Chapter

Modeling of Damage Evolution of Fiber-Reinforced Composite Structure

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Abstract

This chapter is the result of a study of many special disciplines, such as damage of matrix, cracking, interface, debonding, and fiber failure. A damage mechanics model is presented to characterize brittle failure in elastic fiber-reinforced composite materials. During the life of the aircraft, cracks and damage can occur in aviation structures that should be analyzed to determine the decrease in stiffness and resistance due to the presence of the cracks. Theoretical and numerical problems related to intralaminar and interlaminar failure modeling are very well discussed. The formulations of the constitutive models presented in this chapter support the Continuum Damage Mechanics (CDM) approach and enable the control of energy dissipation in relation to each failure mode, regardless of the refinement of the network and the orientation of the fracture plane. In context to CDM, internal thermodynamic irreversible damage variables are defined to quantify the damage concentration in relation to each possible failure mode and to predict the gradual reduction in stiffness for each bond layer. Numerical examples are provided to possibly explain the capabilities of the model.

Keywords: cracking, debonding, damage mechanics, fiber-reinforced, modeling of damage

1. Introduction

Composite materials—the history of their use dates back to the ancient times. Already the early South American and African civilizations used to build from mud and straw bricks. This is not, however, an example of a composite material as we know it, but its purpose was the same as it is today—a complex material which takes the benefits of all its constituents.

Today composite material is most common and mostly used in every field of industries, from Aircraft to naval craft automotive industries to sport industries. They also can find in medical industries hospital application. Since the 1980s, the scope of their usage has increased thanks to the significant progress in material science and technology continuously, and mainly the computer equipment. While the initial driving force yielded mostly from the need for weight savings, other factors play important roles today when inclining to composites, such as cost competitiveness, lifetime, durability, chemical resistance.

We say that composite is a combination of two different components. Presently days in industry composites are materials made by two different more material. One is natural one and other is artificial material components. That are both stronger as a team than work alone player. They join and contribute their generally stunning amazing properties to improve the desirer final outcome product, commonly in view of utilization.

For example, if you are want to add more quality, more effectiveness, and more toughness and more strength, more durability. Composite, likewise know as fiber-Reinforced polymer (FRP) composites are made as a polymer matrix that is joined with reinforced with the help of engineered. Human-made, or some regular fibers (like glass, carbon) or other reinforced material. The matrix protects the fiber from any kind of environment cold hot any kind and each sort of outside damage transfers the external and internal load between the fiber. Fiber provides strength to the reinforced matrix, which resisting cracking and fracture (**Figure 1**).

In huge numbers of our industry's items, for example, the polyester material resin is such a matrix and glass fiber is reinforcement. However, we realize that mixing of resin and reinforcement composite are utilized in composite and each, also, every material adds to the most astonishing and interesting properties of the last item. Fiber, amazing yet we realize it is a week, gives quality and firmness, and strength and more important stiffness.

And keeping in mind that it is progressively adaptable and flexible resin, give shape, and protect the fiber of the composite final product. (FRP) composite may likewise contain fillers, additive substances, material and surface finishes designed to improve the final product the whole manufacturing and the assembling procedure, appearance and more important is the performance of the final product of composite. In the aerospace sector, development of high-performance aircraft cannot be counted without the use of composite technology. Composite material has reached 50%, while the usage of composite has reached 24% in the production has reached 25% on the AirbusA380.

In military aircraft, composite amount reached 24%, in the production of (F35) and for the making (F22) fighter composite usage is reached 30%. **Figure 2** below gives a brief account of composite material used till now in the aerospace industry. Composite material has played a fundamental role in weight decrease, and we can utilize composite for both internal and external structure basic application and segments of air plane and rocket and more important in a space vehicle. Furthermore, air planes from lightweight planes and tourist balloons to numerous air plane whatever such aircraft is used for military or civil purposes, space transport, and air crafts.

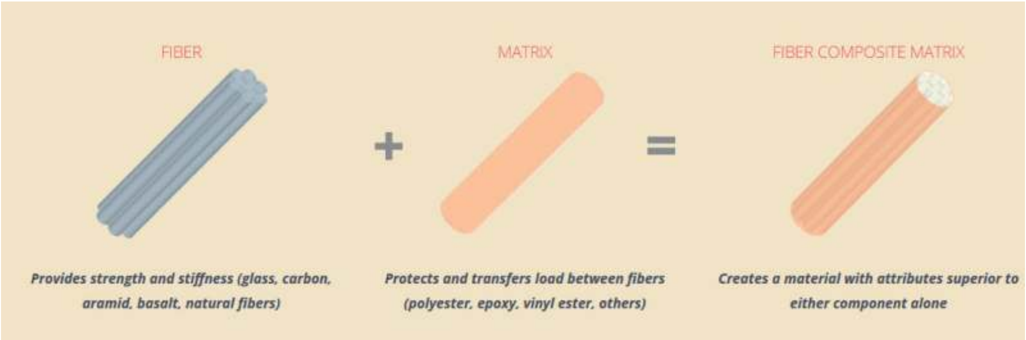


Figure 1.
How to make fiber-composite matrix.

When we talk about advanced composite, manufacturing costs are relatively high in the aviation Markets. The very high coast of fabrication is the leading cause of the slow development of Advanced Composite in the civilian and military sectors. However, due to the development of advanced composite manufacturing technologies and economic globalization has made it easy for the industry to use them. Developing interest for better execution of final product items and material has developed every year on prompted consistent improvement in the field of composites must more advanced separate composite fiber.

Resins and cores and new manufacturing fabricating techniques were created and used to build different materials or items that have stunning and remarkable mechanical properties thought to be exotic a few years ago. Those next-level generation composites are utilized in numerous businesses like aviation and spacecraft. Are also given so much importance in other industries such as automotive, energy, significant sport, and just every everywhere low weight give the composite so much importance in all industries.

1.1 Fiber-reinforced composites (FRC)

Fiber composites material are also known as fiber-reinforced composites (FRC) having continuous fibers that are of particular relevance. And the first composite used in the modern era, in the marine and automotive industries due to the less weight and strength.

Their mechanical properties as we know strength and stiffness and strongly direction which allows the engineering and designer to get his desired final product in many attractive and high-tech applications, for example, replacing the metals of water boats with the composite and now the water boats are more fuel-efficient and lightweight and spend more time in the water than before.

It is, therefore, so important to know or seek essential and necessary tools for the description of the behavior of such a dynamic composite since these substituents must undergo the same production procedures as their metal. The impact of the analytical and numerical method, together with the corresponding computer

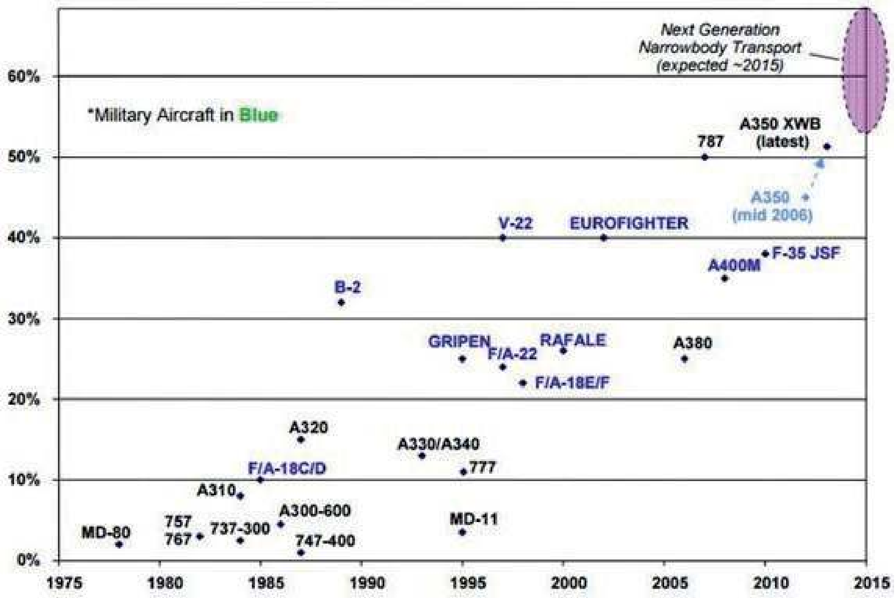


Figure 2.
Usage of the composite in the aerospace industry.

hardware equipment, is more important. The thesis should be focused mainly on the theoretical field of research. The individual goals of this thesis were stated as follows:

1. To perform a survey of literature focusing on proposed topic

2. To study the behavior of Fiber-reinforced composite

3. To seek appropriate local failure criteria for FRC

4. To seek appropriate material damage model of FRC

5. To seek appropriate damage analysis methods of FRC

Advantages of composites usage in aerospace:

1. Weight decrease up to 20–60%.

2. Single-shell formed structure gives higher quality at the lower weight.

3. The amazing ability of the impact, for instance, like we also know Kevlar reinforcement armor, let planes have less accidental harm and damage to main frame engine which carry most of important fuel lines and engines control systems.

4. Higher thermal stability ability.

5. Structural important components made of composite material are very important for the aircraft.

2. NDE tools and method

Non-destructive evaluation (NDE/NDI) is a tool that most of the time used interchangeably with non-destructive tools. So far, non-destructive evaluation is used to describe measurement that is quantitative in nature. We can use the non-destructive method not only defect, but we can use for measurement something about defects such as more important its size shape and orientation. We used non-destructive evaluation to find material important properties; one of them is fracture of the product and toughness, formability, and other physical properties characteristics. (NDE) is essential and a necessity for both the manufacturing quality of the final product of the composite material and in-service performance monitoring for the maintenance purpose. With every day, new composite materials and advance composite materials are coming in industries and their broader application in the aerospace industry. An increasing need and fast and robust and reliable and economical (NDE) techniques to inspect composite components that have uniquely new and complex damage failure modes and responses are evident.

We can say that one of the designs of modern aircraft. The structure consists of higher fatigue life damage tolerance capability and corrosion resistance to fewer maintenance costs and also comply with operator requirement and full fill the airworthiness requirement.(NDE) is essential, although time-consuming and much expansive, to fulfill all requirements and for the assessment of widespread damage and repairs. The existing major non-destructive inspection/evaluation methods include the following techniques:

2.1 Tapping technique

- Thermography
- X-ray Radiography
- Eddy Current

2.2 Tapping TechniqueTab

Testing is an old and extremely dimple Non-destructive technique. and that we also are referred to as coin Testing, which involves the knocking of an one which one you want testing object surface with a little or big hammer or coin and judging its incorruptibility and damage by the sound that come from the thing because of the result when someone knocking on the object. A duller sound come from the object would indicate that such a sway has been dampened possible due to the presence of a defect in the object within the final product.

However, when we used this method is applied manually it does't provide too much data and record of such response and it naturally start begs to question of the object reliability of the evaluation.so the main thing is that it highly dependent on such operators' perception. Real time, a permanent record of the method in such identifying the presence of the flaw and defect and establishing its size and placement of the object (**Figure 3**).

2.3 Thermography

Infrared thermography from (NDE) tools aims at the detection and finding of subsurface features of an object, which incorporates subsurface defects and cracks, and more important anomalies. Attributable to the important is temperature difference observed, the final product surface during monitoring of object by the infrared camera. As we know that at temperatures above temperature all bodies emit non-particulate radiation within the spectrum usually in such region from 2 to 5.6mm to 8–14 mm. These two important spectral bands are commonly mostly used

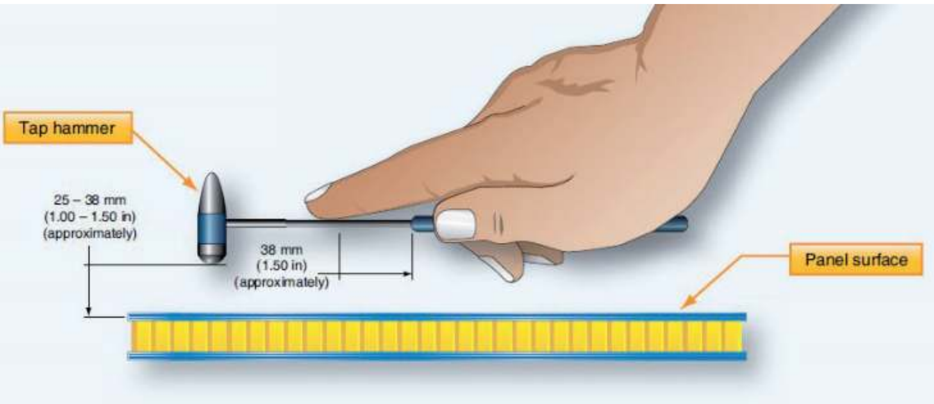


Figure 3.
Use the method of TabTechnique.

due to their atmosphere absorption. It is very useful to detect in-service damage such we know as impact, and lightning damage whose superficial visual appearance often belies the full extent of their underlying damage.

As we know recently, a new thermography method called Lock-in Thermography has been found. So this method is a combination of infrared thermo-graphy and thermal wave method and thus is more sensitive and higher detection capability compared to conventional reflection and through transmission methods (**Figure 4**).

2.4 X-ray radiography

Radiographic Testing is additionally one in every of the (NDT) methods, which uses either one method is x-ray and gamma rays to look at and therefore the internal and external structure of the manufacturing of components identifying every kind of crack, damage or some flaws or defect as we all know that in radiography. Testing the object test-part of the final product is placed between the radiation sources and the film.

The fabric density and therefore the thickness difference of the test part will attenuate to the object and the going through radiation through the interaction process involves scattering and absorption. In industries radiography, there are many types of imaging methods available, such as film radiography, real-time radiography, computed axial tomography, digital radiography, or computed radiography. There are two different but important radioactive sources used for industrial use; X-ray or Gamma-ray. If we are used these two methods the radiation origin mostly use higher energy levels, as an example, shorter wavelength and different forms of electromagnetic waves due to the radioactivity involved in radiography examination or testing (**Figure 5**).

2.5 Eddy current

The eddy current array is also one of all NDT test methods that offer the flexibility and flexibility to operate multiple electronic eddy current coils that are

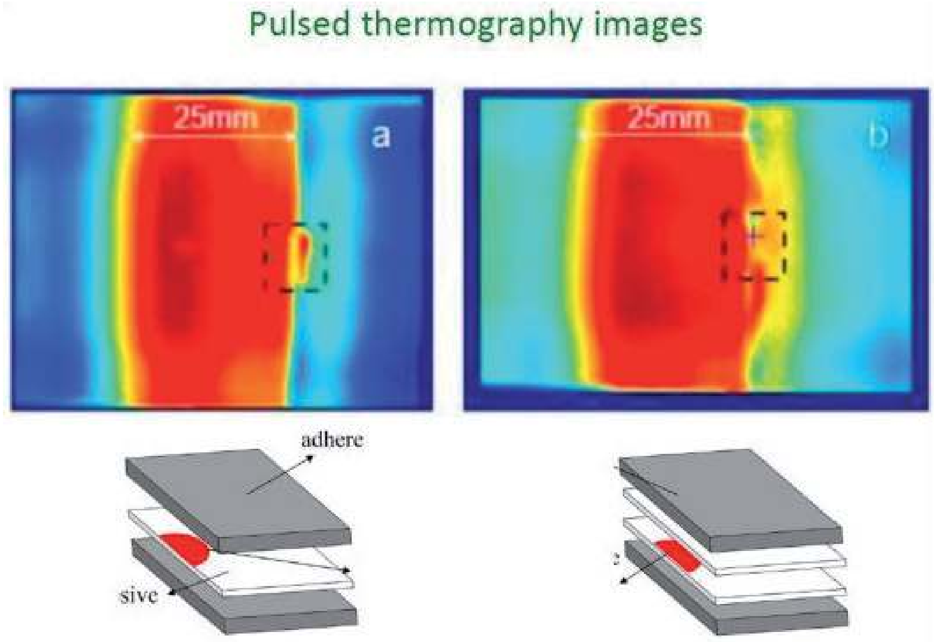


Figure 4.
Show the image of thermography how it work.

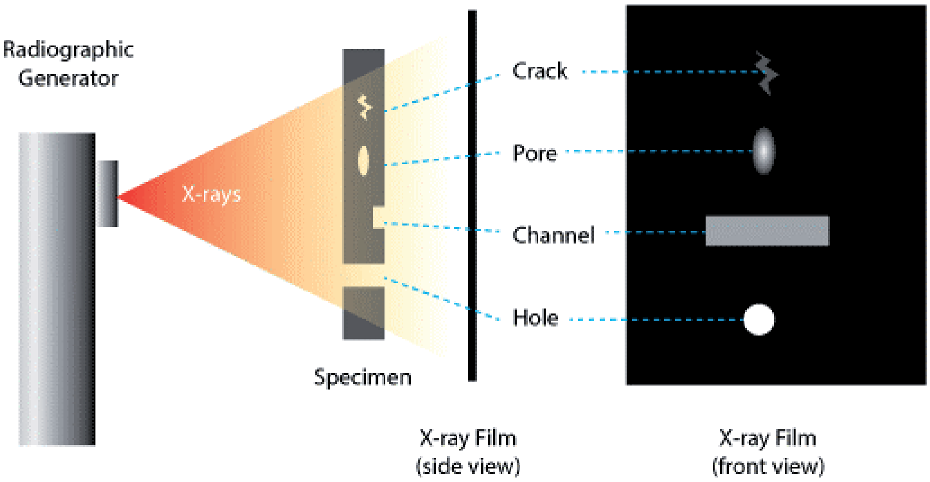


Figure 5.
Show how X- ray radiography find crack.

juxtaposed in a single collection of queries and each eddy current coil within the probe result signal is discussed for the shape and spread of its downstream design. These data are assigned to the encryption positive and thus to the time and is described graphically as a C scene image. As we investigate, the eddy current fault detection or discovery method is created with the ECA inspection.

Nevertheless, the amazing advantage of the ECA method or technology enables better detection and inspection. The eddy current array is additionally one in each NDT test method and technology, which offers the flexibility to drive multiple electronic eddy current coils currently used in the identical probe arrangement of these methods, and each eddy current coil within the request generates a sign proportional to the phase and Amplitude of the frame and structure below. These data relate to a coded positive and a coded time and are shown schematically as a C-Sean image. As we know, the eddy current error check and detection method are reproduced with the ECA check. However, the great advantage of the ECA method and application enables improved detection and investigation.

The eddy current is a very high test speed and no need a black surface is no longer required and there is no longer any danger to our environment. Colored surfaces have no influence, no temperature influence, and no calculation of the crack height of an object. And with the assistance of the eddy current, many materials such as steel, stainless -steel, duplex, alloy, and other conductive material can be checked (**Figure 6**).

2.6 Evolution of multiple matrix cracking

Composite laminates are those composites that provide the intended stiffness. If you see laminated, the properties have a linear or longitudinal direction and a direction outside the axis due to the combination of laminates axis and axis positions. As soon as we have carried out the quasi-static loading, the matrix suddenly fails first, which leads to the formation of micro-cracks. Such a product is inherently sensitive. These micro-cracks increase quickly.

Cover the thickness and build up the width of the layers transversely to the direction of loading. If we put more stress on such a product of an object, more new cracks appear in the transverse piles, which form an almost parallel arrangement that is even the same size and the same distance from the surface. There they are considered fully grown for damage mechanics. The expansion of a personal layer tear is not very important in our final product, which is important for the object, or the increase in its

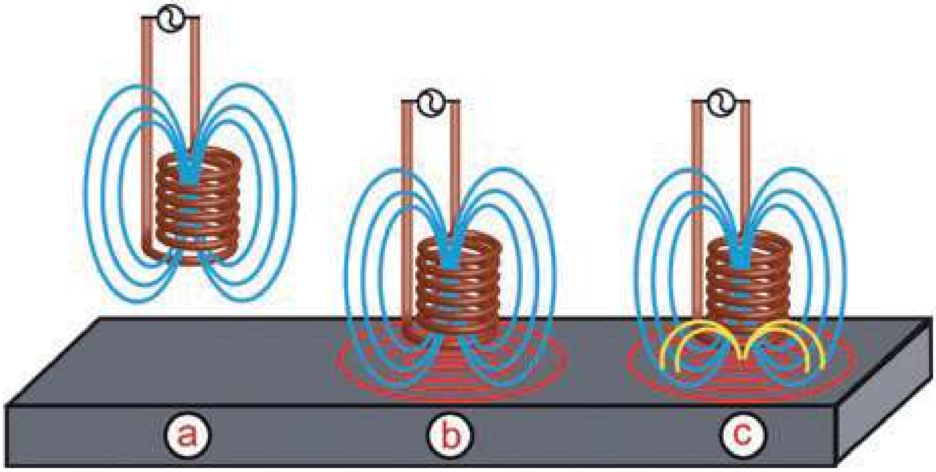
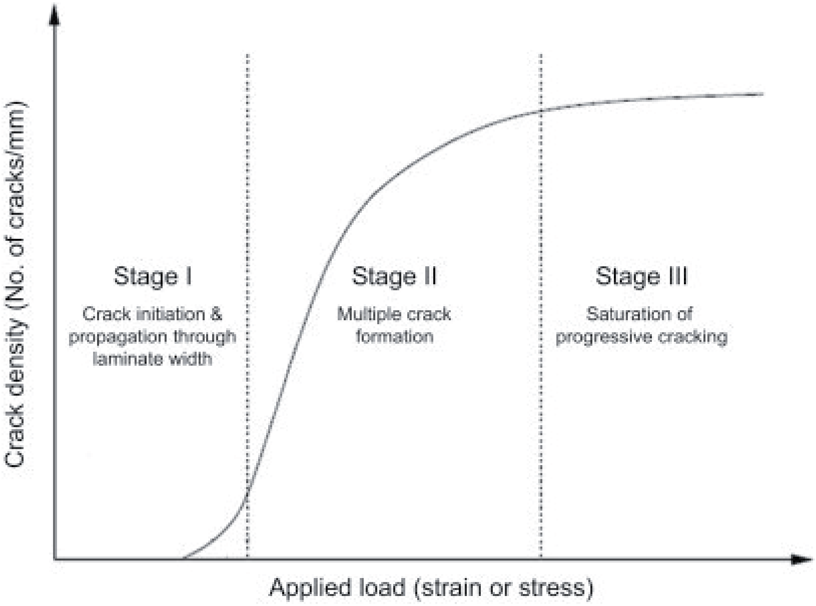


Figure 6.
Show how the eddy current work.

density if further loads are exerted on the composite laminate material is of concern as all of such cracks decrease the stiffness of such a composite structure. Because we have equal size and reliable spacing, such ply cracks we will find by the analyzed through many methods like edge- replication, acoustic- emission or, X-ray radiography, and ultrasonic C-scan, or Raman spectroscopy is used worldwide.



2.7 Analytical models for evolution of multiple matrix cracking in cross ply laminates

This technique to seek out or predict damage evolution because of multiple matrices cracking maybe we classify into a two-group (1) strength-based and (2) energy-based. And once we are talking about strength-based concept used some extent failure criterion for the crack initiation and increase, and once we speak about the energy-based techniques consider the balance of energy while the cracking process or formation and are conceptualize same because of the to the energy discharge rate concept in linear-elastic fracture or crack mechanics.

Most models developed so far have 90% cross-ply laminates for ply cracks. Many studies have shown that great progress has been made in dealing with off-axis layer cracks in multi-directional laminates. First we looked at analytical models for the detection and prediction of cross breaks in cross-layer laminates.

Assuming the self-similarity of fully developed layer cracks, we can define the boundary value problem as shown in **Figure 7**, whereby state 1 shows the damaged state with crack spacing, while s = 2 l, while state 2 represents the crack density twice s = l. The damage process normally involves a tension and stress field in the composite laminate with a presetting of equivalent breaks in the transverse planes.

For this purpose, an increase in the applied far-field pressure or stress σ0 is required to create further fractures between the existing fractures. And the energy-based approach is therefore expressed in terms of the energy required to make these cracks Multiplication. Self-similarity of stress fields around existing fractures and constant resistance to fractures in material micro-structure and new fractures and new cracks. The existing fractures (points A and B) must be from the middle (point C). But, in fact, local fracture toughness varies spatially due to material heterogeneity and manufacturing-type defects and cracks.

2.8 Fiber failure and debonding in composite materials

When we talk about fiber-matrix interface de-bonding initiation from random fiber breaks is thought in this idea of the critical losses and loss mechanisms in unidirectional composites subjected to quasi-static and cyclic loading. The rise in fiber-matrix interface de-bonds ends up in a discount of the difference and ultimately to the final word failure of the UD composite.

2.9 Damage mechanisms in UD composites in quasi-static loading

As we know that in fiber failure and debonding in composite materials, Damage mechanisms in (UD) composites in quasi-static loading are more critical, so let we talk first about (UD) composite. In polymeric (UD) composite, the fiber strain to failure is so smaller than the matrix strain to failure of fiber, and when they are loaded in quasi-static tension in the fiber direction as the first fiber breaks occur in a somewhat random position.

As we know, because of statistical defect size distribution in fibers, which leads to the famous Weibull strength distribution, which has been used and, which is

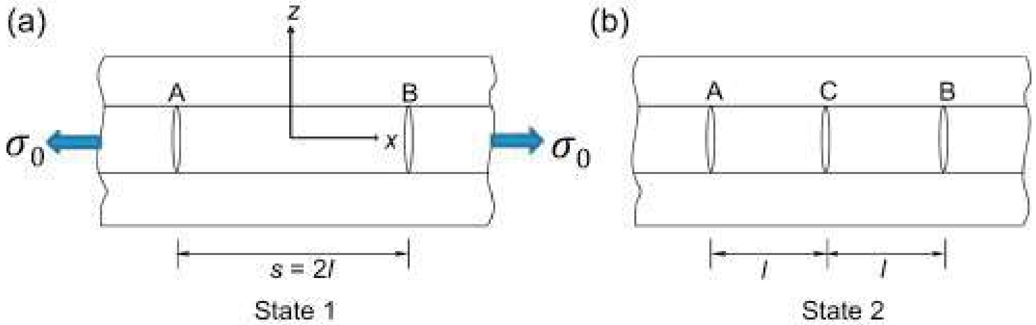


Figure 7.
Show schematics showing progressive multiplication of transverse ply cracks in a cross-ply laminate.

employed and that we know that fiber breaks make less and reduced the viscosity and stiffness and viscosity of the UD composite (**Figures 8** and **9**).

Stress travel or moves through the fiber-matrix interface causes multiple cracks fractures of one fiber. It depends on the main point of the properties of the fibers, matrix, or and fiber-matrix interface. Many of this event may follow formation of each fiber breaks (**Figure 10**): (a) The fracture or cracks extends from the fiber to the matrix until it's capturer by the neighboring fiber. (b) Fiber break tip, which can occur at the shear yield of the matrix, will slow the fracture or crack. Or (c) the deboned crack increases from the fiber to fiber break.

The latter layout is commonly observed and calculated and we are using the single-fiber fragmentation test. In the mix, this deboned crack increases until another material of deboned crack is met. It's growing together with the identical or

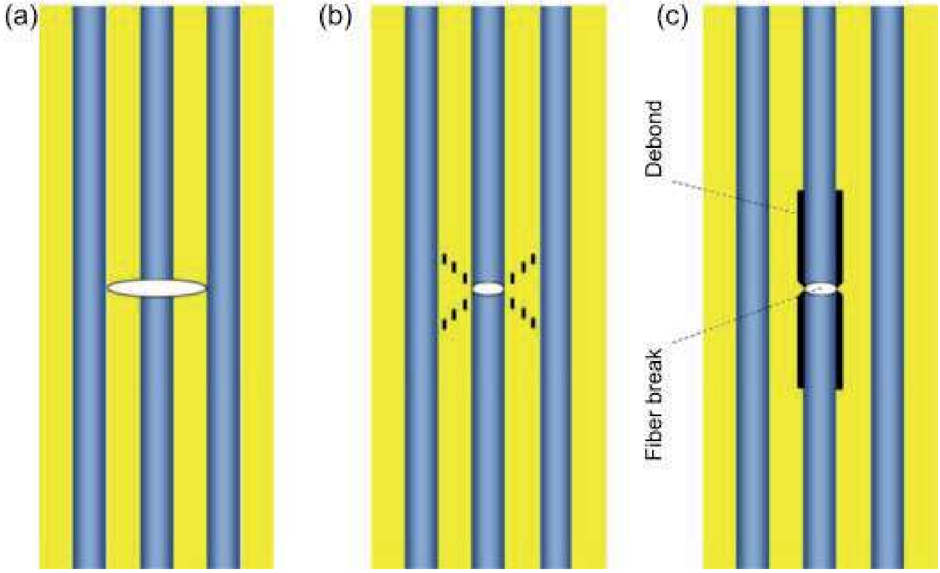


Figure 8.
Damage development scenarios after fiber break formation. (a) Crack propogation in the matrix. (b) Matrix yielding. (c) Debonding of the fiber–matrix interface.

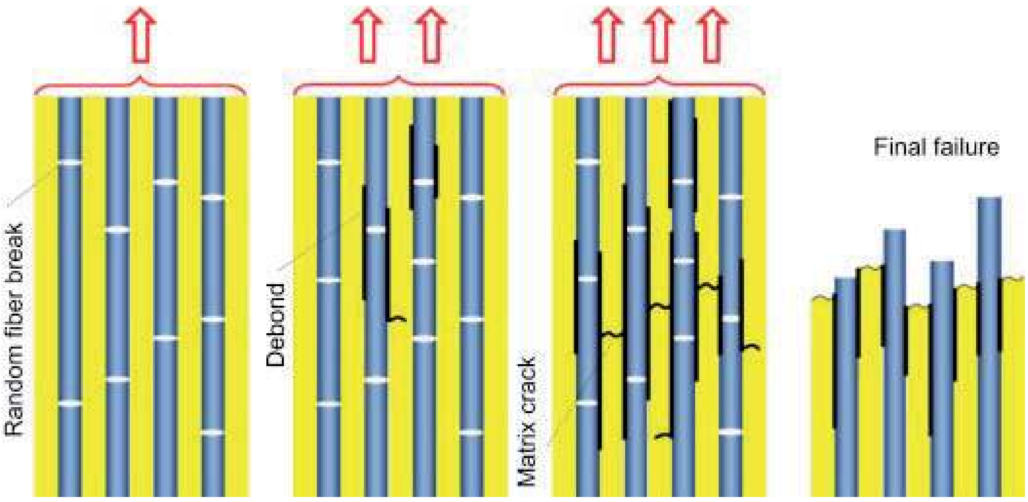


Figure 9.
Schematic of damage events leading to the final failure of a UD composite due to increase of the applied tensile load.

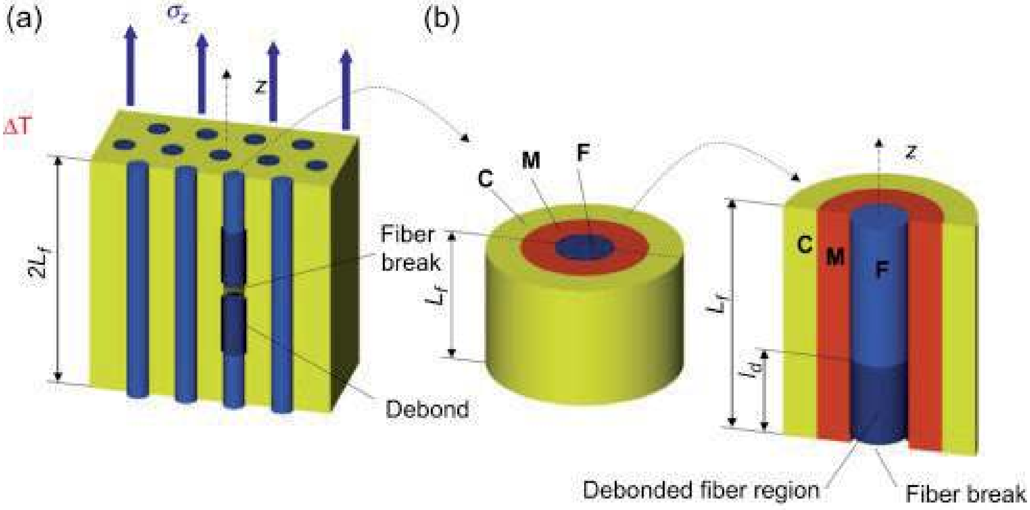


Figure 10.
UD composite with random fiber break and partial interface debonding. (b) Representation of the UD composite by a CCA model. C, effective composite; F, fiber; M, matrix.

other thing is that neighboring fiber. Finally, all fractures and cracks are combined into large fracture or crack, which ends up in complete totally failure of the UD alloy or composite, as shown systematically in **Figure 10**.

2.10 Fiber de-bonding in quasi-static loading

The fiber-matrix de-bond crack propagation usually applies linear-elastic fracture mechanics (LEFM). In LEFM, the analysis first requires calculation of the energy release rate of the (ERR). In the under-static loading, the EER within the initial standard is often compared to the crucial ERR value. EER is that the most ordinarily used single-fiber fragmentation test worldwide and round the industries.

is mostly used around the world analyzed for denond growth in the single-fiber fragmentation test.

The way of the method used to cover a wide spectrum from analytical method to numerical methods such as finite-element method (FEM) or we have other methods called boundary element method (BEM). If we want very accurate numerical local stress state analysis at debonding, the crack tip was only performed using (BEM). But this method is some limitation to isotropic constituents. And one more important thing is that such a method is not used for the carbon fibers (transversally isotropic) or another anisotropic constituent in the model.

The (EER) debond crack propagation in (UD) composite has been previously analyzed. In frictional sliding of debonding, faces were analyzed using a fiber-matrix unit with a free outer surface without including in the analysis the surrounding composite. The (UD) composite may be represented by a model with axial symmetry, a broken and partially debonded fiber surrounded by matrix embedded in an effective composite.

3. Damage evolution in composites using damage mechanics and micro-mechanics

When we think about the composite material first thing, come our mind is the specific strength and stiffness are the primary concern about the application of

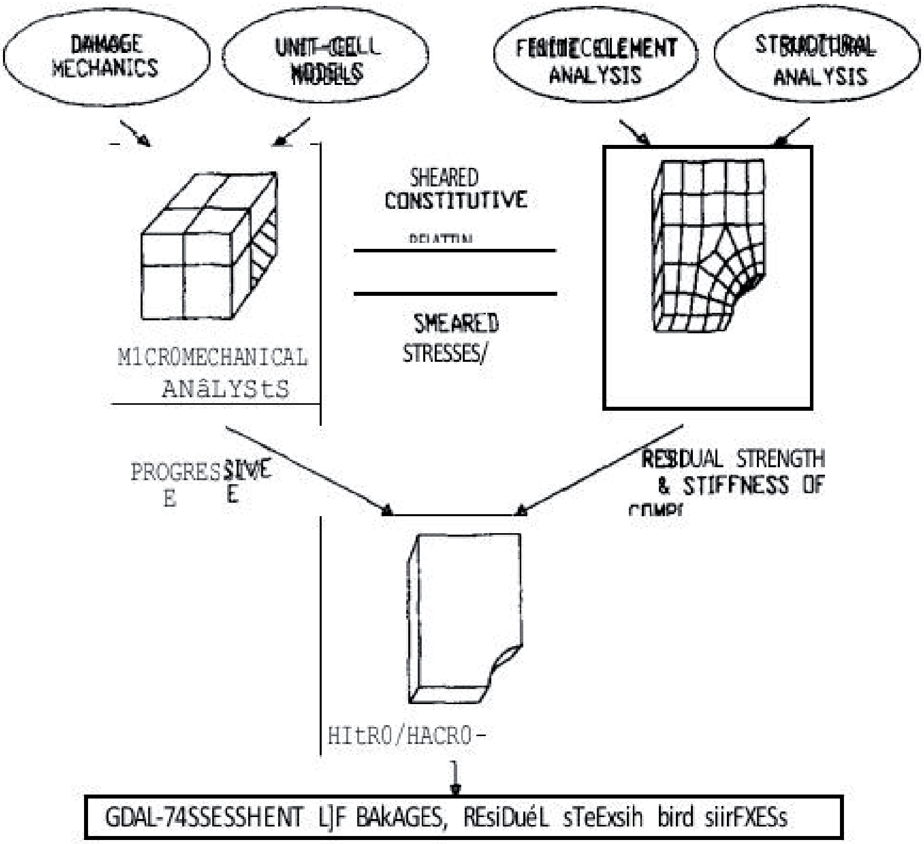


Figure 11.
Micro-/macro-mechanical approach.

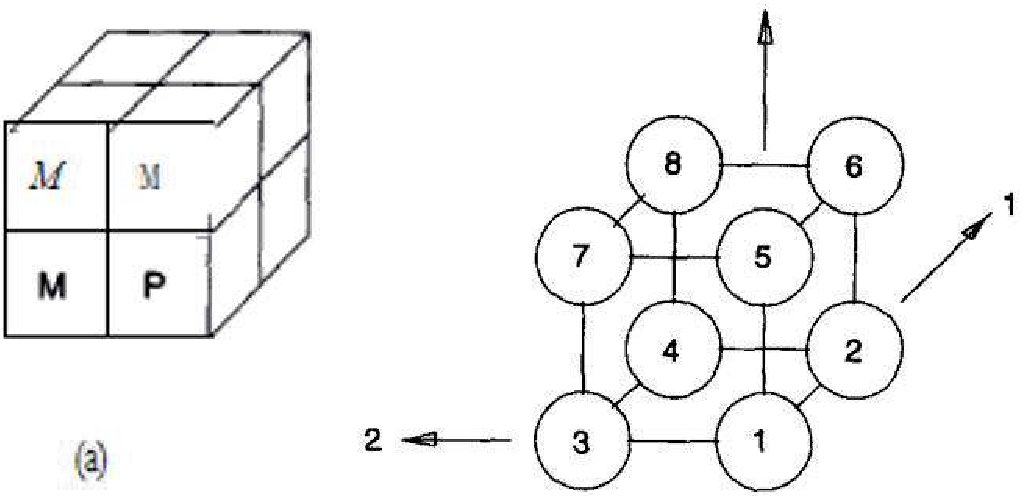


Figure 12.
Simplified, three-dimensional micromechanical model.

composite material is using in the aerospace and military structure aircraft and also in civil aviation. Many more industries used composite material around the world. So, around the world, the engineer has significant challenges about Design and analysis of the composite because of the complex nature of the compositional failure modes and mechanisms of the composite. Predicting and evaluating the progressive damage of the composite structure is critical for analysis and style using the advanced composite and property.

Formerly want to model damage or defects in composites generally employing a macro-mechanical approach [1–7], since we all know that there are many various kinds of damage or defect states in composites, looking on their physical properties and their layout or damage. or error criteria depend. In macro-mechanics we have got assumed for each case [8–16] because we all know that different damage and failure states at the macro-mechanical level can cause the identical damage and failure state within the macro-mechanical model. For instance, once we do matrix damage or failure, we understand the results of fiber splitting, cross-matrix cracking, and de-lamination. So, if we use the damage or failure in terms of the micro-mechanical level, this could be more immediate (**Figures 11** and **12**).

4. Micro/macromechanical approach

The micro/macro mechanical consists of the two levels of detection and analysis. One is called macro-mechanical and micro-mechanical. If you need the input and output data, we have to join it together these methods. **Figure 1** shows the schematic diagram of the procedure is illustrated. The finite-element technique [18] is used for the macro-level analysis.so this way, we can analyze the general composite structure, which also includes plates and shells.

Finite-element analysis is very useful and so much effective for the composite material properties if we are used this method in the form of micro-level analysis using a micro-mechanical model. So, can say that the micro level analysis calculates much useful and more effective material properties from the constitutional material properties. If we talk about the mixed tensions from the finite element analysis using the micro-mechanical model, this can be broken down into a constitutional micro-structure. Micro-stress and micro strain are applied for continuous damage. On the other hand, the smeared, mixed-level stresses from the finite-element analysis using the micro-mechanical model can be decomposed into micro-structures (i.e., stresses—fiber, particle and matrix species) at the constitutional level. Then, continuous damage mechanics is applied to microstress-micro strain. Determine loss initiation or increase in the constitutional material. We also do independent analysis for the damaged fiber and matrix failure.

5. Three-dimensional micromechanical model

A micro-mechanical model for a fibrous combo- site was developed by Know et al. [17, 19, 20]. Thus, this section presents a micro-mechanical model for a particulate composite. The fibrous.

The micro-mechanical model can be considered as a subset of the particle micro-mechanical model. A simplified, micro-mechanical, unit-cell model is shown in **Figure 13(a)**. **Figure 13(b)** shows a clear view of the positions of the eight subunits of the unit-cell as seen in **Figure 13(a)**. Sub-cell 1 is a subset of cells and the rest are binder subunits. 1–2, 2–3 and 3–1 are symmetrical planes. For simplicity, it is assumed that each subunit has uniform stresses and strains. The balance of sub-cellular pressures at all interfaces must be satisfied as given below

$$\sigma_{11}^{1} + \sigma_{11}^{2}, \sigma_{1}^{3}, -\delta_{11}, \sigma_{11}^{5} = \sigma_{11}^{6}, \sigma_{11}^{7} = \sigma_{1}^{8} \tag{1}$$

$$\sigma_{22}^{1} + \sigma_{22}^{3},\ {}_{22}^{2}\sigma_{22}^{4},{}_{22}^{2}\frac{7}{22s}22'22 \tag{2}$$

$$\sigma_{33}^{1} = \sigma_{33}^{5}, \sigma_{33}^{2} = \sigma_{33}^{6}, \sigma_{33}^{3} = \sigma_{33}^{7}, \sigma_{33}^{4} = \sigma_{33}^{8} \tag{3}$$

The subscripts here represent the stress components along the axis shown in **Figure 2**, and the superscript denotes the subcell number. Only the normal stress components are considered in these equations. Similar equations can be written to cut the stress components. However, each subunit is assumed to be orthotropic or isotropic, so that the normal stress–strain components are not attached to the shear components. Therefore, the current development is limited to normal parts of stress–strains and a similar development can be developed for shear stress–strains. Subcells are thought to satisfy the following strain compatibility.

$$\begin{aligned} l_{\mathrm{p}}\varepsilon_{11}^{1} + l_{\mathrm{m}}\varepsilon_{11}^{2} = {} & l_{\mathrm{p}}\varepsilon_{11}^{3} + l_{\mathrm{m}}\varepsilon_{11}^{4} = l_{\mathrm{p}}\varepsilon_{11}^{5} + l_{\mathrm{m}}\varepsilon_{11}^{6} \\ & = l_{\mathrm{p}}\varepsilon_{11}^{7} + l_{\mathrm{m}}\varepsilon_{11}^{8} \end{aligned} \tag{4}$$

$$\begin{aligned} l_{\mathrm{p}}\varepsilon_{22}^{1} + l_{\mathrm{m}}\varepsilon_{22}^{3} \quad & l_{\mathrm{p}}\varepsilon_{22}^{3} + l_{\mathrm{m}}\varepsilon_{22}^{4} = l_{\mathrm{p}}\varepsilon_{22}^{5} + l_{\mathrm{m}}\varepsilon_{22}^{7} \\ & = l_{\mathrm{p}}\varepsilon_{22}^{6} + l_{\mathrm{m}}\varepsilon_{22}^{8} \end{aligned} \tag{5}$$

$$\begin{aligned} l_{\mathrm{p}}\varepsilon_{33}^{1} + l_{\mathrm{m}}\varepsilon_{33}^{5} = {} & l_{\mathrm{p}}\varepsilon_{33}^{2} + l_{\mathrm{m}}\varepsilon_{33}^{6} = l_{\mathrm{p}}\varepsilon_{33}^{3} + l_{\mathrm{m}}\varepsilon_{33}^{7} \\ & l_{\mathrm{p}}\varepsilon_{33}^{4} + l_{\mathrm{m}}\varepsilon_{33}^{8} \end{aligned} \tag{6}$$

In which

$$l_{\mathrm{m}} = 1 - l_{\mathrm{p}} \tag{7}$$

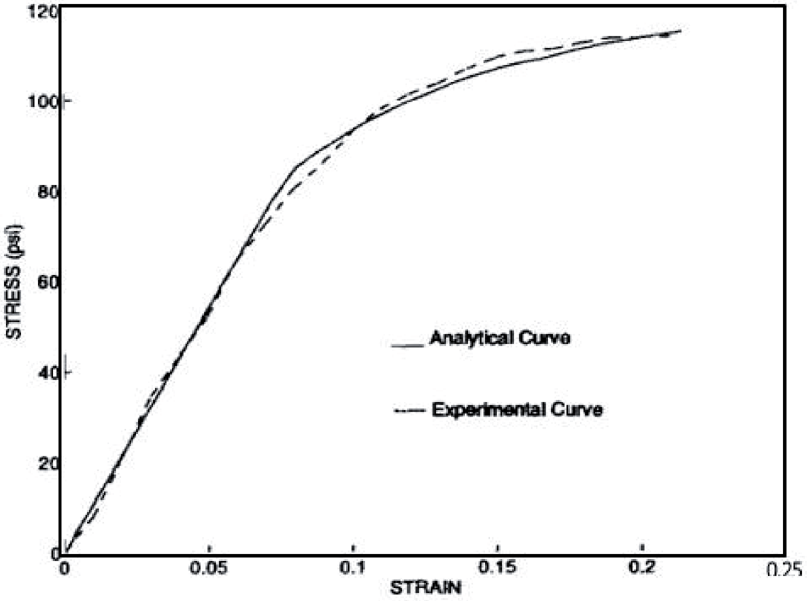


Figure 13.
Stress–strain curves.

and Up is the particle volume fraction of the composite. The unit-cell stresses and strains are obtained from the volume average of sub-cell stresses and strains. In other words,

$$\sigma_{ij} = \sum_{n=1}^{8} V^{n_{\sigma_{ij}}} \tag{8}$$

$$\varepsilon_{ij} = \sum_{n=1}^{8} V^{n_{\varepsilon_{ij}^{n}}} \tag{9}$$

In other words, we say Here V^n is define the volume fraction in terms of nth sub-cell complete over unit-cell. i represent the subscripts i and j from 1 to 3 and σ_{ij} and ε_{ij}, represent in this equation average cell stresses and strain. And the constitutive in the terms of equation between the sub-cell stresses and strains is defined.

$$\sigma_{ij} = E_{ijkl^{\varepsilon_{kl}}} \tag{10}$$

If we combine or manipulating these equations result, we get Eqs. (11) and (12)

$$\sigma_{ij} = E_{ijkl^{\varepsilon_{kl}}} \tag{11}$$

$$\varepsilon_{ij}^{n} = T_{ijkl^{\varepsilon_{kl}}} \tag{12}$$

References [17, 19, 20] show that the Eq. (11) define in terms of the structural equation for the unit-cell. And you see in this equation the E_{ijkl} is represented the composite material properties matrix which we get from the physical properties of the cell and the matrix. This Eq. (11) gives us a straight path from the micro-mechanical method analysis to macro-mechanical analysis. If we see, Eq. (12) shows us more relates to the macro-species and the micro-strain. Substituting micro-strains into Eq. (10) yields subtle stresses. Therefore, these equations cause the macro species to decompose into micro-structures and thus cause micro-stress. For the present analysis, we have the Micro-strain and micro-states are used for the criteria of the damage mechanics or failure criteria. Equation (12) gives relation and relation of the macro-mechanical analytic thinking to micro-mechanical analysis definitely, which is opposite to all process which we get from the last paragraph.

6. Continuum damage model

In the continuum damage model, if we talk about the loss and failure in a composite material structure are defined constitutional level. And we have many examples like fiber particle fracture or matrix cracking or the fiber/matrix debonding. The following derivative in this part is continuous loss and the mechanics for the matrix loss. Current policy of It begins to occur when the current species reaches its previous maximum. This phenomenon has been observed in some particle. If we are seeing in the Ref. [22] we find the composite material such as the solid rocket propellant material.

Equation of risk evolution is described as Number D - digit u g [é] (18) Overate refers to a temporary derivative. In Ref. [21], it is clearly shown that the loss loading and unloading condition can be defined and follows the Simo and Xu develop the

Continuum Damage Mechanics is a race-based isotropic damage model and we can introducing as the quantitative relation variable as the parameter and loss of stress is expressed as:

$$\sigma_{ij} = \frac{\sigma_{ij}}{(1-d)} \tag{13}$$

where $\bar{\sigma}_{ij}$ and, σ_{ij} denoted the effective and home-agenized stress tensors, respectively is defined as a limited damage variable d between 0 and $d_c\,(<1)$, denoted the damage saturation. And the equation number 15 we get the stress tensor and free energy.

$$\sigma_{ij} = \frac{\partial^{\emptyset}}{\partial_{\varepsilon_{ij}}} = (1-d)\frac{\partial^{\emptyset\circ}}{\partial_{\varepsilon_{ij}}} \tag{14}$$

where Ψ° is defined as $\frac{1}{2}E^{\circ}_{ijkl}{}^{\varepsilon_{ij}\varepsilon kl}$ and E°_{ijkl} defined in terms of the tensor of the undamaged material properties. In Eq. (15), we also assumed function for the damage criterion.

$$F = f\left(\varepsilon_{ij,}\sigma_{ij}\right) - k \tag{15}$$

Eq. 15, we have, which is continuant for the damage beginning and the quantity, which kept increases with the damage. On another side, we have the F, which is less than zero. We know that at zero, damage in this equation does not occur. But we have one condition when damage happens when $F = 0$ =0. For the existing damage, the model f is assumed.

$$f(\varepsilon_{ij)} = \bar{e} \tag{16}$$

$$\bar{e} = \sqrt{2\Psi^{\circ}} \tag{17}$$

In Ref. [21], which is defined by Simo and Ju. This tells us the equivalent strain measure in Eqs. (16) and (17), which shows us count on the previous maximum state of strain. But when we see the damage, the damage starts to happen when the existing state of strains reach the former rate, which we have the maximum state of strain. We observed this concept in some particulate composite material, such as we know that is solid rocket propellant material [22]. In terms of damage evolution is defined in terms of Eq. (18).

$$d = kg\left(\bar{e}\right) \tag{18}$$

where the over-dot defines in the terms of the temporary derivative. We can say that Damage loading and the unloading conditions can be define as in Eqs. (19)–(21).

$$k \geq 0 \tag{19}$$

$$F \le 0 \tag{20}$$

$$kF = 0 \tag{21}$$

$F < 0$ defines the unloading and $k = 0$, then $d = 0$ from the Eq. (18), which inform no more damage. If look another side if $k = 0$, then $F = 0$ and $d > 0$ damage is happening. In order to find or find out the damage tangent modulus. And in Eq. (14), the time derivative substituted.

$$\dot{\sigma}_{ij} = \left(1-d\right)E^{\circ}_{ijkl^{\varepsilon_{kl}}} - \dot{d}\,\sigma^{\circ}_{ij} \tag{22}$$

where

$$\sigma^{\circ}_{ij} = \frac{\partial^{\varnothing^{\circ}}}{\partial_{\varepsilon_{ij}}} \tag{23}$$

If we are using the previous equation, finally get the outcome in damage tangent modulus.

$$E_{ijkl} = \left(1-d\right)E^{\circ}_{ijkl} - \frac{g}{e}\sigma^{\circ}_{ijk^{\mathring{\sigma}_{kl}}} \tag{24}$$

Present study shows a mixture of particles. Function g we take like the constant. When we see the rate of loss, the rate of loss is definitely proportional to the rate of equal strain measurement. If parametric quantity d damage reaches its critical value at the general zone. Facture is assumed to occur at that location, and the damage is saturated. We have also thought that the direction of crack propagation is discovered from the path of d in the material.

7. Results and discussion

This is all study conduct to find about the crack beginning in a particle composite material while using a micro-mechanical mode, which is what damage mechanics are described in the last section. Uniaxial tensile testing for the material was carried out the exam the micro-mechanical model and other one is damage mechanics model. For the micro-mechanical model study, we need the physical properties of the particle and the matrix. For the studies in which the current mixture we have to need, the elastic modulus of the particles is about the 1.0 *106 psi, and the binding matrix is 110 psi. Therefore, the cell is much Stiner than which matrix material we have. And the particle volume fraction is 0.78 as you see in **Figure 13**, the stress-strain curve shown by the violent stress well with the experimental curve.

The study we have inspect crack start beginning or initiation from a sample made with the above-mentioned material. The models were 3 inches wide by 3 inches long and 0.25 inches thick. We have to make Two circular holes of two modification different sizes are drilled within the center one hole is 0.25-in. Diameter and therefore the other contain 0.5-in. Samples were subjected to tension with regular displacement until the fracture began from the outlet. Numerical estimation for crack initiation was also performed. A finite-element mesh is shown in **Figure 1**. Refined round the mesh hole. For a sample containing 0.25-in. The applied load vs. displacement for the experimentally and numerically diameter hole is plotted in **Figure 13**.

Call outcome of examination until a crack begins. Due to symmetry of the sample displacement reaction is half the displacement reaction between the two grips (**Figure 14**). The curve is linear until the displacement of 0.11 inches and then becomes linear. Fractures occurred at approximately 0.14 inches of displacement. Damage is initiated from the linearity of the curve before the breaking point. However, the tangent modulus had a very little effect because of the small quantity of damage in the local area around the notch tip of the hole. As the loss increases the loss tangent modulus decreases from the Virgin modulus and the curve deviates from the linearity. Some curve was obtained from both (**Figure 15**).

Numerical and experimental studies and analyses show an identical result. Also, the size of the crack is cracked more than 0.048 in. But the measured size of the crack is almost between 0.048 and 0.051. Therefore, estimation rest on we have experimental data if you see **Figure 16**, which illustrates the circular hole, which is deformed deformation shape of the initially. The circular hole we have in an elliptical shape, and the main circular diameter is about 60 taller than the smaller diameter. Then we have the saturation loss zone, which did not increase for some time even when the pressure to sample was increased.

This all phenomenon and analysis were also exam and study in an experiment. The critical fracture was hesitant for some time before the experimental study was published. If you see in **Figure 17** in terms of the normalized species distribution from the distance from the opening come near the load direction as a function. With relation to the opening, the gap is normalized but with relation to the applied strain, but the strain is normalized. With the increase of the applied strain but before the damage occurs and therefore the density of the opening decreases within

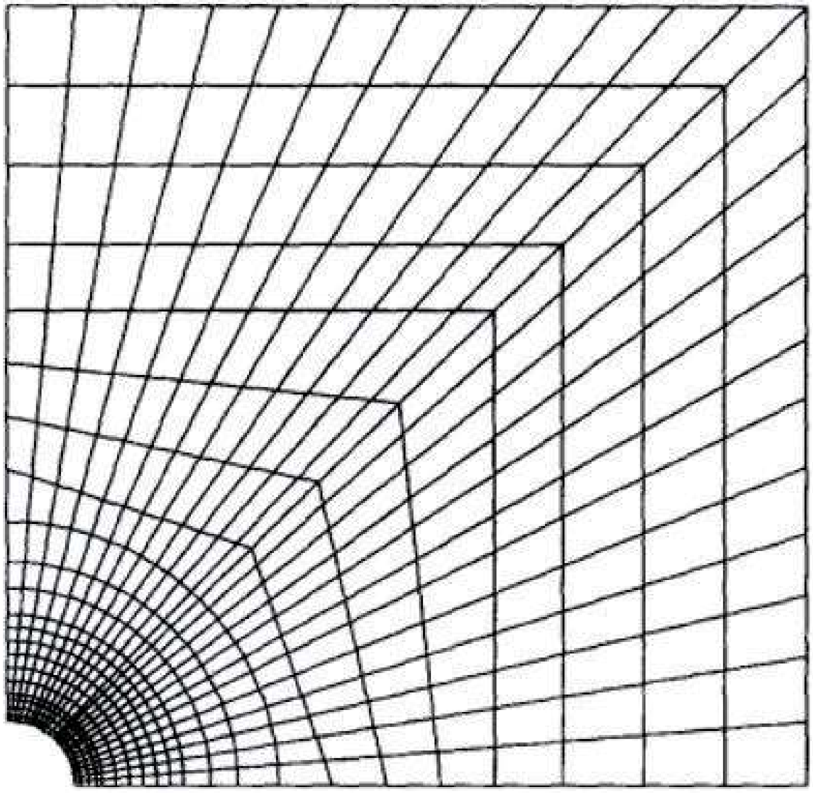


Figure 14.
Finite-element mesh for a specimen with a 0.5-in. Diameter hole.

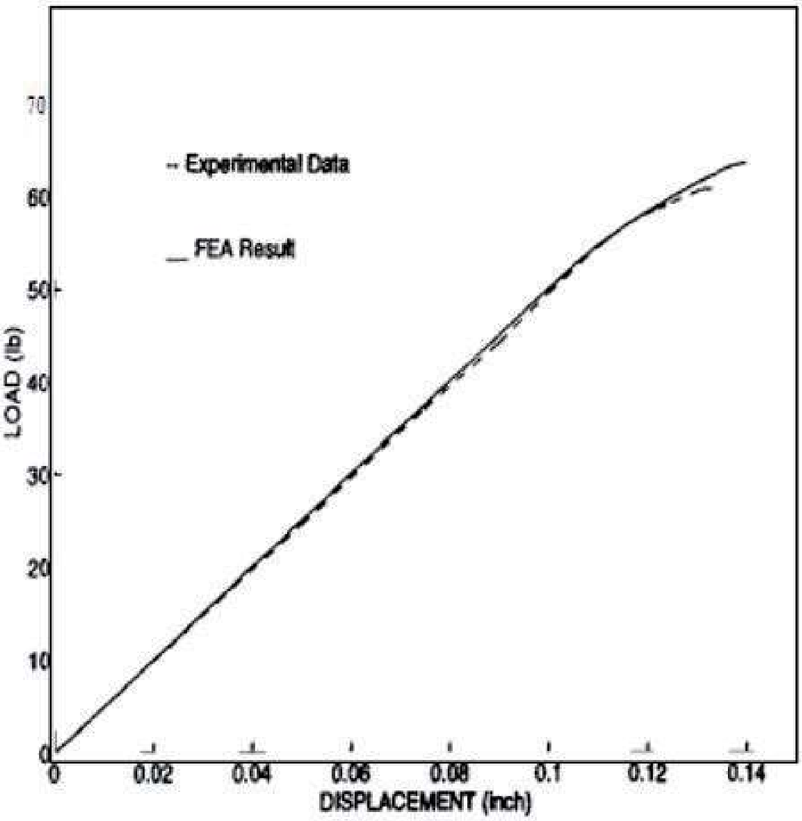


Figure 15.
Deformed shape of a specimen with a 0.25-in. Diameter hole.

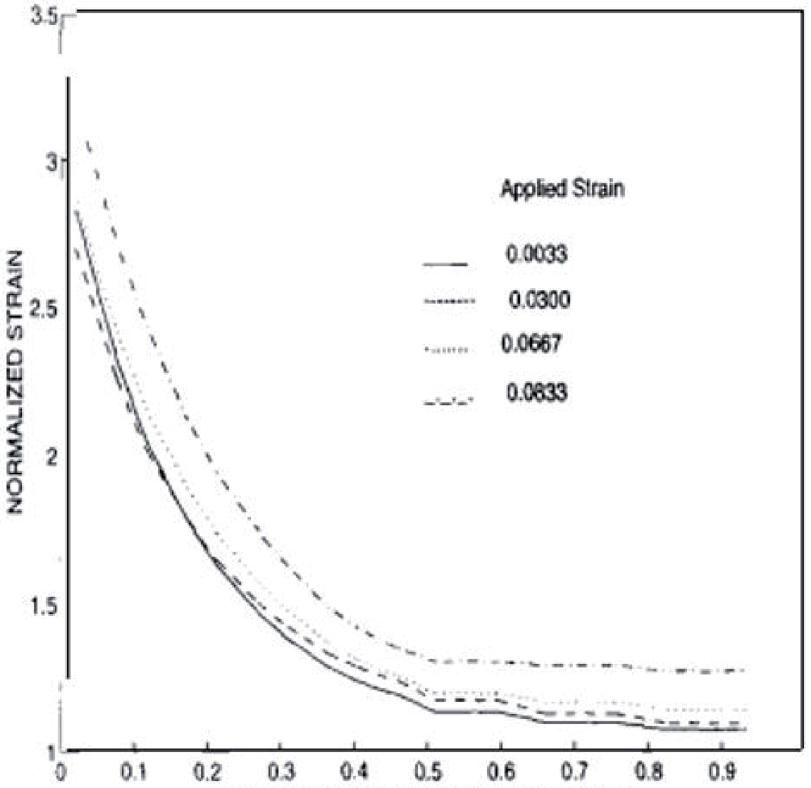


Figure 16.
Strain distribution along the minimum section.

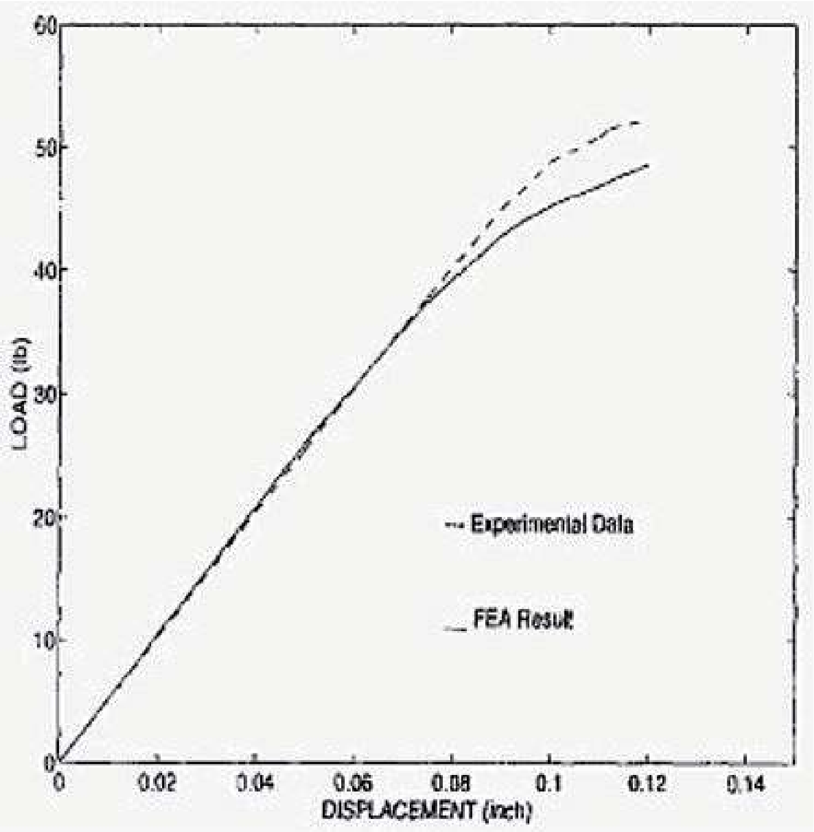


Figure 17.
Load-displacement curve for a specimen with a 0.5-in. Diameter hole.

the vicinity of the resin. This phenomenon is that the reduction caused by deformation of the circular hole into ellipse along the main axis of the loading direction. The concentration factor of the elliptical hole is given by Timoshenko and Goodier [22] (I + 2 *alb*), where 2a is the axis of the ellipse.

Axis of loading direction and 2b loading direction. So this expression matched the current result. However, as the load increases, the normal size elongation increases far from the opening. (Compare the two curves in **Figure 16** for the species used, 0.0033 and 0.0300, respectively.) Regarding as the loss begins and spreads, the normalized elongation increases because the loss tangent modulus decreases. In **Figure 17**, the cases with applied strains of 0.0667 and 0.0833 show a generalized strain increase compared to other curves. Similar comparisons were also made for the 0.5-inch sample. Hole diameter (**Figure 17**).

gives the load-displacement curve for comparison. The predicted crack size was 0.045 in., while the measured crack was between 0.035 and 0.067 in. Therefore, the prediction agreed well with the experimental data. The measured crack size for the 0.5-in. diameter hole had a larger variation than that for the 0.25-in. diameter hole.

8. Conclusions

This research presented a general approach in analyzing the modeling of damage evolution of fiber-reinforced composites structure. It is clear that in both major cases modeling of damage evolution method and the damage evolution in composites using damage mechanics and micro-mechanics method obey the basic principle rule that in every type of the crack in unidirectional FRC material tends to grow in the matrix and find it in the parallel to the direction of the fiber, for example, we know that and studies shows that the crack grows from one location definitely from the weakest direction which is characterized by the matrix.

This phenomenon is proscribed by the standard of the mesh within the finite element numerical model. The foremost crossroads and significant moment is essentially the purpose of initial failure. That is why we used mesh. The mesh surrounding the entire is intentionally modeled, and therefore the uniform rings of the weather have a decent chance of accurately predicting the constant initiation. The following process of crack growth is then influenced by the interaction point size and therefore the shape of the element.

Therefore the direction of the crack growth deviates slightly from the assumed direction parallel to fiber. And which mesh and therefore the design we have and experimental data. Such a design of the mesh and therefore the values of the unknown material properties should be justified by comparing the results with relevant experimental data.

The FEM method is using only an approach for the micro/macro mechanical model. As simple, we can say that a simplified micromechanical model. And the damage mechanics was created or developed to simulate the growth and initiation in a composite structure. In terms of this model, we can approach a general composite framework made of fibrous or particulate composite material and is computationally efficient. The proposed approach only investigates the crack growth in some particulate composite material specimens with a center hole. The numerical calculation predicted result that we have is agreed well with the experimental data. So in this thesis, all the proposed approach is useful for the design and detection and analysis of composite structure in terms of damage and failure.

We also examine the techniques of NDT to analyze the damage detection in the fiber or material, which is more important for detecting the crack and fracture in fibers. We used visual observation, optical microscopy, X-rays, acoustic emission eddy current, ultrasonic, tapping technique, laser-based technology (LBT). In this thesis, we discuss the principle and hole working of all these NDT tools for the analysis of modeling damage of the evolution of fiber-reinforced composite.

9. Recommendations for future work

9.1 Partially growth and curved cracks

In the off-axis planes, the fractures do not increase. Furthermore, if we speak about the multi-axial stress state and also the material variability also causes the crack path to bend round the stable regions. we will ignore these styles of complexities in most cases using an approximation, but our main objective is strictly the evolution of crack density, which is not significantly plagued by thesis complexities.

9.2 Fatigue loading

The joint response under fatigue loading for structural applications is of primary importance. Therefore, an extension of this work is required within the case of fatigue loading to supply an understanding of the damage initiation, progression and failure mechanisms for this loading case, which might be further evidence of structural durability and reliability assessment.

9.3 Wideband transducers

Narrow band resonance sensors are used for threshold-based acoustic systems and typically have an operating frequency range of 100 kHz to 300 kHz, while wideband displacement sensors are used for waveform-based AE systems and their operating frequency reaches 150 MHz or higher. There are two significant difficulties with the narrow band approach. First, it's difficult to differentiate between real, crack-based AE and extra AEs (for example, because of friction and anger). Second, the accuracy of the source position is poor or nonexistent for narrow band, threshold-based systems. Thanks to these limitations of the resonant transducer, the AE data obtained during this study distort actuality source-wave characteristics.

9.4 Transient AE analysis

With data acquired by wideband transducers, it is possible to perform a transient AE analysis, and a database of signature waveforms for each damage mechanism could be established.

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