymer composite subjected to longitudinal loading and transverse loading. It is observed that in longitudinal loading the composite have a better mechanical properties due to good interfacial bond present between fibre-matrix interfaces. Also investigated the stress analysis inside the composite and the voids are present between fibre matrix interfaces in transverse loading observed from ANSYS results.
2. Jute fibre reinforced six ply composite subjected to three point bending (flexural test) with and without crack. It is investigated that the stress-strain distribution at each layer of six ply composite, also observed the first ply failure and last ply failure in the six ply composite from ANSYS results.

3. It is observed that the stress intensity factor (SIF) depends on the length of the crack and applied stress, by variation of these two stress intensity factor changing for Jute fibre reinforced six ply composite. And also investigated that stress intensity factor ANSYS values are more accurate than theoretical values.

References

[1] Mukherjee, G.S. & Saraf, M.N. Studies on the fibre reinforced plastics honeycomb structure. *Polymer Composites*, 1994, **16**, 217-22

[2] D C mitra, Defence Science Journal, Environment Friendly Composite Materials: Bio composites and Green Composites. Vol. 64, No. 3, May 2014

[3] T. Munikenche Gowdaa, A.C.B. Naidua,*, Rajput Chhayab Some mechanical properties of untreated jute fabric-reinforced polyester composites.

[4] Shah AN, Lakkad SC. Mechanical properties of jute reinforced plastics.Fibre Science and Technology 1981; 15:41–46.

[5] Atkinson RR. Jute Fibre to Yarn. Bombay: B.I. Publications, 1965:27–37.

[6] Gassan, J. and A.K. Bledzki. 1999. Alkali treatment of jute fibers: relationship between structure and mechanical properties *Journal of Applied Polymer Science*, 71: 623–629.

[7] William D Callister,Jr-ABM ,Materials science and Enginerring.

[8] David Broek, Elementry Engineering Fracture mechanics, 1982

[9] Bhattacharyya DN, Chakravarti IB, Sengupta SR. J. Sci. Industries Res. 1961;20D:193

[10] Verma IK, Anantha Krishnan SR, Krishna Murthy S. Composites of glass/modified jute fabric and unsaturated polyester resin. Composites 1989;20:383–388.

[11] Mohan R, Kishore, Shridhar, Rao RMVGK. Compressive strength of jute–glass hybrid fibre composites. Journal of Material Science Letters 1983;2:99–102.

[12] Chawla KK, Bastos AC. The mechanical properties of jute fibre and polyester/jute composite. Mechanical Behaviour of Materials 1979; 3:191–196

[13] Winfield AG. Proceedings of second symposium on new fibres and composites, sponsored jointly by Dept. of Science and Technology, India, and UNIDO, January 10–11, 1977:31

[14] Winfield AG. Plastics and Rubber International 1979;4:23

[15] Agarwal, B. D., Broutman, L. J., 1980. Analysis and Performance of Fiber Composites. John Wiley, New York

[16] Tolson, S., Zabaras, T., 1991. Finite Element Analysis of Progressive Failure in Laminated Composite Plates. Computers and Structures, 38, p. 361.

[17] Mahmud, J., Ismail, A. F., and Pervez, T., 2005. Employing a Failure Criterion with Interaction Terms to Simulate the Progressive Failure of Carbon- Epoxy Laminates. IEM Journal 66, p. 6.

[18] Zhang, Y. X., Yang, C. H., 2009. Recent Development in Finite Element Analysis for Laminated Composite Plates. Composite Structures, 88, p. 147.

[19] Liu, P. F., Zheng, J. Y., 2010. Recent Developments on Damage Modeling and Finite Element Analysis for Composite Laminates: A Review. Material and Design, 31, p. 3825

[20] John R Tylor, ISBN, Classical mechanics.

[21] T.E. Tay, F. Shen, K.H. Lee, A.M. Di Sciuva, Mesh design in finite element analysis of post-buckled delamination in composite laminates, Composite Structures 47 (1999) 603–611.

[22] W.N. Paepegem, J. Degrieck, P. De Baets, Finite element approach for modeling fatigue damage in fiber-reinforced composite material, Composites Part B 32 (2001) 575– 588.

[23] Z.A. Hashem, R.L. Yuan, Experimental and analytical investigations on short GFRP composite compression members, Composites Part B 31 (2000) 611–618.

[24] C. Bisagni, Numerical analysis and experimental correlation of composite shell buckling and post-buckling, Composites Part B 31 (2000) 655–667.

[25] S.V. Thiruppukuzhi, C.T. Sun, Testing and modelling high-strain-rate behavior of polymeric composites, Composites Part B 29B (1998) 535–546.