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Topic

Influence of the orientation of a multiple crack in V-shape under tensile stresses

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Nomenclature

t_c : fail thickness [mm]

L: length [mm]

W: width [mm]

H_c :hight of cell unit [mm]

t: thickness [mm]

[C] : stiffness matrix of the material .

E: Young's modulus (elasticity) [MPa]

b: width of the plate [mm]

M: applied moment [mm. N]

Y: the distance between natural axis

Y_{max}: farthest distance from natural axis

M_{max} : maximum moment [mm.N]

σ_{max}: maximum allowable stress [Mpa]

F: applied force [N]

C_{ij}: stiffness matrix i,j=1,..,6

E_i : young's modulus in i direction [Mpa] i , j =1,2,3

E_{hc}:young's modulus of the honeycomb core . [Mpa]

ϑ_{ij} : Poisson's ratio in i,j = 1,2,3

ϑ_{hc} : Poisson's ratio for the honeycomb core material .

G_{ij} : shear modulus in i direction i =1,2,3 [Mpa]

G_{hc} : shear modulus for honeycomb core [Mpa]

A_{hc} : area of honeycomb in 1-2 planes .

ε_{hc}:strain of the honeycomb .

k: plate stiffness [N/mm]

$w_{\bar{x}}$: partial derivate of w in $\bar{x}$.

w_{x}— : 2nd partial derivate.

w_{x}—— : 3rd partial derivate

w_{x}——— : 4th partial derivate

α : angle of cell honeycomb longitudinal [º]

β: transversal angle of honeycomb cell [º]

Φ : angle between horizontal and diagonal walls (Φ =π/4)

N: stress resultants

Q: shear resultants

M: stress couples

V_n: the effective “shear resultant “

τ:shear stress

X: is the tensile stress (or compression) in L direction

Y: is the tensile stress (or compression) in T direction

Z: is the tensile stress (or compression) in T’ direction

S_{LT}: shear stress in the plane (L, T)

Φ: angle between horizontal and diagonal walls of the unit cell

[D]: stiffness matrix.

DEDICATION

GhAZLI TARIK, I Dedicate this Modest work to my parents to my brothers,

And All my familly and all my friends

Mezili Adel, I Dedicate this modest work to my parents to my sister and my brothers,

My wife and All my family and All my friends

ملخص

قمنا بدراسة تأثير التوجه من تحت اختبار الشد من لوحات المركبة (الزجاج / الايبوكسي والكربون / الايبوكسي) .

لدينا أربعة فصول .

أولا، تعريف وخصائص، ميزة وعيب المواد المركبة، تحدثنا أيضا عن الطبقية وتوجه الألياف. ثانيا، نظريات وقوانين الفشل والكسر وفقا لمعايير مختلفة، ومعيار الطاقة، ومعيار تساي_و، ومعيار تساي-هيل. ثالثا، قمنا بتجريب الألواح الزجاجية والألياف الكربونية المقواة بألواح الإيبوكسي بأحجام وتوجهات مختلفة من الشقوق، وأخيرا قمنا بعمل نموذج باستخدام . برنامج أباكوس لمقارنة النتائج بين التجريبية والمحاكاة، وشكرا لكم .

Résume

Nous avons étudié l'influence de l'orientation de la fissure sous essai de traction des plaques en composite (verre / époxy et carbone / époxy). Nos quatre chapitres.

Tout d'abord, la définition et les caractéristiques, l'avantage et le désavantage des matériaux composites, nous avons parlais aussi du stratifié et de l'orientation des fibres. Deuxièmement, les théories et les lois de l'échec et de la fracture selon les différents critères, critère énergétique, critère Tsai_wu, critère tsai-hill. Troisièmement, nous avons fait une expérience (traction) sur des plaques de matrice époxy renforcées par la fibre de verre et la fibre de carbone avec différentes tailles et orientations de fissures Enfin, nous avons fait un model a l'aide du logiciel Abaqus pour compare les résultats Entre expérimentale et simulation, merci.

Abstract.

We studied the influence of the orientation of the crack under tensile testing of composite plates (glass / epoxy and carbon / epoxy). We four chapters.

First, the definition and characteristics, the advantage and the disadvantage of the composite materials, we also spoke about the laminate and the orientation of the fibers. Second, the theories and laws of failure and fracture according to different criteria, energy criterion, Tsai_wu criterion, tsai-hill criterion. Thirdly, we experimented on fiberglass and carbon fiber reinforced epoxy matrix plates with different sizes and orientations of cracks. Finally, we made a model using the Abaqus software to compare the results Between experimental and simulation, thank you.

Chapter I

1.1 Introcuction 1
1.2 Composite materials 1
1.3 General Characteristics 2
1.4 Classification of composite materials according 4
1.4.1 Form of constituents 4
1.4.1.1 Fiber composites 4
1.4.2 Particle composites 4
1.4.2.1 Depending on the nature of the constituents 4
1.5 Components 5
1.5.1 Reinforcements 5
1.5.2 Fibers 5
1.5.2.1 Discontinuous Fibers 6
1.5.2.2 Continuous Fibers 6
1.6 Strong fiber 7
1.6.1 Glass fiber 7
1.6.2 Carbon fiber 8
1.6.3 Aramid fiber 9
1.6.4 Ceramic fiber 9
1.7 Matrix 11
1.7.1 Functions of the matrix 11
1.7.2 Type of matrix 11
1.7.2.1 Polymer matrix materials 12
1.7.2.2 Metal matrix materials 13
1.7.2.3 Ceramic matrix materials 13
1.7.2.4 Carbone matrices 14

1.7.2 Glass matrices 14

1.8 structural composites materials 15

1.8.1 monolayers 15

1.8.2 The laminates 15

1.8.3 Sandwiches 16

1.9 Woven composite multi-directional structures 16

1.10 Advantages and Disadvantages of composite materials 17

1.11 Implementation Technology 17

1.12 Some application of composite 18

1.13 laminates 19

1.14 Laminates Classification according to the fiber orientation. 20

1.14.1 Unidirectional Laminate. 20

1.14.2 Cross Ply Laminate. 20

1.14.3 Angle Ply Laminate. directions. 20

1.15 Laminates classification based on stacking sequence 20

1.15.1 Symmetric Laminate.. 20

1.15.3 Asymmetric Laminate 20

1.15.4 Quasi isotropic Laminate. 20

1.16 Designation of laminates based on unidirectional threads or fabrics 21

1.17 Specific stratification modes 23

1.17.1 Balanced 23

1.17.2 Symmetrical 23

1.17.3 Crossed. 23

1.17.4 Orthogonal. 23

1.17.5 Hybrids laminates 23

1.17.6. Interplays hybrids 23

1.18 Conclusion 24

Chapter II

2.1 Introduction 25

2.2 Mechanical Behavior of Composite Materials Laminates 25

2.3 Constitutive equations of the monolayer..26

2.3.1 Mechanical characteristics and modulus of elasticity 26

2.3.2 Young longitudinal modulus, E1 26

2.3.3 Young transversal modulus, E2 27

2.3.4 longitudinal Poisson coefficient 27

2.3.5 Longitudinal shear modulus 28

2.4 Generalized Hooke's Law...28

2.4.1 Constants of compliance 30

2.4.2 Constants of stifness..30

2.5 Failure Mechanics of composites 31

2.6 Mechanisms of degradation of a laminated structure...31

2.7 Macro-mechanical Failure Theories in laminate...32

2.7.1 Failure criteria 32

2.7.2 Strength of lamina 33

2.7.3 Limit Criteria...33

2.7.3. MAXIMUM STRESS CRITERION ……………………………………………………........34

2.7.3.2 Maximum strain criterion.. 35

2.7.4 Interactive criteria 35

2.7.4.1 TSAI-HILL THEORY...36

2.7.4.2 Tsai-Wu Theory..37

2.8 Macro-level Failure Mechanism 39

2.8.1 Causes of Delamination 40

2.8.1.1 Manufacturing Defects..40

2.8.1.2 Loading Generating Transverse Stresses...40

2.8.1.3Laminate Geometry..40

2.9 Suppression of Delamination 41

2.10 Fracture mechanism 41

2.10.1 Ductile Fracture..42

2.10.2 Brittle Fracture 42

2.11 Principles of Fracture Mechanics..43

Brittle materials 43

2.12 Fracture modes 44

2.13 The stress intensity Approach..45

2.17 CONCLISION……………………………………………………………………………. 46

Chapter III

3.1 Introduction 47
3.2 The aim this work 47
3.3 Overview about the machine of traction (ZWIKC ROELL) 47
3.3.1 Description 47
3.4 Use of the machine 48
3.5 Material tested by machine zwick roell 48
3.6 Tensile test 49
3.7 Material and geometry of Specimen used 49
3.8 Specimen preparation 50
3.9 Propriety of Materials 52
3.9.1 Matrix 52
3.9.2 The hardener 52
3.9.3 Reinforcements 52
3.10 simple specimen 54
3.11 Specimens of glass fiber with crack (V Form) 54
3.12 Specimens Carbone fiber with crack (V Form) 55
3.13 Analyses and technical experience 56
3.14 Result for glass epoxy after tensile Test1 57
3.15 Result for glass /epoxy after tensile test 2 59
3.16 Result of (carbone /epoxy) specimens after tensile Test1 62
3.17 Result of (carbone /epoxy) specimens after tensile Test2 64
3.18 conclusion 69

Chapter IV

4.1 Introduction..........70

4.2 Design and geometry of specimen..........70

4.2.1Gemometry of speciman..........70

4.3Abaqus softwer simulatoin..........71

4.3.1 Part of modeling..........71

4.3.2 Property function..........71

4.3.3 Assembly..........72

4.3.4 Interaction..........72

4.3.5 Loads and boundary conditions..........73

4.3.6 Mesh Function..........73

4.4 Results of specimens without crack..........74

4.5 Calculate the stress (S_{max}), and strain (E_{max}) ,and displacement (U_{max})..........75

4.6 Result of crack specimen Carbon with different crack size and angle fixed (45°)..........75

4.7 Calculate stress $S_{max,}$ strain E_{max}, displacement U_{max}..........76

4.8 Result of crack specimens (carbon /epoxy) with different angle and crack fixed..........78

4.9 Calculate the stress, and the strain and the displacement..........80

4.10 Conclusion..........82

List of Figures

Chapter I

Figure 1.1composit materials .... …………………………………………………………..........2
Figure 1.2 various geometrical and characteristic may influence the properties of composite..….3
Figure 1.3 component of composite .... ……………………………………………………....4
Figure 1.4 classification of fiber in composite materials .... …………………………………....6
Figure 1.5 types of fibre ………………………………………………………………………...7
Figure 1.6 glass fibre …………………………………………………………………………8
Figure 1.7 carbone fibre ………………………………………………………………………...9
Figure 1.8 aramide fibre ………………………………………………………………………10
Figure 1.9 ceramic fibre ……………………………………………………………..…...10
Figure 1.10 type of matrix 12
Figure 1.11 polymer matrix 13
Figure 1.12 metal matrix composite 14
Figure 1.13 Ceramic matrix composite 15
Figure 1.14 monolayers composite 16
Figure 1.15 composite laminate 17
Figure 1.16 Sandwiches composite 17
Figure 1.17 Designation of honeycomb core 18
Figure 1.19 propeller 19
Figure 1.20 Helmet motorcycle 19
Figure 1.21 basic model of laminate 19
Figure 1.22 Quasi -isotropic laminate 19
Figure 1.23 the orientation and reference of fiber 20
Figure 1.24 the Designation and reference of laminate 21
Figure 1.25 laminate with repeated sequence 22
Figure 1.26 Designations of symmetrical laminates 23
Figure 1.27 Designation of hybrid laminate 24

Chapter II

Figure 2.1 Laminate with different orientations f fiber 26
Figure 2.2 Longitudinal tensile test 26
Figure 2.3 transversal tensile test   27
Figure 2.4 longitudinal Shear test 28
Figure 2.5 Failure in tension in the 2 direction 31
Figure 2.6 Failure in Shear in the 2-3 planes 31
Figure 2.7 odes of rupture and delamination front 32
Figure 2.8 Uniaxial stresses Inclined at angle to the fiber of unidirectional composites 34
Figure 2.9 variation with θ of σ_x at failure 35
Figure 2.10 the domain of elasticity obtained by the Tsai-hill criterion 36
Figure 2.11 The domain of elasticity obtained by the Tsai-Wu criterion 37
Figure 2.12 Macro-level damage mechanism (delamination) 39
Figure 2.13 situations conducive delamination 41
Figure 2.14 graphs of stresses-strain for two materials 43
Figure 2.15 Mode 1-opening 44
Figure 2.16 Mode 2 in plane Shear 45
Figure 2.17 Mode-3 out of -plane Shear 45
Figure 2.18 stress intensity factors for three cases of cracked plates under tension.......................46

Chapter III

Figure. 3 1 The machine of tensile test ZWICK ROELL.. 48

Figure .3.2 materials used for preparation specimen.. 49

Figure .3.3 resin and hardener... 50

Figure. 3.4 Geometry and dimension of specimen.. 50

Figure .3.5 the two specimens carbon/epoxy and glass/epoxy preparation.................................. 51

Figure .3.6 simple specimens made of glass /epoxy after preparation..51

Figure 3.7simple specimen made of carbon fiber without crack………………………………....54

Figure 3.8 the specimen glass/epoxy with crack angle (45°) 54

Figure 3.9 the specimen glass/epoxy with crack angle 55

Figure 3.10 the specimens carbon with different crack 55

Figure 3.11 the specimens carbon/epoxy with crack angle 56

Figure 3.12 the specimen carbon /epoxy between the two jaws of the machine 56

Figure 3.13 the test specimen glass/epoxy between the two jaws of the machine 57

Figure 3.14 specimen glass/epoxy after tensile test with and without crack size 57

Figure 3.15 graphs a, b, represents the specimens with and without crack size 58

Figure 3.16 specimens glass/epoxy after tensile test with crack angle 59

Figure 3.17 the graph c,d,e,f represents the specimens glass/epoxy with crack angle 60

Figure 3.18 the specimens carbon/epoxy after tensile test with different crack size 62

Figure 3.19 the graphs a, b, represents the specimens of carbon/epoxy with crack...................... 62

Figure 3.20 specimens carbon/epoxy after tensile tests with crack angle……………………..... 63

Figure 3 21 the graphs a.b,c,d represents the specimens of carbo/epoxy .... 64.

Figure .3.22 the graph a, b, c, and d specimens carbon /epoxy with crack angle
(a):15mm,30°,**(b):**15mm,45°,**(c):**15mm,60°,**(d):**15mm,90°.. 65

Figure. 3. 23 the graphs a, and b the maximum stress of glass/epoxy on function of size and angle of crack 66

Figure .3.24 the graphs c, and d the maximum stress of carbon/epoxy on function of size and angle of crack...….67

Chapter IV

Figure 4.1 geometries of specimen……………………………………………………………70
Figure 4 2 modelling specimen 71
Figure 4. 3 specimen properties 71
Figure 4.4 Assembly specimen 72
Figure 4. 5 interactions of specimen 72
Figure 4.6 load and boundary conditions 73
Figure 4.7 Mesh of specimen 73
Figure 4.8 maximum displacement 74
Figure 4. 9 maximum strain 74
Figure 4 10 Von mises stress maximum 75
Figure 4.11 Von mises maximum stress 75
Figure 4. 12 strain maximum 76
Figure 4.13 Displacement maximum 76
Figure 4.14 the graph of Smax on function of crack size.. 77
Figure 4 .15 from table we have this graph of strain on function of crack size 77
Figure 4.16 from the table we have this graph of displacement on function of crack………...78
Figure 4. 17 Von mises maximum stress 78
Figure 4.18 maximum strain…………………………………………………………………..79
Figure 4.19 the maximum strain………………………………………………………………79
Figure 4.20 the graphs of specimens on function of angle of crack………………………… 80
Figure 4.21 The graph of specimens on function angle of crack…………………………… 81
Figure 4.22 The graph of specimens on function angle of crack…………………………… 81

Table 1. 1 proprieties of some fiber 9
Table 1.2 some properties of matrix 10
Table 2.1 typical strenght of unidirectional PMC $\nu f = 0.5$.. 26
Table 2. 2 different strenght between ductile and brittle materials.. . 34
Table3.1 the epoxy resin properties... 51
Table 3.2 the hardener properties...51
Table3.3 general property of carbon fiber... .52
Table3.4 general property of glass fiber... .53
Table 3.5 properties off specimen glass/epoxy with and without crack size.......................... 60
Table3 6 property of glass epoxy with crack angle.. ..62
Table 3.7 property of carbon/epoxy with and without crack.. 64
Table 3.8 property of carbon/ epoxy with crack angle... 65
Table 3.9 characteristics of specimens carbon and glass epoxy.. 67
Table3 10 Material properties of specimens.. 67
Table 4.1 static parameters of various specimens without crack..73
Table 4.2 stress max (S_{max} MPa) versus crack size of specimens..75
Table 4.3 strain max E_{max} versus crack of specimens...75
Table 4 4 displacement U_{max}(mm) versus crack of specimens..76
Table 4 5 maximum strain specimen versus angle of crack..78
Table 4.6 stress max (Smax MPa) versus crack angle of specimen..78
Table 4 .7 the maximum displacement U_{max} versus angle of crack 79

GENERAL INTRODUCTION

General introduction

Man knew Materials and used it since long years ago, he didn't stop his development from that time until now and also to the future, development of human's life style, environment and surroundings won't stop, so the need of new upgraded tools and materials is not an option but it is the issue, it is a necessary need.

Man knew composite materials from centuries ago, he used it in some life's parts after he discovered its benefits against simple materials, due to their characteristics and performance it took day after day a more space of his interests.

Nowadays, composite materials take the majority of scientists and engineers researches, their wide field of use made it the axis of development of the other goods.

We can find composite material everywhere in trees, seeds (like alpha), birds and even humans body is a composite material, also we use composite materials in several domains such as means of transportation like aircrafts, trains, submarines, cars, building, arms and a lot of other applications.

The enemy of each material in first degree is fracture, it reduces its life time, characteristics and performance so we can find several researches in this issue, we tried also in this work to study the rupture of laminar composite material using some methods and technics to analyze this phenomenon.

Our work is structured as follow

Chapter 1: generalities on composite materials: definition, advantages, domain of use, classification…

Chapter 2: fracture and failure of composite materials: definition of fracture, modes, laws and criteria

Chapter 3: experimental study using carbon/epoxy and glass/epoxy specimens submitting tensile test.

Chapter 4: simulation using Abaqus software.   General

conclusion.

Chapter I

GENERALITIES ON COMPOSITE MATERILAS

1.1 Introduction

The purpose of this chapter is to define the basic elements that constitute a composite material and to structure the essence of the composite material, the use of composite materials instead of metals and the way in which composite materials used in structures, A general set of composite materials will be defined. Classified. And characterized. We will study the advantages of composites on metals from the point of view of force. Stiffness Weight and cost. Then, our attention will turn to stratified composites. In use, we will classify the stratified according to the designation and orientation, in the mode, we will examine examples and short histories of important structural applications of composite materials to see even more reasons, Finally, the material " Perfect "must have high mechanical properties, be durable and preserve the environment during its life cycle. The economic factor remains the main engine because to be viable, the composite must be competitive.

1.2 Composite materials

A composite material is made by combining two or more materials often ones that have very different properties. The two materials work together to give the composite unique properties. however, within the composite you can easily tell the different materials apart as they do not dissolve or blend into each other. [1]

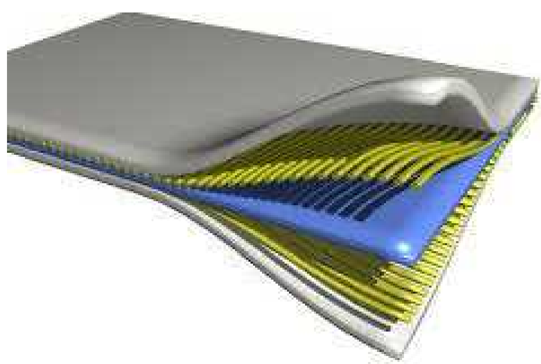


Figure. 1. 1 Composite Materials [9]

1.3 General Characteristics

In general, a composite material is a product consisting of at least two materials - one being a reinforcement and the other a binder (or matrix) uniting the two materials (Figure. 1. 2). There are many composite products made with more than two raw materials. These materials are not miscible and have dissimilar characteristics. The amount, position and orientation of reinforcements and the selection of the matrix are critical aspects of product design and development. The properties of composite materials depend on many factors and Are different according to the various types of composite materials. These properties Result

- The gain of mass,
- The properties, nature and quantity of the constituent materials
- The constituents, the geometry and the distribution of the reinforcement
- Their interactions, the nature of the matrix-reinforcement interface, etc.
- The main characteristics of parts made of composite materials are

Good fatigue strength (increased lifetime),

The absence of corrosion,

The absence of plasticity (their elastic limit corresponds to the limit of rupture)

Aging under the action of moisture and heat,

The insensitivity to certain common chemicals (solvents, paint, oils,

Petroleum, etc.), resistance to impacts and shocks very average, - very strong anisotropy

There are two types of composite materials:

high diffusion composites (GD)

high- performance composites (HP)

GD composites represent 95% of the composite materials used. In general, these are reinforced plastics or reinforced plastics with a volumetric reinforcement rate of about 30%. The main basic constituents are polyester resins (95% of thermosetting resins) with glass fiber (more than 99% of the reinforcements used). HP composites are mainly used in aeronautics, boating, sports and leisure or industrial construction. The reinforcements used are rather long fiber with a reinforcement rate of more than 50%. Unlike GD composites, their mechanical properties, mechanical strength and stiffness are far superior to those of metals. [3]

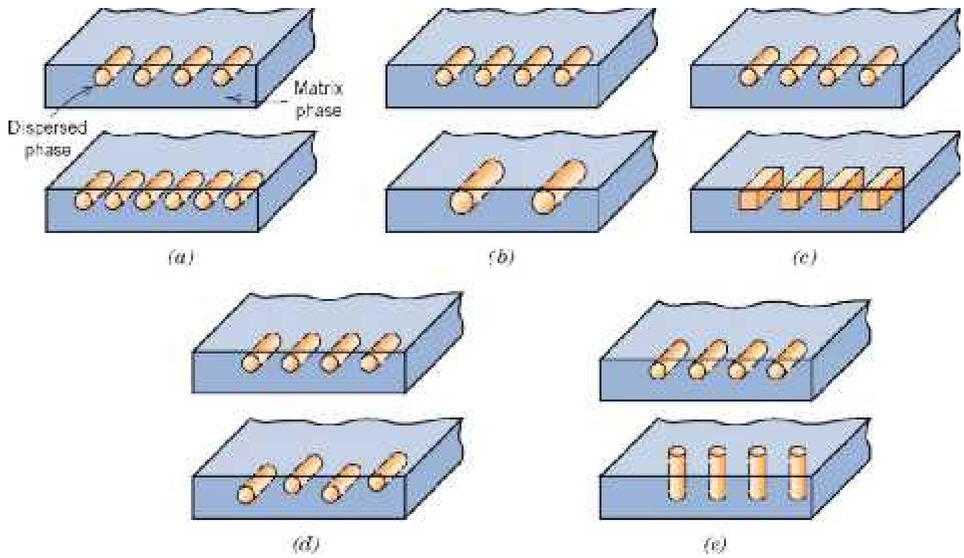


Figure.1.2 various geometrical and characteristics may influence the properties of composites(a)Concentration, (b)Size, (c)Shape, (d)distribution and (e)Orientation. [7]

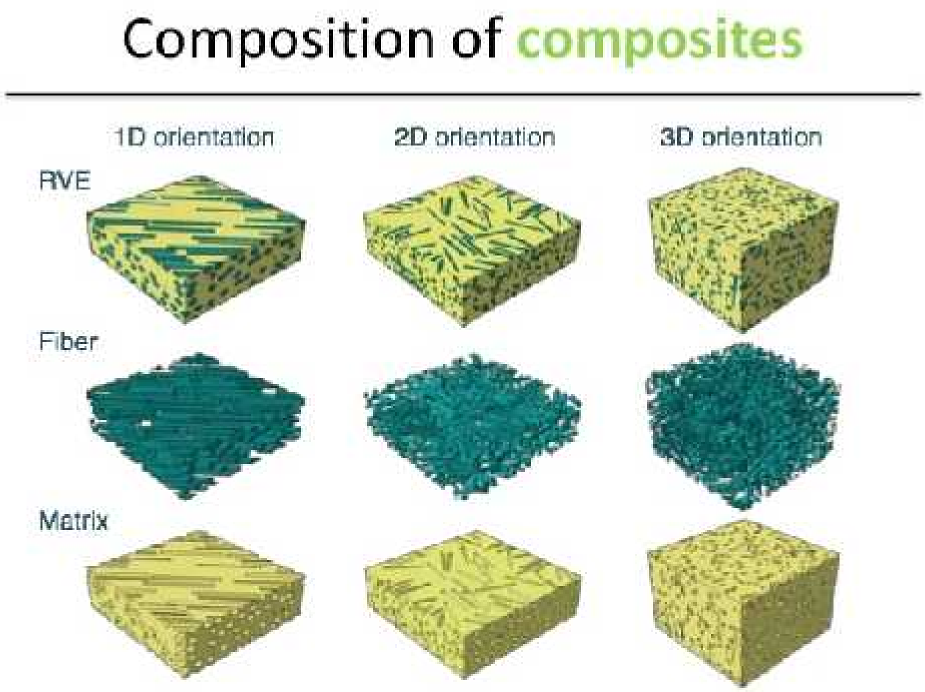


Figure. 1. 3 components of composite. [5]

1.4 Classification of composite materials according

1.4.1 Form of constituents

In great function of the form of the constituents, the composites are classified in two classes:

• Particle composite materials

• Composite fiber materials

1.4.1.1 Fiber composites

A composite material is a fiber composite if the reinforcement is in the form of fiber. The fiber used are in the form of continuous fiber, either in the form of staple fiber, short fiber, staple fiber, etc. The arrangement of the fiber and their orientation make it possible to modulate on a card the mechanical properties of the composite materials to obtain materials ranging from highly anisotropic materials to anisotropic materials in a plane. The importance of fiber composites justifies an exhaustive study of their mechanical behavior

1.4.2 Particle composites

A composite material is a particulate composite if the reinforcement is in particle form. A particle as opposed to fiber, has no privileged dimension. Particles are generally used to improve some of the properties of materials or dies, such as stiffness, abrasion resistance, shrinkage etc. In many cases, the particles are simply used as fillers to reduce the cost of the material without diminishing it characteristics

1.4.2.1 Depending on the nature of the constituents

Depending on the nature of the matrix, composite materials are classified as organic matrix, metal matrix or mineral matrix composites. Various reinforcements are associated with these matrices. Only some pairs of associations currently have an industrial use, others are developed in research laboratories. [3]

1.5 Components

The main constituents are the reinforcement and the matrix. The reinforcement has the role of bringing to the composite material its high mechanical performances. The matrix which is also called a binder, its role is to transmit to the fiber the external mechanical stresses and to protect the fiber from external aggressions. By adding additives to modify some of the physical or chemical properties. They are used even for economic reasons and sometimes for ease of implementation. [3]

1.5.1 Reinforcements

Reinforcements are used to make the composite structure or component Stronger. The most commonly used reinforcements are boron, graphite (often referred to as simply carbon), and Kevlar, but there are other types of reinforcements such as aluminium, silicon carbide, silicon nitride, and titanium. [4]

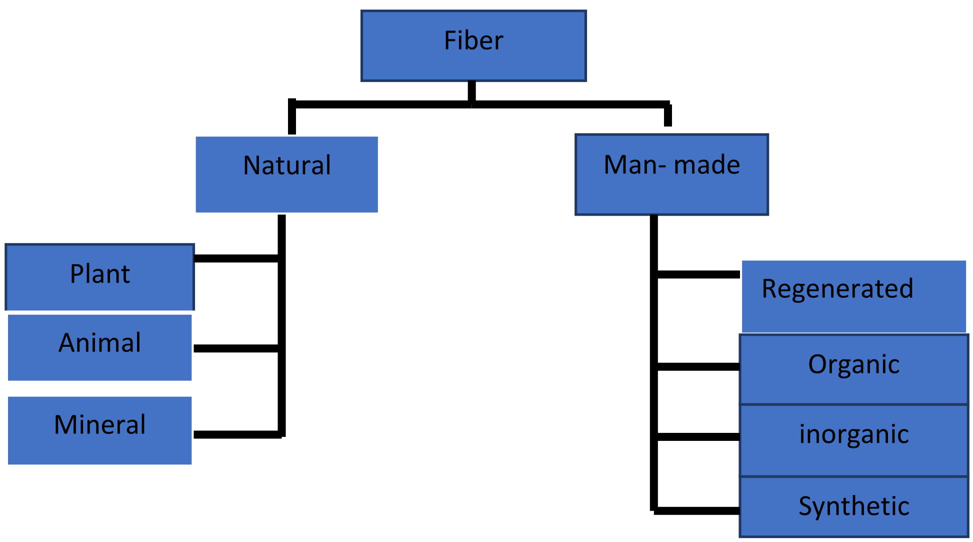


Figure. 1. 1 classification of fiber in composite materials. [3]

1.5.2 Fiber

Fiber are a special case of reinforcements. They are generally continuous and have diameters ranging from 120 to 7400 pin (3-200 pm). Fiber are typically linear elastic or elastic-perfectly plastic and are generally stronger and stiffer than

the same material in bulk form. The most commonly used fiber are boron, glass, carbon, and Kevlar. Fiber and whisker technology is continuously changing.

The physical and mechanical properties are strongly influenced by the nature of the fiber.
The shape of the reinforcement depends on the application and the volume of parts to be made, it makes it possible to distinguish two main families.

1.5.2.1 Discontinuous Fiber

Short fiber or particles (fillers in the form of microbeads, ground fiber, flakes or powder) make it possible to improve certain properties of the matrix (wear resistance, thermal properties, weight). This remains the basic element and a "reinforced polymer

1.5.2.2 Continuous Fiber

In the form of long fiber which are generally used for HP composites. This fibrous form offers a breaking strength and often a modulus of elasticity much higher than those of the same solid material, with an increase in length of 10,000 times, or for the same volume, the surface is multiplied by 100 in the case of glass fiber. These reinforcements have the function of ensuring the good mechanical strength of the composites and are placed within the material according to the properties sought. To create a resistant structure adapted to mechanical constraints, there are several architectures of reinforcements: unidirectional (nerves or roving), bidirectional (fabrics or complexes 2D), three-dimensional (fibre oriented in three directions). [5]

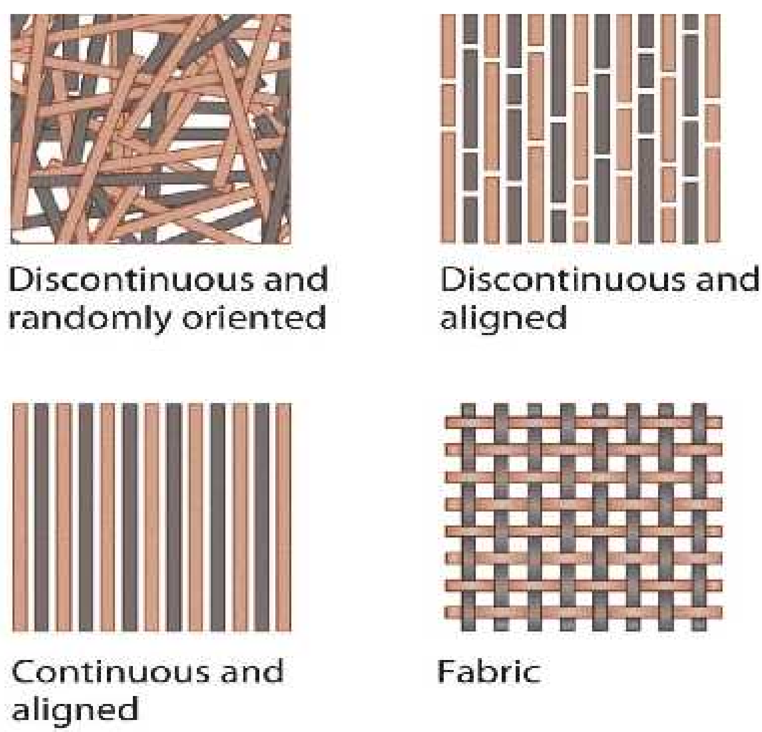


Figure.1.2 Types of Fiber. [11]

1.6 Strong fiber

The engineer who uses materials for structural or load-bearing purposes is
quickly aware of an important feature of engineering solids, which is that they are never as strong as we would expect them to be from our knowledge of the strengths of the chemical bonds which hold them together. The reason for this is that all materials contain defects of various kinds which can never be entirely
Eliminated in particle manufacturing operations. For example, the strength of bulk glass and other ceramics is determined not by their strong covalent or ionic bonds, hut by the many tiny pores or sharp cracks mat exist either on the surface or in the interior. Themast highly polished and dense bulk ceramic will rarely have a strength that exceeds one thousandth of the theoretically predicted strength .similiraly,metas contain faults in the stacking of atoms in their crystalline arrays, and the most damaging of these imperfections(dislocations)cause most bulk metal samples to deform plastically at loads which are, again, perhaps a thousandth or less of the theoretically calculated shear strength The strength of any sample of a glass or ceramic is actually determined by the size of the largest defect, or crack, which it happens to contain. Roughly, the strength is proportional to the inverse square root of the length of the largest haw. A relationship developed in a thermodynamic argument by Griffith in the 1920. [6]

1.6.1 Glass fiber

Over 95% of the fiber used in reinforced plastics are glass fiber, as they are inexpensive, easy to manufacture and possess high strength and stiffness with respect to the plastics which they are reinforced. Their low density, resistance to chemicals, insulation capacity are other bonus characteristics, although the one major disadvantage in glass is that it is prone to break when subjected to high tensile stress for a long time. However, it remains break-resistant at higher stress-levels in shorter time frames. This property mitigates the effective strength of glass especially when glass is expected to sustain loads for many months or years continuously. Period of loading, temperature, moisture and other factors also dictate the tolerance levels of glass fiber and the disadvantage is further compounded by the fact that the brittleness of glass does not make room for prior warning before the catamorphic failure. [7]

Figure. 1.3 glass fiber. [12]

1.6.2 Carbon fiber

Graphite has a structure where the carbon atoms are distributed in parallel crystallographic planes. Carbon atoms in the planes are arranged according to a hexagonal structure in such a way that a carbon atom of a layer is projected at the center of a hexagon of neighbouring layers. The bonds between atoms in the same plane are strong, providing high mechanical properties in directions parallel to the crystallographic planes. Theoretical considerations on the bonds between carbon atoms predict a young's modulus of 1,200 Gpa and a tensile fracture stress of 20 ,000 MPA furthermore, the low density less than (2,000 kg/m^3) leads to remarkably high theoretical specific mechanical properties.[8]

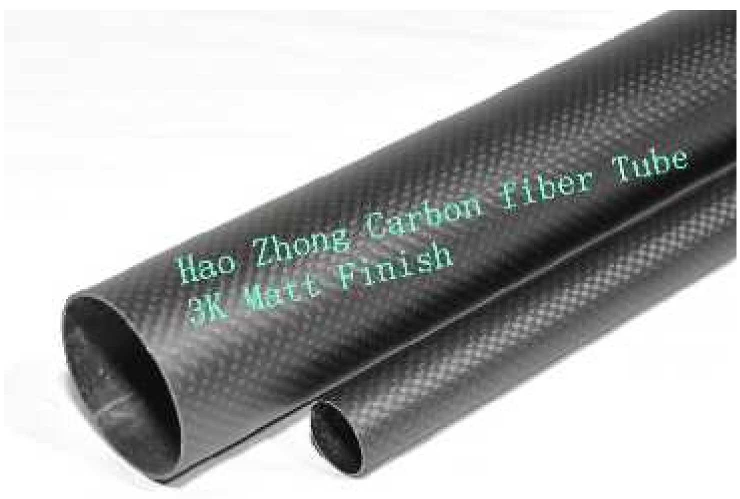


Figure. 1.7 Carbone Fiber. [13]

1.6.3 Aramid fiber

Aramid fiber are made aromatic polyamides which are long polymeric chains and aromatic rings. They are structures in which six carbon atoms are bonded to each other and to combinations of hydrogen atom. in aramid fiber, these rings occur and reoccur to form the fiber. They were initially used to reinforce automobile tires. Since then, they have also found other uses like bullet proof vests. Their use in power boats is not uncommon. Aramid have high tensile strength, high modulus and low weight. Impact- resistant, structures can be produced from aramids. The density of aramid fiber is less than that of glass and graphite fiber. Aramid fiber have a negative coefficient of thermal expansion in the fiber direction and failure of aramid fiber is unique. When they fail, the fiber break into small fiber, which are like fiber within the fiber. this unique failure mechanism is responsible for high strength. [9]

Figure. 1.4 Aramid Fiber

(Https://netcomposites.com/guide-tools/guide/.../aramid-fibrefiber/)

1.6.4 Ceramic fiber

Different Fibers constituted of refractory or ceramic materials (carbides, borides, nitrides etc.) can be produced by chemical deposition of vapor phase onto a thread support boron(B)fiber, boron carbide(B_4C) fiber, silicon carbide (SiC) fiber, boron-silicon, carbide fiber. [10]

Figure. 1.5 Ceramic Fiber.[17]

Table1.1 proprieties of some fiber

Property	E- glass	Carbon	Aramid	Bamboo
Stiffness (GPa)	70-80	160-440	60-180	10-15
Breaking strenght (MPa)	2400	2000-5300	3100-3600	100-200
Failure strain (%)	2.6	1-1. 5	1. 7	-
Density (kg/m^3)	2500-2600	1800-2000	1540	400-800
Fracture length (km)	96	187	238	25

1.7 Matrix

The composite matrix is required to fulfil several functions, most of which are vital to the performance of the material. Bundles of fibres are in themselves, of little value to an engineer and it is only the presence of a matrix or binder that enables us to make use of them. the roles of the matrix in fiber-reinforced and particulate composites are quite different. [11]

1.7.1 Functions of the matrix

- The matrix binds the fiber from together, holding them aligned in the important stressed directions.
- The matrix must also isolate the fiber from each other so that they can act as separate entities.
- The matrix should protect the reinforcing filaments from mechanical damage and from environmental attack.
- A ductile matrix will provide a means of slowing down or stopping cracks that might have originated at broken fiber. [11]

1.7.2 Type of matrix

The composite materials are commonly classified based on matrix constituent the major composite classes include organic matrix composites (OMCs), metal matrix composites (MMCs) and ceramic matrix composites(CMCs). the term organic matrix composite is generally assumed to include two classes of composition, namely polymer matrix composites. [12]

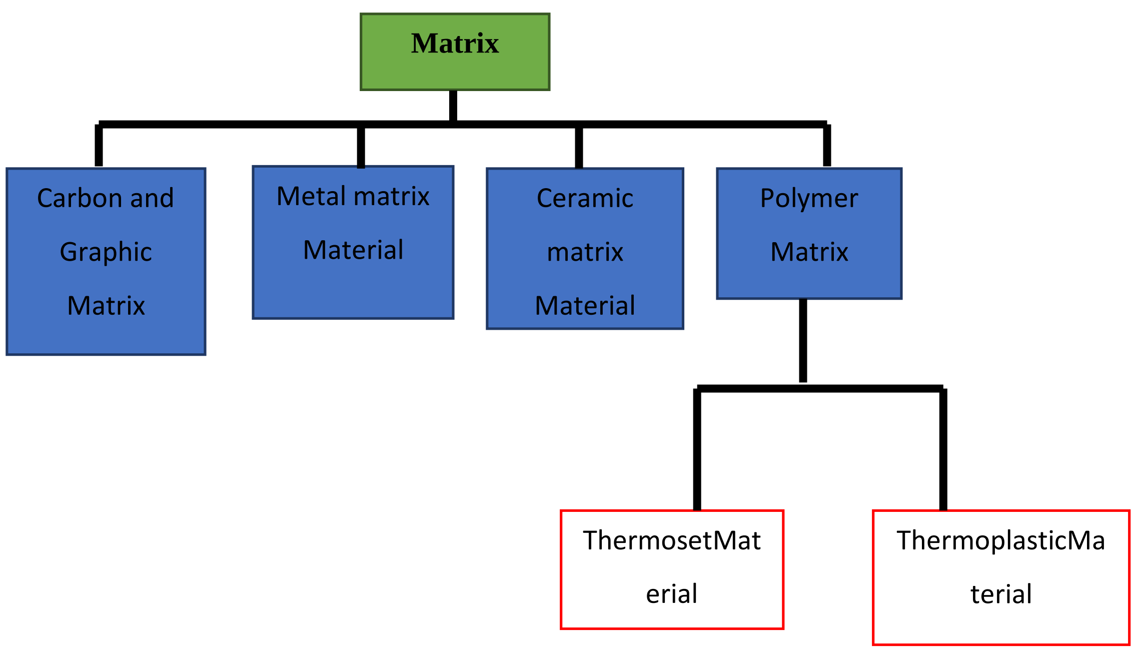


Figure. 1.6 type of matrix

1.7.2.1 Polymer matrix materials

Polymer make ideal materials as they can be processed easily, possess light weight and desirable mechanical properties.it follows, therefore, that high temperature resins are extensively used in aeronautical applications.[13]

Table 1. 2 Some properties of matrix

Property	Polyester	vinyl ester	Epoxy
Stiffness (GPa)	2.4-4.6	3-3.5	3.5
Ultimate strength (MPA)	40-85	50-80	60-80
Ultimate strain (%)	1. 2-4.5	5	3-5
Density (kg/m^3)	1150-1250	1150-1250	1150-1200
Curing hrinkage (%)	6-8	5-7	<2

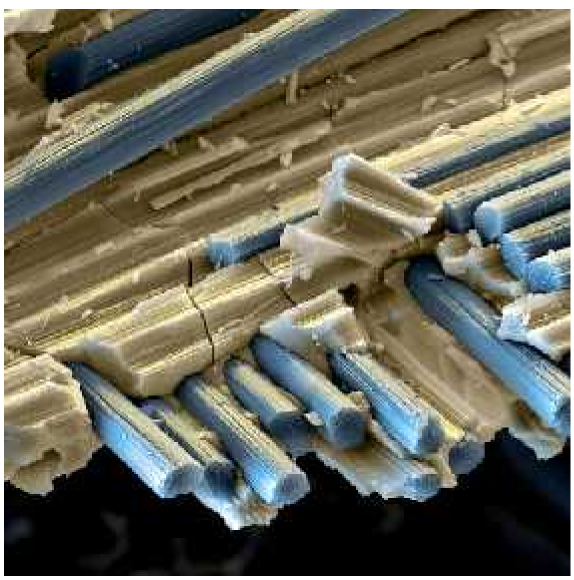


Figure. 1.7 polymer matrix [14]

1.7.2.2 Metal matrix materials

Metal matrix composites, at present though generating a wide interest in research fraternity, are not as widely in use as their plastic counterparts. High strength, fracture toughness and stiffness are offered by metal matrices than those offered by their polymer counterparts. They can withstand elevated temperature in corrosive environment than polymer composites. Most metals and alloys could be used as matrices and they require reinforcement materials which need to be stable over a range of temperature and non-reactive too. However, the guiding aspect for the choice depends essentially on the matrix material. Light metals from the matrix for temperature application and the reinforcements in addition to the aforementioned reasons are characterized by high module.[14]

Figure. 1.12 metal matrix composite (Photo courtesy of Specialty Materials, Inc., http://www.specmaterials.com.)

1.7.2.3 Ceramic matrix materials

Ceramics can be described as solid materials which exhibit very strong ionising in general and in few cases covalent bonding. High melting points, good corrosion resistance, stability at elevated temperatures and high compressive strength render ceramic-based matrix materials a favourite for applications requiring a structural material that doesn't give way at temperature above 1500°C. naturally ceramic matrices are the obvious choice for high temperature applications. [15]

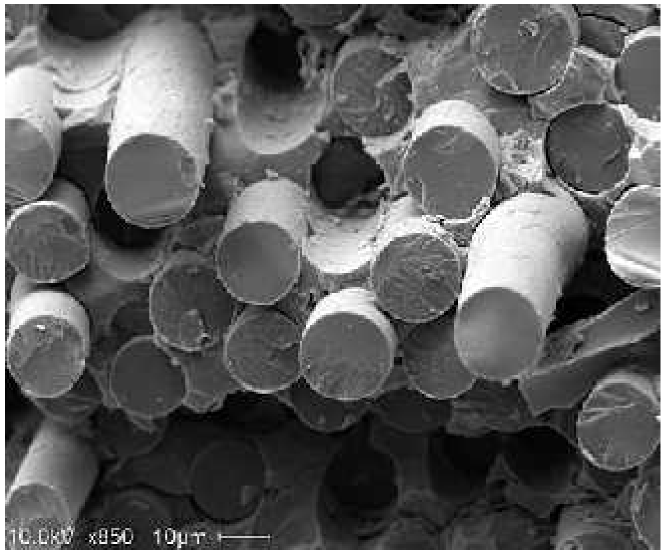


Figure. 1.8 Ceramic matrix composite

(//www.ultramet.com/fiber_interface_scanning.html)

1.7.2.4 Carbone matrices

Carbon and graphite have a special place in composite materials options, both being highly superior, high temperature materials with strengths and rigidity that are not affected by temperature materials up to 2300°C.These carbon-carbon composites fabricated through compaction of carbon or multiple impregnations of porous frames with liquid carbonise precursors and subsequent pyrolization. they can also be manufactured through chemical vapor deposition of pyrolytic carbon. Carbon composites are not be applied in elevated temperatures.as many composites have proved to be far superior at these temperatures. However, their capacity to retain their properties at room temperature as well as at temperature in the range of 2400°C and their dimensional stability make them the oblivious choice in a garnet of applications related to aeronautic military, industry and space. [16]

1.7.2.5 Glass matrices

In composite to ceramics and even considered on their own merit, glass matrices are found to be more reinforcement-friendly. The various manufacturing methods of polymers can be used for glass matrices. Glasses are meant to improve upon performance of serval applications glass matrix composite with high strength and modulus can be obtained and they can be maintained up to temperature of the order of 650°. [17]

1.8 structural composites materials

The structures of composite materials can be classified into three types:

- Monolayers
- The laminates
- Sandwiches

1.8.1 monolayers

Represent the basic element of the composite structure. The different Types of monolayers are characterized by the shape of the reinforcement: with long fiber (Unidirectional DUs, randomly distributed), woven fiber, short fiber. [18]

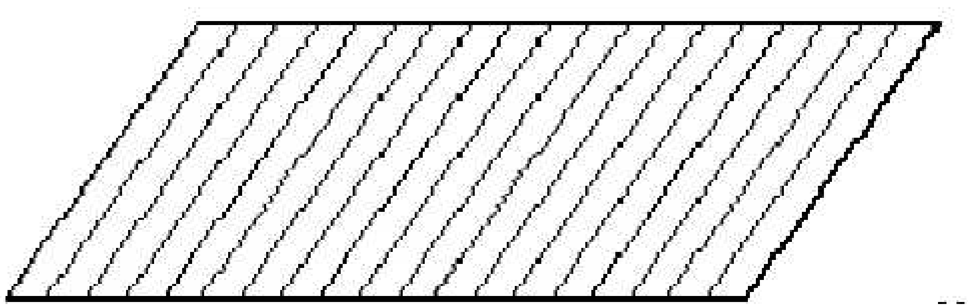


Figure. 1.14 Monolayers composite. [15]

1.8.2 The laminates

A laminate consists of a stack of monolayers each having an orientation to a repository common to the layers and designated as the repository of the
laminate. The choice of stacking and more particularly of the orientations will make it possible to Specific mechanical properties

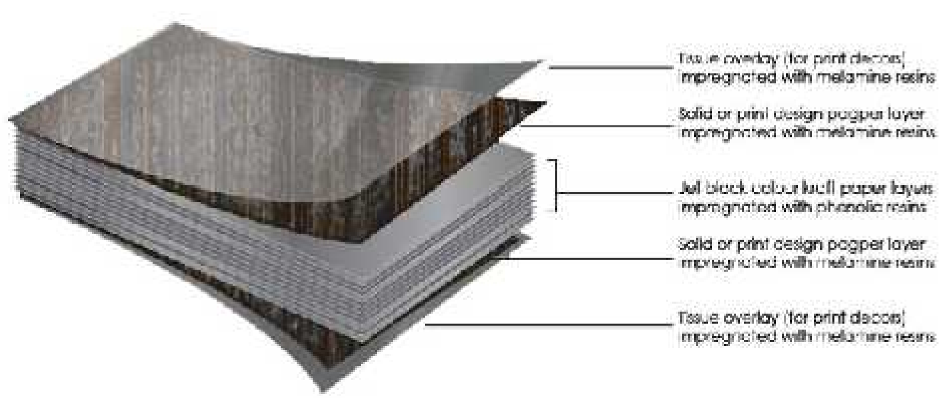


Figure. 1. 15 composite laminate. [16]

1.8.1 Sandwiches

Materials composed of two soles (or skins) of high rigidity and of small thickness Enveloping a core (or core) of high thickness and low strength. The Structure of great lightness. The sandwich material has a high flexural lightness and it is an excellent thermal insulation.[19]

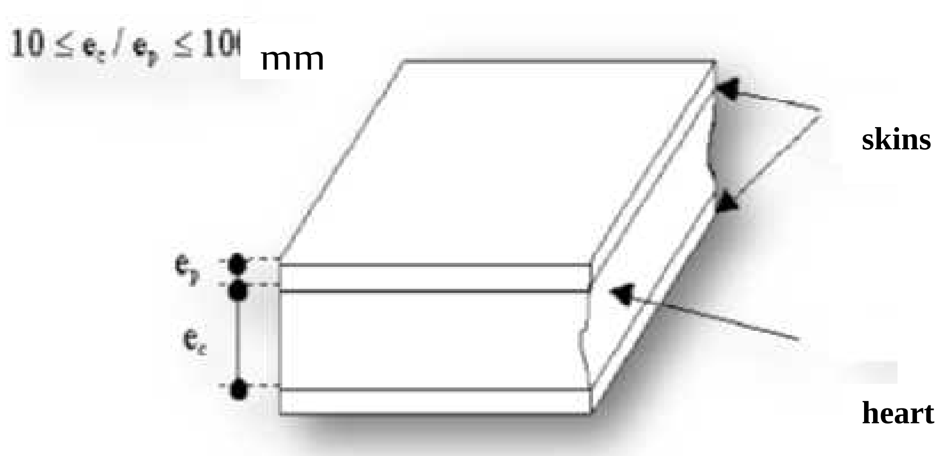


Figure. 1.16 Sandwiches composite. [18]

1.9 Wovencomposite multi-directional structures

It is possible to create composite three-dimensional composite material parts or forms of revolution. 2D-type volumic weaves (two directions of Reinforcement), 3D-Evolution (two directions of reinforcement and a stitching in the third direction), 3D (three reinforcement directions), 4D (four reinforcement directions), or more are developed in the aerospace industry. It is also possible to weave cylinders or cones to make reservoirs or nozzles. In these latter cases, the reinforcing threads intersect Infan. Some examples of multi-directional composite materials are Now presented. Massive structures are mainly used in the field Aerospace and remain very marginal because of their very high cost of production. high. [20]

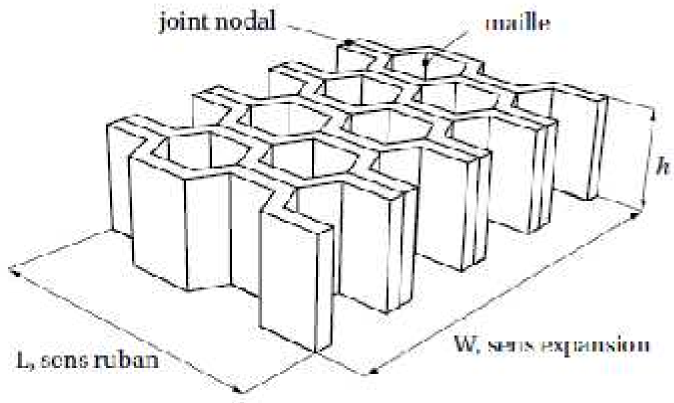


Figure. 1.9 Designation of honeycomb core [19]

1.10 Advantages and Disadvantages of composite materials

Composites are preferred over other materials because they offer strengths related to

- Their lightness.
- Their resistance to corrosion and also fatigue.
- Their insensitivity to products such as greases, hydraulic fluids, paints and solvents.
- Their ability to take many forms, integrate accessories and allow noise reduction.

Disadvantages that impede their diffusion

- The costs of raw materials and manufacturing processes.
- The management of the waste generated and the regulation increasingly strict.
- Today, the composite materials industry faces challenges such as
- Control of emissions of volatile organic products, styrene.
- The mastery of the transformation processes and the performances of the materials which implies a very good knowledge of the constituents put in place.
- The introduction of technologies and channels for the management of waste at the end of life which is the most difficult part to satisfy because of the thermos ability of most composites.

1.11 Implementation Technology

Three operations are essential:

1. Impregnation of the reinforcement by the resinous system.
2. Forming to the geometry of the part.
3. Hardening of the system;

by poly-condensation and crosslinking for thermosetting matrices,
or by simple cooling for thermoplastic materials.
There are different techniques but the most used is by molding. [2]

1.12 Some application of composite

Figure .1.18 boat oracle

Figure. 1.19 propeller

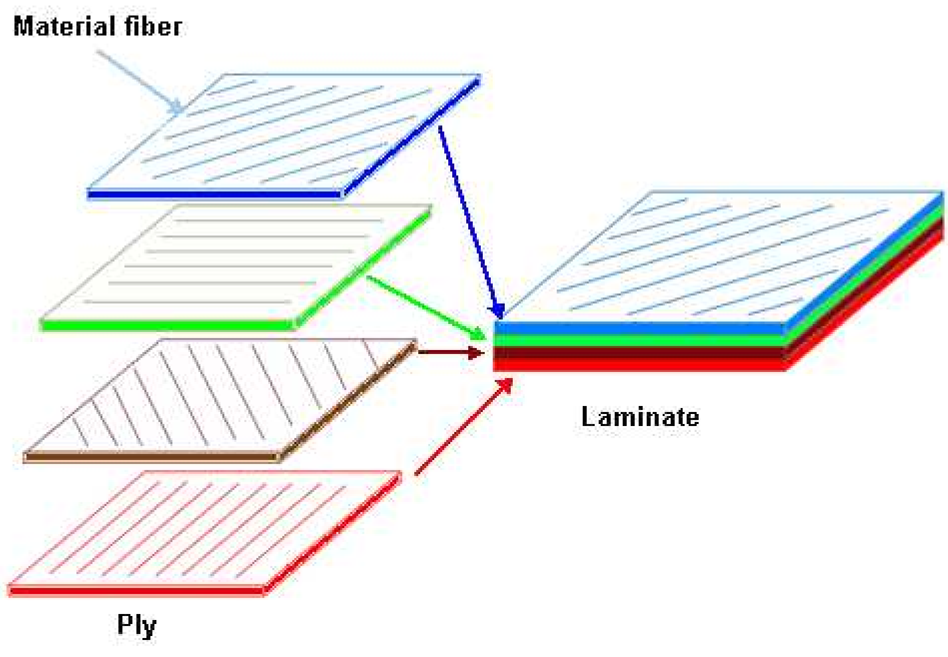
Figure. 1.20 race bicycle

Figure. 1.21 Helmet motorcycle

(www.compositesworld.com/.../oracle-teams-new-boat-uses-Dassault.)

1.13 Laminates

Laminates are composites formed by a stack of layers' Successive reinforcement-matrix called plies or monolayers constituting the basic element of any composite structure. The folds are characterized by the shape Reinforcement (mat, yarn, roving, fabric, etc.) that determines their behavior Mechanical, a random distribution of short or long fiber (matte for example) Corresponds to a substantially isotropic layer in its plane, an orientation fiber corresponds to a marked anisotropy. The layers may be of different natures in terms of fiber and form of the reinforcement. In addition to stacking and orientation, these two parameters allow to modulate the characteristics of the laminate to best respond to the stresses Imposed. The designation of a laminate must take account of all these parameters. It is generally done according to a code established for laminates based on yarns or unidirectional fabrics to which can be reduced the study of any other Type of laminates Figure. (1.22). [21]



. **Figure. 1.22** basic model of laminate (www.cirmib.ing.unitn.it/Compositi/Laminates.)

1.14 Laminates Classification according to the fiber orientation.

1.14.1 UnidirectionalLaminate. The fiber angle in any ply is parallel to the fiber angle in every other ply. This is a thick lamina from a mechanics point of view

1.14.2 Cross Ply Laminate. The fiber angle in any ply is normal to at least one other ply and parallel to any other ply or plies (i.e., contains only 0 and 90° plies).

1.14.3 Angle Ply Laminate. Fiber angle of any ply is not restricted to parallel and normal directions.

1.15 Laminates classification based on stacking sequence

1.15.1 Symmetric Laminate. In a symmetric laminate, all plies above the midplane have the same angle as the ply in the equivalent position below the midplane (i.e., the midplane of the laminate is a plane of symmetry).

1.15.2 Antisymmetric Laminate. All plies above the midplane have the opposite (negative) angle as the ply in the equivalent position below the midplane. (The midplane is a plane of anti-symmetry)

1.15.3 Asymmetric Laminate. The midplane is not a plane of symmetry or anti symmetry.

1.15.4 Quasiisotropic Laminate. Three or more plies in which the orientation of constituent are increments of p n where n is the Total number of plies. [22]

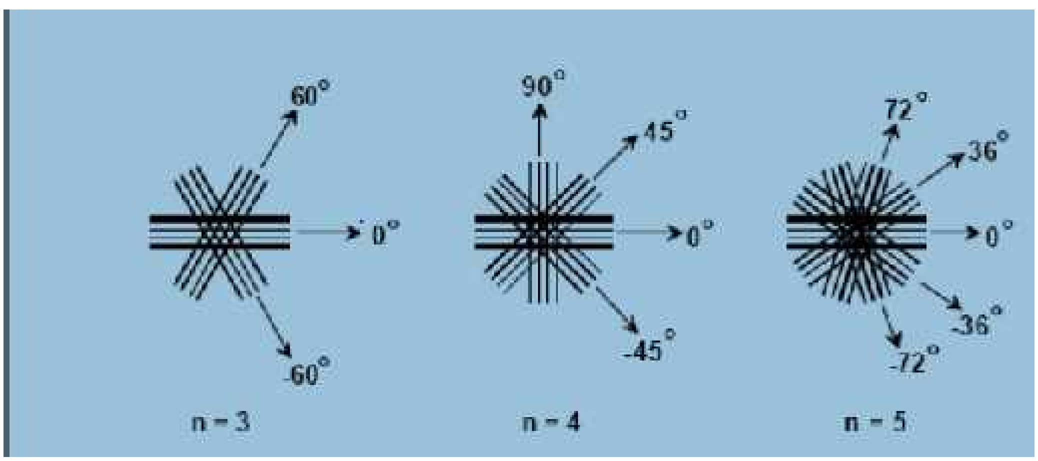


Figure. 1.23 Quasi -isotropic laminate http (www.cirmib.ing.unitn.it)

1.16 Designation of laminates based on unidirectional threads or fabrics

The rules for designating a laminate are as follows.

Each layer is denoted by the value of its orientation angle (angle of the fiber in degrees relative to the reference x-axis). The meaning of Orientation is taken into account (positive or negative), the designation therefore depends on the Chosen frame of reference figure. (1. 24)

The successive layers of different angles are separated by a / if their English Are difference;

The successive layers of the same orientation are designated by an index Numberindicating the number of layers in that direction

If two successive layers have orientations of the same values and meanings, they may be designated by the sign ±: $+\theta/-\theta = \pm\theta \quad -\theta/+\theta = \pm\theta$

Designation is made layer by layer from one side to the other, hooks Indicating the start and end. Figure. (1. 25) Example of designation of a laminate. [23]

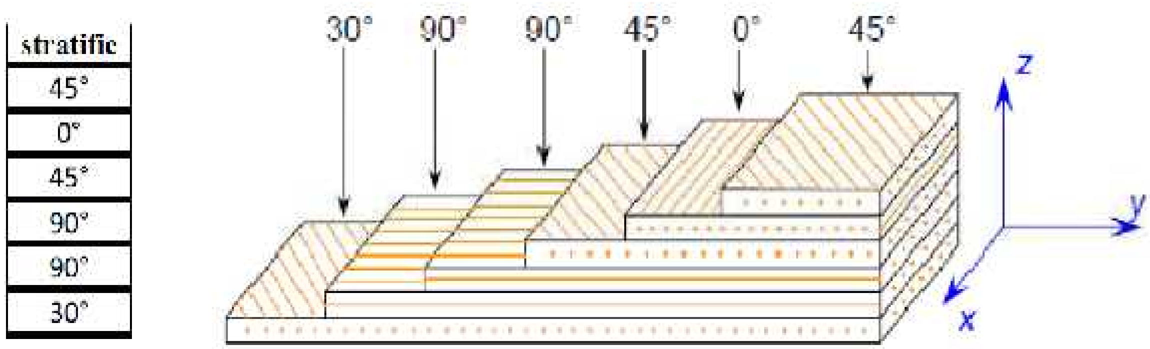


Figure. 1.24 the orientation and reference of fiber. [20]

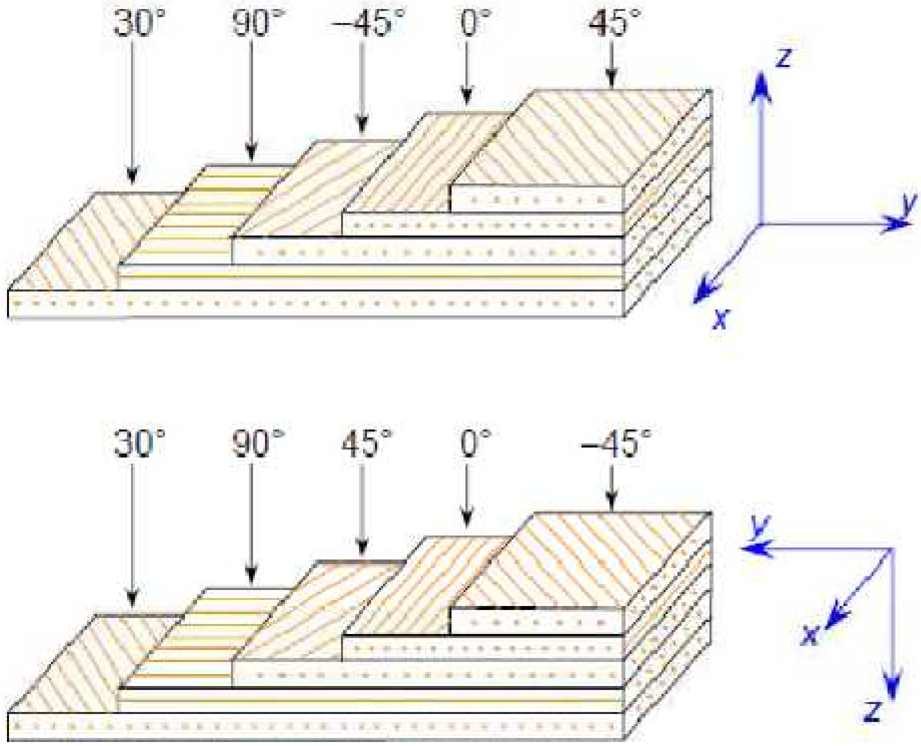


Figure. 1.25 The Designation and reference of laminate. [21]

If there is a sequence that repeats, the layers in question are placed between Parentheses to designate the sequence. A numerical index indicates the number of Repetition of the latter figure. (1. 21)

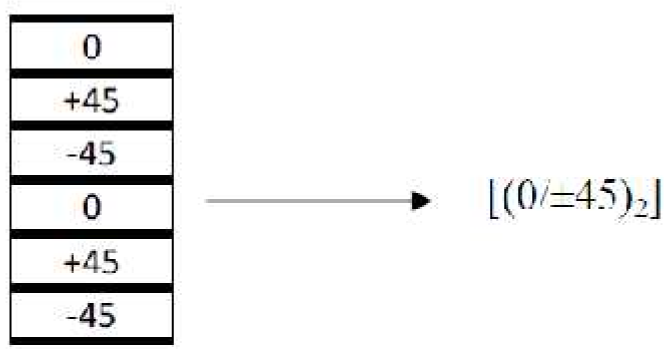


Figure. 1.26 laminate with repeated sequence

(Nptel.ac.in/courses/101106038/mod04lec01)

1.17 Specific stratification modes

According to the stacking sequence, laminates are encountered

1.17.1 Balanced thelaminate has as many layers oriented according to the Direction +0 than layers oriented in the direction 0.

1.17.2 Symmetrical: the mean plane of the laminate is the plane of symmetry (with respect to the Layering). The designation in this case may be limited to half the folds Starting from one side and stopping at the mean plane with an index "s" Refers to this symmetry. If the total number of layers is odd the central layer (Plane of symmetry) is highlighted Figure. (1. 27)

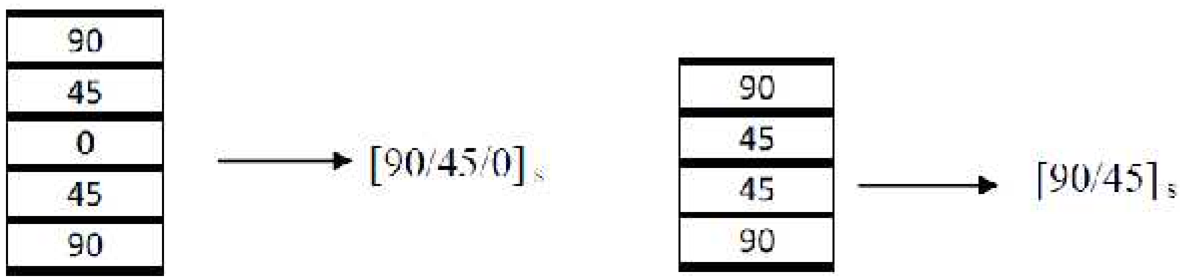


Figure. 1. 27 Designations of symmetrical laminates. [22]

1.17.3 Crossed a crossed laminate consists exclusively of the [0/90 °] sequence which Repeats n times.

1.17.4 Orthogonal they have as many layers at 0 ° as layers at 90 °.

1.17.5 Hybridslaminates composed of fiber reinforced layers of Natures. Better performance can be achieved by using best The properties of each type of reinforcement. We can distinguish

1.17.5.1 Interplays hybrids consisting of a series of layers, each of nature Different. Interplay hybrids, consisting of a sequence of identical folds, each fold Being made up of different layers; Metal layers can also be inserted between the layers. The fiber material must be mentioned for each layer. An example is given in figure (1. 28). [23]

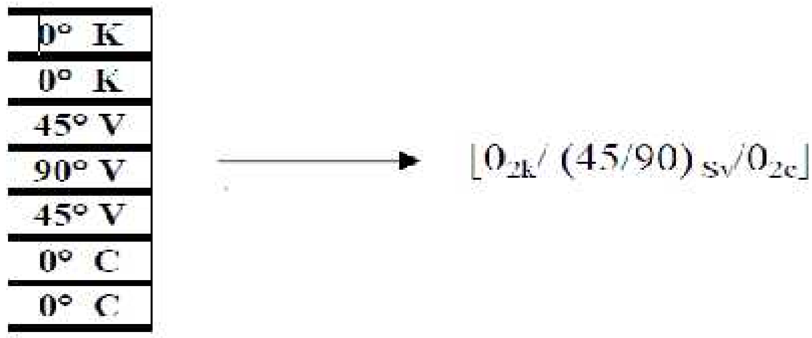


Figure. 1.28 Designation of Hybrid laminate. [23]

1.18 Conclusion

In this first chapter, we saw an overview on composite materials with characteristics and component which is the fiber and the matrix, and also saw the advantage and inconvenient Of composite materials, which is the strong resistance with a lightness of weight, we have noticed that the composite is applied in the best field of technology which is the aircraft and space shuttle and automotive. We interest has the composite laminate and his composition and the orientation of the fiber which play an important role for obtain a best result. [24]

Chapter II

Failure and Fracture Criteria

2.1 Introduction

Specialists now have more and more powerful investigation methods to study composite materials. These methods allow a quasi-optimal definition Reinforcement-matrix association for a given application. Paradoxically, the methods of dimensioning and analysing stratified structures are based on Pragmatic and primitive approaches. To evaluate the strength of a laminate structure, design criteria must be available. The criteria for dimensional limitations in loading monotone or Breaking criteria are based on the hypothesis of fragile elastic behavior of constituents Basic, fiber and matrix. They are generally deduced from the criteria of elasticity Isotropic. These criteria are usually expressed as a function of the constraints of a scalar function called the limit criterion. This function allows to quantify the intensity of stress applied. Conventionally, the criterion of maximum stress, the criterion of deformation Maximum and energy criteria of Hill, Tsai-Hill. They provide a first Evaluation of the mechanical strength of the laminate. These criteria require know ledge Stresses or strain at break.

2.2 Mechanical Behavior of Composite Materials Laminates

It should be noted that the mechanical behavior of composite stratified structures is not always linear until the final phase of the rupture. In particular, the stacks Disoriented layers generally exhibit behavioral Non-linear as soon as the loading exceeds a critical value from which the degradations Are increasing. Nevertheless, in a first phase of conception, theory

Linear elasticity of the laminated plates makes it possible to carry out the dimensioning of the structures Composites. Much work has been devoted to the development of theories

Of multilayer composite plates. These different theories range from a equidimensional theory, To the theory of Love-Kirchhoff. This latter model is Plates are thin. On the other hand, for thick plates or sandwiches, the effects of Transverse shearing become important and the Reissner-Mindlin theory is more appropriate. In this chapter, under the hypothesis of small perturbations (HPP), The linear elastic behavior equations of the composite plate theory Stratified by Love-Kirchhoff. In theory HPP, displacements and deformations remain Small.[1]

2.3Constitutive equations of the monolayer

2.3.1 Mechanical characteristics and modulus of elasticity

The determination of the moduli of elasticity of a unidirectional composite consists in finding the expressions of these modules as a function of the modulus of elasticity of the matrix and of the fiber (E_m, E_f), volume fraction of the matrix and fiber (V_m, V_f), (the Poisson coefficients (ν_m,ν_f), the fiber length, and so on. The solution to this problem is not simple and the solution is not unique. Nevertheless, there is a simplified approach to behavior Mechanics of the elementary cell of the material which provides practical expressions of the modules. [1]

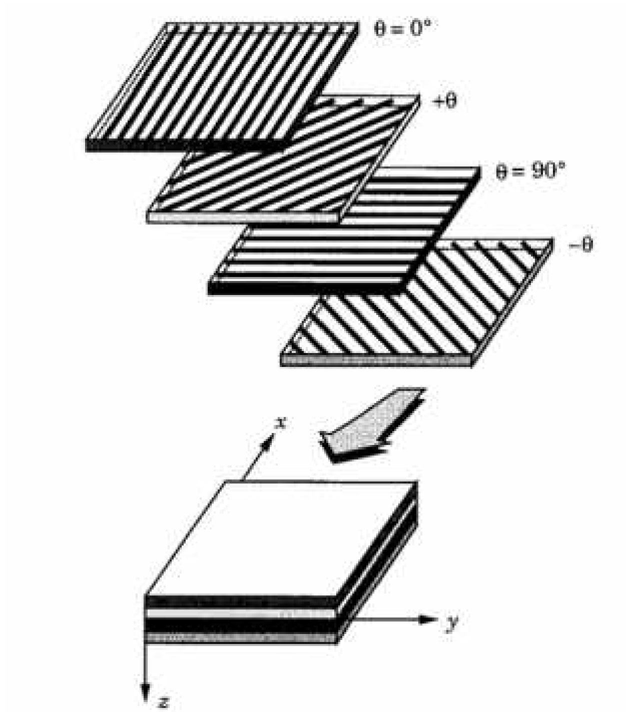


Figure 2.1 Laminate with different orientations of fiber. [6]

2.3.2 Young longitudinal modulus, E1

The longitudinal Young's modulus is determined in a longitudinal tensile test (Figure 2.2). The simplifying hypothesis is to assume uniform deformation in the fiber and in the matrix. This hypothesis leads to the following formula: [2]

$$E_1 = E_f V_f + E_m V_m \quad (1)$$

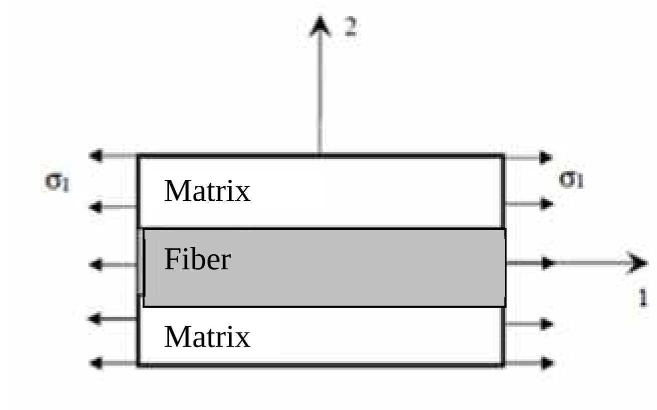


Figure2.2 Longitudinal tensile test

2.3.3 Young transversal modulus, E2

Transverse Young's modulus is determined in a transverse tensile test (Figure 2.3). In this test, it is assumed that the transverse stress is the same in the fiber and in the matrix. This hypothesis leads to the following formula:

$$E_2 = \frac{E_f E_m}{E_f V_m + E_m V_f} \quad (2)$$

Figure2.2 Longitudinal tensile test

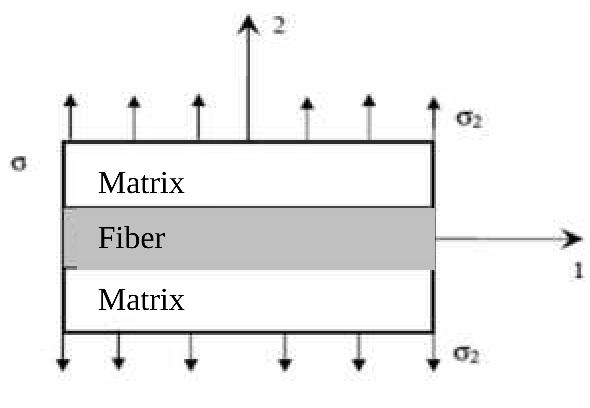


Figure 2.3 transversal tensile test

2.3.4 longitudinal Poisson coefficient

The longitudinal Poisson coefficient is determined in a tensile test longitudinal. Using the approach of the mechanical behavior of the material, the coefficient Of Poisson in the plane is given by the following formula:[2]

$$\nu_1 = \nu_f V_f + \nu_m V_m \quad (3)$$

2.3.5 Longitudinal shear modulus

The longitudinal shear modulus is determined in a shear test (Figure 2.4). To determine this module, the approach of Considers that the shear stresses in the fiber and in the matrix, are Equal. This hypothesis leads to the following formula:

$$G_{12} = \frac{G_f G_m}{G_f V_m + G_m V_f} \quad (4)$$

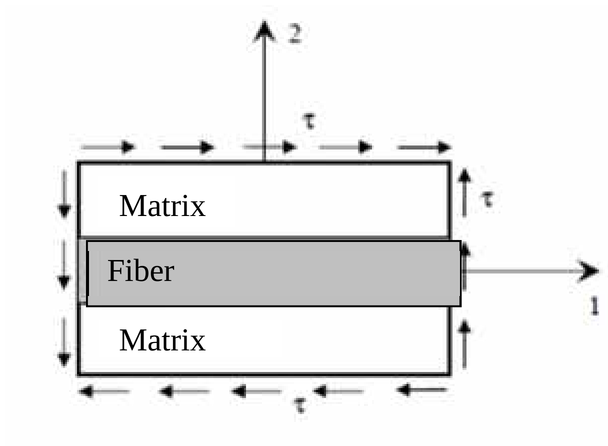


Figure 2.4 longitudinal shear test

2.4 Generalized Hooke's Law

The generalized Hooke law for anisotropic material under isothermal conditions is given according to one of the two forms:

$$\sigma_i = C_i \varepsilon_i \quad (5) \qquad \varepsilon_i = S_i \sigma_j \quad (6)$$

Where σ_{ij} and ε_{ij} are components of the stress and deformation in the material coordinate system (1, 2, 3). C_{ij} and S_{ij} are the stiffness and flexibility coefficients,[3] respectively. In matrix and explicit form we will have:

$$\{\sigma\} = [C]\{\varepsilon\} \quad (7)$$

$$\begin{Bmatrix} \sigma_1 \\ \sigma_2 \\ \sigma_3 \\ \sigma_4 \\ \sigma_5 \\ \sigma_6 \end{Bmatrix} = \begin{Bmatrix} C_1 & C_1 & C_1 & C_1 & C_1 & C_1 \\ C_2 & C_2 & C_2 & C_2 & C_2 & C_2 \\ C_3 & C_3 & C_3 & C_3 & C_3 & C_3 \\ C_4 & C_4 & C_4 & C_4 & C_4 & C_4 \\ C_5 & C_5 & C_5 & C_5 & C_5 & C_5 \\ C_6 & C_6 & C_6 & C_6 & C_6 & C_6 \end{Bmatrix} \begin{Bmatrix} \varepsilon_1 \\ \varepsilon_2 \\ \varepsilon_3 \\ \varepsilon_4 \\ \varepsilon_5 \\ \varepsilon_6 \end{Bmatrix} \quad (8)$$

The inverse form of the generalized Hooke law will be:

$$\{\mathcal{E}\} = [S]\{\sigma\} \tag{9}$$

$$\begin{Bmatrix} \mathcal{E}_1 \\ \mathcal{E}_2 \\ \mathcal{E}_3 \\ \mathcal{E}_4 \\ \mathcal{E}_5 \\ \mathcal{E}_6 \end{Bmatrix} = \begin{Bmatrix} S_1 & S_1 & S_1 & S_1 & S_1 & S_1 \\ S_2 & S_2 & S_2 & S_2 & S_2 & S_2 \\ S_3 & S_3 & S_3 & S_3 & S_3 & S_3 \\ S_4 & S_4 & S_4 & S_4 & S_4 & S_4 \\ S_5 & S_5 & S_5 & S_5 & S_5 & S_5 \\ S_6 & S_6 & S_6 & S_6 & S_6 & S_6 \end{Bmatrix} \begin{Bmatrix} \sigma_1 \\ \sigma_2 \\ \sigma_3 \\ \sigma_4 \\ \sigma_5 \\ \sigma_6 \end{Bmatrix} \tag{10}$$

The matrices C and S are called respectively, stiffness matrix and compliance matrix of the material. The relationship between the stiffness matrix and the compliance matrix is given by:

$$C = S^{-1} \tag{11}$$

In the most general case, the stiffness matrix and the compliance matrix are Each determined by 21 independent constants. This case corresponds to a material Possessing no property of symmetry. Such a material is called triclinic material. When a material has one or more planes of material symmetry, the number of Independent elastic constants can be reduced. For materials that have Single plane of symmetry, called monoclinic materials, there are only 13 parameters Independent, and for materials with three planes of symmetry perpendicular two by two, called orthotropic materials, the number of parameters of the material is reduced to 9 in the Three-dimensional cases. For an orthotropic material, the matrices of rigidity and compliance are written in the form. [3]

$$\begin{bmatrix} C_1 & C_1 & C_1 & 0 & 0 & 0 \\ C_2 & C_2 & C_2 & 0 & 0 & 0 \\ C_3 & C_3 & C_3 & 0 & 0 & 0 \\ 0 & 0 & 0 & C_4 & 0 & 0 \\ 0 & 0 & 0 & 0 & C_5 & 0 \\ 0 & 0 & 0 & 0 & 0 & C_6 \end{bmatrix} \qquad \begin{bmatrix} S_1 & S_1 & S_1 & 0 & 0 & 0 \\ S_2 & S_2 & S_2 & 0 & 0 & 0 \\ S_3 & S_3 & S_3 & 0 & 0 & 0 \\ 0 & 0 & 0 & S_4 & 0 & 0 \\ 0 & 0 & 0 & 0 & S_5 & 0 \\ 0 & 0 & 0 & 0 & 0 & S_6 \end{bmatrix}$$

The elastic behavior of an orthotropic composite material can be described by the 9 Independent modules:

- Young modulus: E_1, E_2, E_3 (E_L, E_T, E_T')
- Poisson coefficients : ν_1 , ν_1 ν_2 ν_{LT}, ν_{LT}', $\nu_{TT'}$
- Shear modulus: G_{21}, G_{13}, G_{23}(G_{LT}, G_{LT}', $G_{TT'}$

The constants of rigidity and compliance are linked to the moduli of elasticity by the relations the following. [3]

2.4.1 Constants of compliance

$$S_1 = \frac{\nu_1}{E_1} \quad , \quad S_1 = \frac{1}{E_1} \quad , S_1 = -\frac{\nu_1}{E_1}$$

$$S_2 = \frac{1}{E_2}, \quad S_2 = -\frac{\nu_2}{E_2} \quad , S_3 = \frac{1}{E_3}$$

$$S_1 = \frac{1}{G_2}, \quad S_5 = \frac{1}{G_1}, \quad S_6 = \frac{1}{G_1} \tag{13}$$

2.4.2 Constants of stifness

$$C_1 = \frac{1 - \nu_2 \nu_3}{E_2 E_3 \Delta} \qquad C_1 = \frac{\nu_1 + \nu_3 \nu_1}{E_1 E_3 \Delta} \qquad C_1 = \frac{\nu_1 + \nu_1 \nu_2}{E_1 E_2 \Delta}$$

$$C_2 = \frac{1 - \nu_1 \nu_3}{E_1 E_3 \Delta} \qquad C_2 = \frac{\nu_2 + \nu_2 \nu_1}{E_1 E_3 \Delta} \qquad C_3 = \frac{1 - \nu_1 \nu_2}{E_1 E_2 \Delta} \tag{14}$$

$$C_4 = G_2 \qquad C_5 = G_1 \qquad C_6 = G_1$$

With

$$\Delta = \frac{1 - \nu_1 \nu_2 - \nu_2 \nu_3 - \nu_3 \nu_1 - 2\nu_2 \nu_3 \nu_1}{E_1 E_2 E_3} \tag{15}$$

2.5 Failure Mechanics of composites

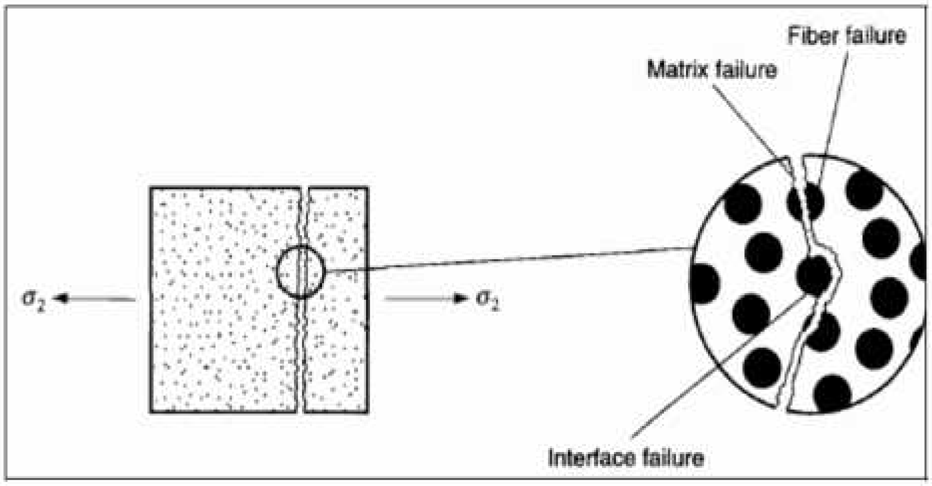


Figure 2.5 Failure in tension in the 2 directions. [7]

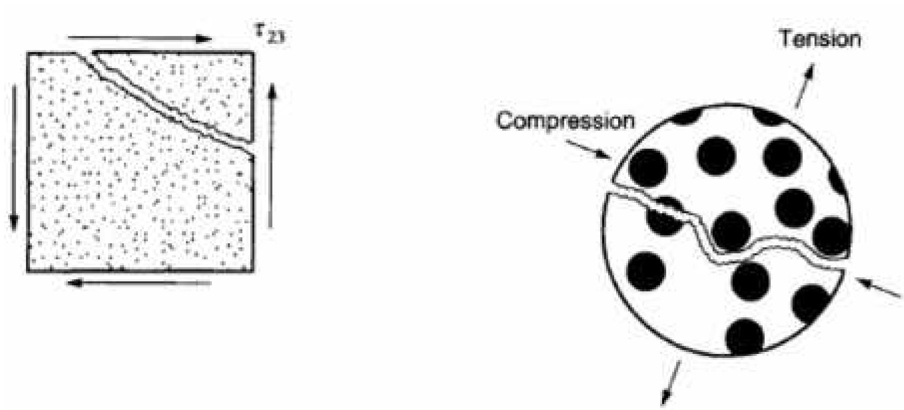


Figure 2.6 Failure in shear in the 2-3 planes. [7]

2.6 Mechanisms of degradation of a laminated structure

The laminated structures made from epoxy carbon composite materials by Example T300 / 914, IM6 / 914 and M55J / M18 consist of stacks of unidirectional sheets. These layers are formed of reinforcements made of long carbon fiber bonded by of the epoxy-type matrix. The role of the reinforcement is to ensure the strength function Efforts. The epoxy resin matrix, for its part, ensures the cohesion between the reinforcements to distribute the mechanical stresses. Structural parts are Made by stacking sheets by optimizing the directions of the reinforcements in function of the burdens they have to bear. Three main modes of degradation are observed. [4]

In the unidirectional layers (see Figure 2.7)

- micro-cracking of the la matrix parallel to the fiber

- degradation of the fiber interface
- breakage of fiber.

Laminated structures, which are by nature highly heterogeneous, are subject to the appearance of Multiple delamination near free edges and areas where a state of over-stress exists. The delamination mechanism is initiated by phenomena of microscopic damage. [4]

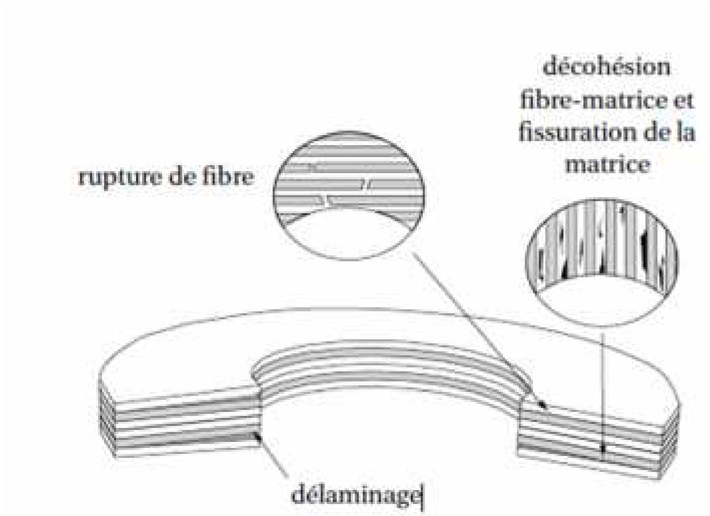


Figure 2.7 modes of rupture and delamination front.[8]

This method of degradation cannot be attributed entirely to deterioration of the inter-laminar connection because the delamination fronts can be transferred from one Interface to another during the evolution of degradations in the structure. In the following, the various criteria conventionally used to evaluate the domain in which no degradation of the layers is to be observed. These

Criteria are commonly used in industry and can be used to dimension parts Composites assuming linear elastic behavior of the layers.

2.7 Macro- mechanical Failure Theories in laminate

2.7.1 Failure criteria

The purpose of the failure criteria is to enable the designer to evaluate the mechanical strength of the laminates. In general, the mechanical strength of a material corresponds to an irreversible degradation: either to the actual failure of the material or to the limit of the elastic domain (Figure

In the case of composite materials, the boundary of the elastic domain is generally related to the appearance of microcracking: micro-break in the matrix, fiber breaks, fiber-matrix decohesion, etc. Once initiated, these microcracks generally remain localized, modifying only very gradually the rigidity of the material.

The criteria for defects are established in the case of a layer of a laminate and can be classified as follows:

• Maximum Stress criteria

• Maximum Strain criteria

• interactive criteria, often called energy criteria

2.7.2 Strength of lamina

Strength can be determined by the application of failure criteria, which are usually grouped into three classes: **limit criteria**, the simplest; **interactive criteria** which attempt to allow for the interaction of multiaxial stresses; and **hybrid criteria** which combine selected aspects of limit and interactive methods. In this text, we shall only discuss criteria that fit into the first two classes.

Table 2.1. Typical strength of unidirectional PMC laminates (= 0.5) (values in MPa).[5]

Materials	**Longitudinal**	**Longitudinal Compression**	**Transverse Tension**	**Transverse Compression**	**Shear**
Glass-polyester	650_950	600-900	20-25	90-120	45-60
Carbon - epoxy	850-1500	700-1200	35-45	130-190	60-75
Kevlar-epoxy	1100-1250	240_290	20-30	110-140	40-60

2.7.3 Limit Criteria

2.7.3.1 Maximum Stress Criterion:

The maximum stress criterion consists of five sub-criteria, or limits, one corresponding to the strength in each of the five fundamental failure modes. If any one of these limits is exceeded, by the corresponding stress expressed in the principal material axes, the material is deemed to have failed. In mathematical terms, we say that failure has occurred if. [5]

$$\sigma_1 \geq \sigma_{1T}\ 0 \quad \sigma_1 \leq \sigma_{1c}\ 0 \quad \sigma_2 \geq \sigma_{2T}\ 0 \quad \sigma_2 \leq \sigma_{2c}\ 0 \quad \tau_1 \geq \tau_1 \qquad (16)$$

or, (Recalling that a compressive stress is taken as negative so, for example, failure would occur if

σ = 0 MPa and σ_{2T} == −150MPa).

2.7.3.2 Maximum strain criterion

The maximum strain criterion merely substitutes strain for stress in the five sub-criteria. we Now say that failure has occurred if

$$\mathcal{E}_1 \geq \mathcal{E}_{1T} \text{ or } \mathcal{E}_1 \leq \mathcal{E}_{1c} \text{ or } \mathcal{E}_2 \geq \mathcal{E}_{2T}\ 0 \quad \mathcal{E}_2 \leq \mathcal{E}_{2c}\ 0 \quad \gamma_1 \geq \gamma_1 \qquad (17)$$

As when calculating stiffness, it is important that we can deal with the situation in which the fiber are not aligned with the applied stresses. We illustrate this by considering the simple case of a single stress $\sigma_{X,}$ inclined at an angle θ *to* the fiber (Table 2.1.). we now use equations. [6]

$$\sigma_1 = T\sigma_X$$

And $\mathcal{E}_1 = T\mathcal{E}_X$ to obtain the stresses in the principal material directions. Putting

$$\sigma_y = \tau_X = 0$$

In those equations, we obtain.

$$\sigma_1 = \sigma_x \cos^2\theta,\ \sigma_2 = \sigma_x \sin^2\theta,\ \tau_1 = -\sigma_x \sin\theta\cos\theta \qquad (18)$$

We then apply equations (16) to determine whether failure has occurred. We are seeking the value of axe to cause failure and we see from equation (18) that there are three possible results

$\sigma_X = \sigma_{1T} / \cos^2\theta$ Fiber failure (19)

$\sigma_x = \sigma_{2T} / \sin^2\theta$_transverse failure (20)

$\sigma_x = -\tau_1 / \sin\theta\cos\theta$ _ Shear failure (21)

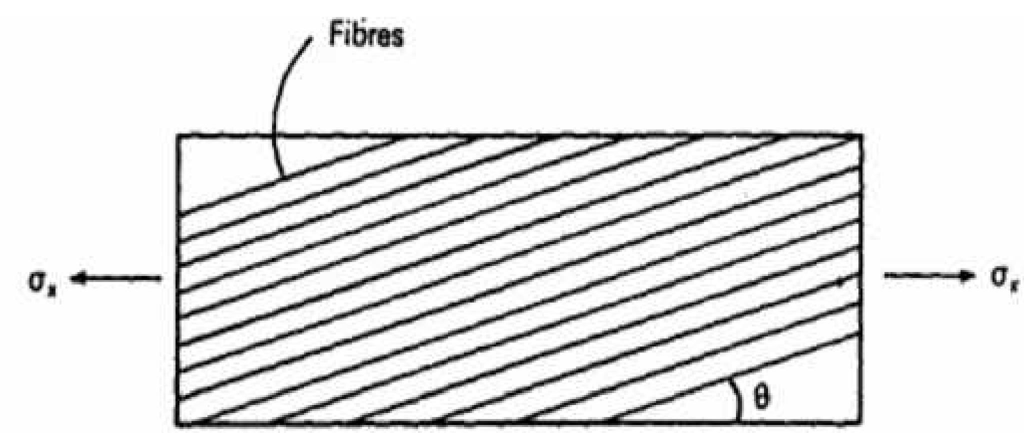


Figure 2.8 Uniaxial stresses Inclined at angle to the fiber of unidirectional composites. [9]

The effect on the value of $\sigma_x$at failure as $\theta$is varied as illustrated in Figure. We see that Each mode of failure is represented by a separate curve. Fibre failure is most likely when θ is small, transverse (either matrix or interface) failure is whenθ approaches 90 °, and shear failure At intermediate angles.

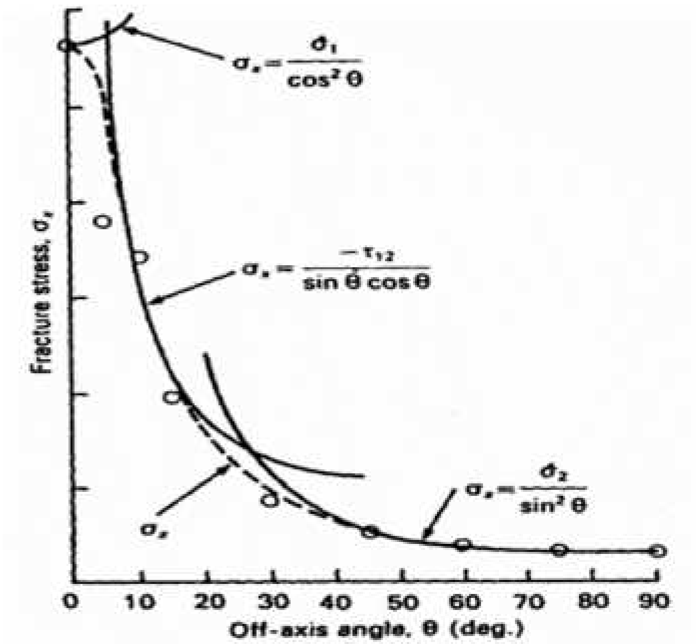


Figure 2.9 variation with θ of σ_x at failure: full line -maximum stress limit criterion dotted line-Tsai hill interactive criterion. [10]

2.7.4 Interactive criteria

2.7.4.1 Tsai-Hill Theory

The Tsai-Hill criterion was developed from Hill's anisotropic failure criterion which, in turn, can be traced back to the Von Mises yield criterion. In its most general form the Tsai-Hill criterion Defines failure as. [8]

$$\left(\frac{\sigma_1}{\sigma_1}\right)^2 - \frac{\sigma_1\sigma_2}{\sigma_1^{\,2}} + \left(\frac{\sigma_2}{\sigma_2}\right)^2 + \left(\frac{\tau_1}{\tau_1}\right) \geq 1 \qquad (22)$$

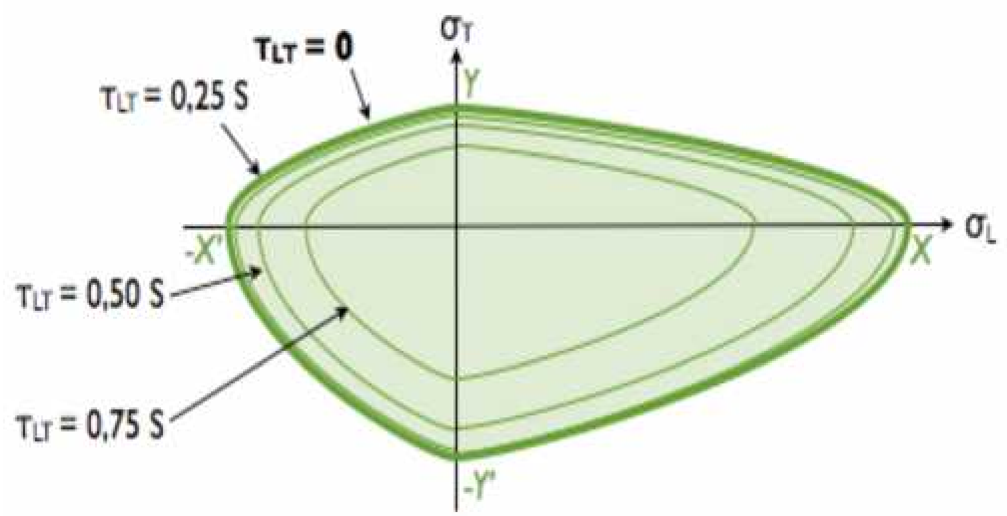


Figure 2.10 The domain of elasticity obtained by the Tsai-hill criterion. [11]

The values of strength used in equation (22) are chosen to correspond to the nature of $\sigma_1$and σ_2. So, if $\sigma_1$is tensile $\sigma_{1T}$is used, if $\sigma_2$is compressive σ_{2C}would be used, and so

As with the limit criteria we are interested in the case of off-axis loading, i.e. stress and fibres not aligned. To illustrate this, we again take the simple case of a single stress $\sigma_x$acting at $\theta$to the fibres. Substituting the stresses of equation (20) in equation (21) g1ives, at failure

$$\left(\frac{\sigma_x \cos^2\theta}{\sigma_1}\right)^2 - \frac{{\sigma_x}^2 \cos^2\theta \sin^2\theta}{{\sigma_1}^2} + \left(\frac{\sigma_X \sin^2\theta}{\sigma_2}\right)^2 + \left(\frac{\sigma_X \sin\theta\cos\theta}{\tau_1}\right)^2 = 1 \tag{23}$$

2.7.4.2 Tsai-Wu Theory

The von Mises criterion, introduced in strength-of-materials courses for studying yielding of metals, can be written as

$$\frac{1}{2}\left(\frac{1}{\sigma^Y}\right)^2[(\sigma_1-\sigma_2)^2+(\sigma_1+\sigma_3)^2+(\sigma_2-\sigma_3)^2] \quad (24)$$

where σ^Y is the yield stress of the metal and σ_1, σ_2 and σ_3 are the principal stress. This equation (24) is of the form,

$$F(\sigma_1,\sigma_2,\sigma_3) = 1 \quad (25)$$

According to the von Mises criterion, if,

$$F(\sigma_1,\sigma_2,\sigma_3) < 1 \quad (26)$$

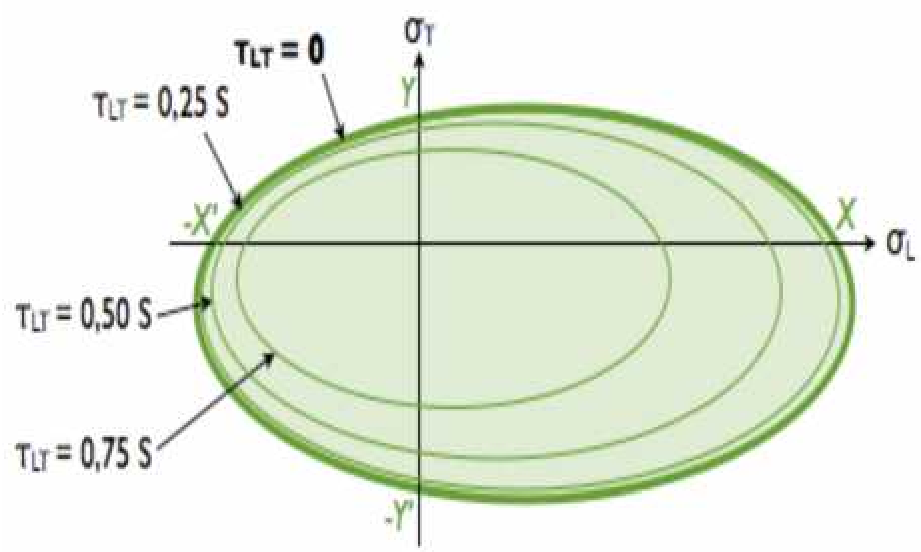


Figure 2.11 The domain of elasticity obtained by the Tsai-wu criterion. [11]

then the material has not yielded. Equation (24) represents the well-known von Mises ellipsoid and thus a surface in $\sigma_1, \sigma_2, \sigma_3$, principal stress space, and equation (26) represents the volume inside this surface. Because rolled metals have slightly different properties in the roll direction than in the other two perpendicular directions, Hill (see Suggested Readings) assumed that the yield criterion for these orthotropic metals was of the form,

$$F(\sigma_1-\sigma_2)^2+G(\sigma_1-\sigma_3)^2+H(\sigma_2-\sigma_3)^2+2L\tau_1^2+2M\tau_1^2+2N\tau_2^2 \quad (27)$$

The constants F, G, H, and so forth, are related to the yield stresses in the different directions, like σ^Y in equation (24.), and either the 1, 2, or 3 direction is aligned with the roll direction. This view of a failure criterion can be extended to composite materials, which are, of course, orthotropic in the principal material coordinate system, by assuming an equation of the form,

$$F(\sigma_1, \sigma_2, \sigma_3, \tau_2 , \tau_1 , \tau_1) = 1 \qquad (28)$$

can be used to represent the failure condition of a composite, while the condition of no failure is Given by

$$F(\sigma_1, \sigma_2, \sigma_3, \tau_2 , \tau_1 , \tau_1) < 1 \qquad (29)$$

For a state of plane stress, if the power of the stress components is maintained at 2, as in equations (24) and (27), the most general form of *F* is

$$F(\sigma_1, \sigma_2, \sigma_3) = F_1\sigma_1 + F_2\sigma_2 + F_6\tau_1 + F_1\ \sigma_1^2 + F_2\ \sigma_2^2 + F_6\ \tau_1^2 + 2F_1\ \sigma_1\sigma_2 + 2F_1\ \sigma_1\tau_1 + 2F_2\ \sigma_2\tau_1 \qquad (30)$$

where in the above $F_1, F_2, F_6, F_1, F_2, F_6, F_1, F_1$, and F_2 are constants. All stress components are represented to the first and second powers, and all products of the stresses are represented.

The constants F_{12}, F_{16}, and F_{26} will be referred to as the interaction constants, and the magnitude

of their value, will dictate the degree of interaction among stress components. Interaction between

the normal stresses σ_1 and σ_2 and the shear stress τ_{12} is included by virtue of constants F_{16} and F_{26}, and interaction between the normal stress components σ_1 and σ_2 is included with the F_{12} term. With the above considerations, the failure criterion that we are seeking takes the form. [9]

$$F_1\sigma_1 + F_2\sigma_2 + F_6\tau_1 + F_1\ \sigma_1^2 + F_2\ \sigma_2^2 + F_6\ \tau_1^2 + 2F_1\ \sigma_1\sigma_2 + 2F_1\ \sigma_1\tau_1 + 2F_2\ \sigma_2\tau_1 = 1 \qquad (31)$$

and the condition of no failure is given by the inequality

$$F_1\sigma_1 + F_2\sigma_2 + F_6\tau_1 + F_1\ \sigma_1^2 + F_2\ \sigma_2^2 + F_6\ \tau_1^2 + 2F_1\ \sigma_1\sigma_2 + 2F_1\ \sigma_1\sigma_2 + 2F_2\ \sigma_2\ \tau_1 < 1 \qquad (32)$$

Where $F_6 = F_{16} = F_{26} = 0$

For this reduced form of the Tsai-Wu criterion to yield the same result as the von Mises criterion It must be That:

$$2F_1 = -\left(\frac{1}{\sigma^Y}\right)^2 \qquad (33)$$

This will be the case if in the Tsai-Wu criterion F_1 is given by

$$F_1 = -\frac{1}{2}\sqrt{F_1\ F_2} \quad (34)$$

Using this relation for composite materials, the Tsai-Wu criterion becomes:

$$F_1\sigma_1 + F_2\sigma_2 + F_1\ \sigma_1^2 + F_2\ \sigma_2^2 + F_6\ \tau_1^2\ - \sqrt{F_1\ F_2}\,\sigma_1\sigma_2 = 1 \quad (35)$$

2.8 Macro-level Failure Mechanism

The macro-level mechanisms are laminate level mechanisms. Here, we are addressing the. [10] delamination. It is seen that the adjacent layers are bonded together by a thin layer of resin between them. This interface layer transfers the displacement and force from one layer to another layer. When this interface layer weakens or damages completely, it causes the adjacent layers to separate. This mode of failure is called delamination. It is shown in Figure (2.5)

Delamination reduces the strength and stiffness and thus limits the life of a structure. Further, it causes stress concentration in load bearing plies and a local instability leading to a further growth of delamination which results in a compressive failure of the laminate. In these two cases delamination leads to a redistribution of structural load paths which, in turn, precipitates structural failure. Hence, delamination indirectly affects the final failure of the structure thus affecting its life. Therefore, delamination is known as the most prevalent life limiting damage growth mode.

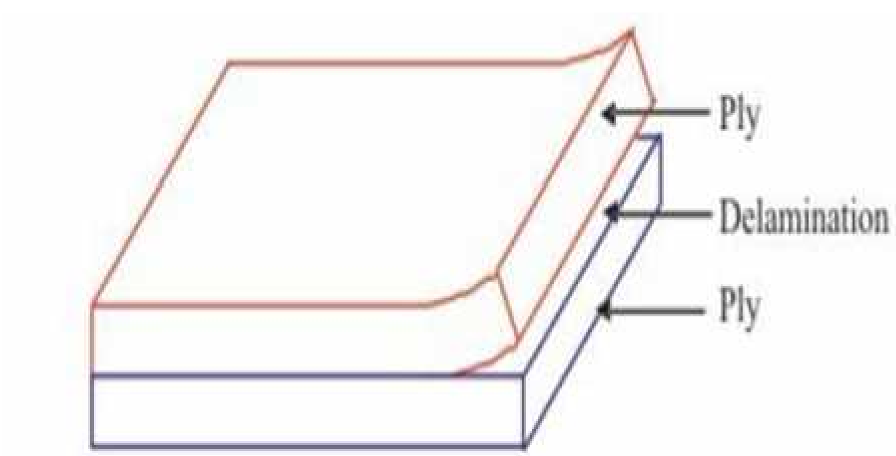


Figure 2.12 Macro -level damage mechanism (delamination).[12]

2.8.1 Causes of Delamination:

Delamination can occur due to variety of reasons. The situations which can lead to delamination initiation and its growth are explained below.

2.8.1.1 Manufacturing Defects

This is the most common reason for existence of delamination in a laminate. Improper laying of laminae, insufficient curing temperature; pressure and duration of curing, air pockets and inclusions are some of the reasons which lead the manufacturing defects causing delamination.

2.8.1.2 Loading Generating Transverse Stresses

The interface is weaker in transverse strength as compared to the layers. Hence, its failure is dominated by the transverse stresses. The interface generally fails under tensile load applied normal to it (see Figure 2.14). Also, the delamination can take place due to compressive stresses in its in-plane direction causing buckling, which in turn, causes delamination.

The in-plane loads applied to angle ply laminate can cause delamination in it. This is because the bending-stretching coupling can give rise to transverse stresses in the interface. A schematic illustration of how axial tensile loading of angle ply laminates cause rotation of the plies is shown in Figure (2.14). This rotation of the plies generates the interlaminar shear stresses, which is one of the Crucial factors in delamination.

Note: The Inter-laminar stresses are the stresses in the interface between two adjacent layers. The existence to these stresses is shown in various references. Further, these stresses can be very high locally depending upon various situations. We will also see the existence of these stresses in a later chapter.

2.8.1.3 Laminate Geometry

a) The free edges of the laminate, have very high transverse normal σ_x and

Shear τ_x τ_x stresses.

It is shown that significant interlaminar stresses are induced in regions near the laminate free edges. Interlaminar stresses near the free edges can be controlled to an extent through the choice of materials, fibre orientations, stacking sequence, layer thickness and the use of functionally graded materials. However, when free edges are present, interlaminar stresses can be completely eliminated through the use of a homogeneous material, locally.

The delamination shown in Figure, infect, is an edge delamination. [10]

locations are potential zones for delamination initiation. Typical doublers are shown in Figure (2.14).

2.9 Suppression of Delamination:

Several possible design changes are suggested for delaying/suppressing the onset and growth of delamination. The primary cause of delamination is the low interlaminar fracture toughness. This is due to brittle

nature of most resins (epoxy) used as matrix material, which have low mode I fracture toughness. The suggested models for improving this property are

- Adding thermoplastics, interleafing soft and hard layers, increasing length of cross-links
- Adding second phase materials to matrix like rubber; chopped fibre, fibrils, etc.
- Through thickness reinforcement by 3D braiding or stitching

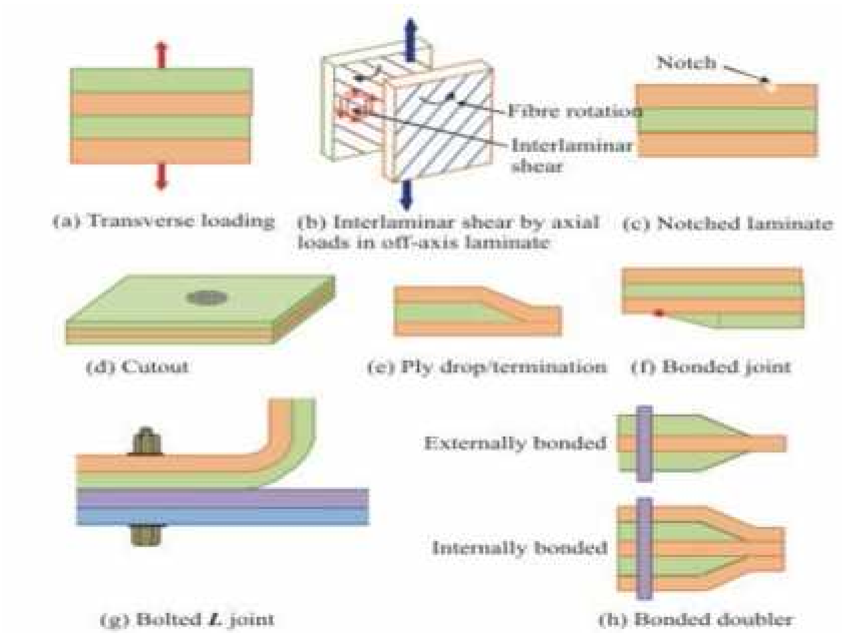


Figure 2.13 situations conducive delamination. [12]

2.10 Mechanism of fracture

Fracture is a form of failure where the material separates in pieces due to stress, at temperatures below the melting point. The fracture is termed ductile or brittle depending on whether the elongation is large or small.

Steps in fracture (response to stress):

- Crack formation
- Crack propagation

Ductile vs. brittle fracture. [11]

Table .2.2 difference strength between ductile and brittle materials

	Ductile	**Brittle**
Deformation	extensive	little
crack propagation	slow, needs stress	fast
type of materials	most metals (not too cold)	ceramics, ice, cold metals
Warning	permanent elongation	none
strain energy	higher	lower
Fracture surface	rough	smoother
Necking	yes	no

2.10.1Ductile Fracture

Stages of ductile fracture

- Initial necking
- Small cavity formation (microvoids)
- void growth (ellipsoid) by coalescence into a crack
- fast crack propagation around neck. Shear traine at 45^o
- final shear fracture (cup and cone)

The interior surface is fibrous, irregular, which signify plastic deformation.

2.10.2 Brittle Fracture

There is no appreciable deformation, and crack propagation is very fast. In most brittle materials, crack propagation (by bond breaking) is along specific crystallographic planes (cleavage planes). This type of fracture is trans granular (through grains) producing grainy texture (or faceted texture) when cleavage direction changes from grain to grain. In some materials, fracture is intergranular.

2.10.3 Principles of Fracture Mechanics

Fracture occurs due to stress concentration at flaws, like surface scratches, voids, etc. If a is the length of the void and ρ the radius of curvature, the enhanced stress near the flaw is:

$$\sigma_m \approx 2\,\sigma_c (a/\rho)^{\frac{1}{2}} \qquad (36)$$

where σ_c is the applied macroscopic stress Note that a is 1/2 the length of the flaw, not the full length for an internal flaw, but the full length for a surface flaw. The stress concentration factor is:

$$K_1 = \sigma_m/\sigma_c \approx 2\,(a/\rho)^{\frac{1}{2}} \qquad (37)$$

Because of this enhancement, flaws with small radius of curvature are called stress raisers.

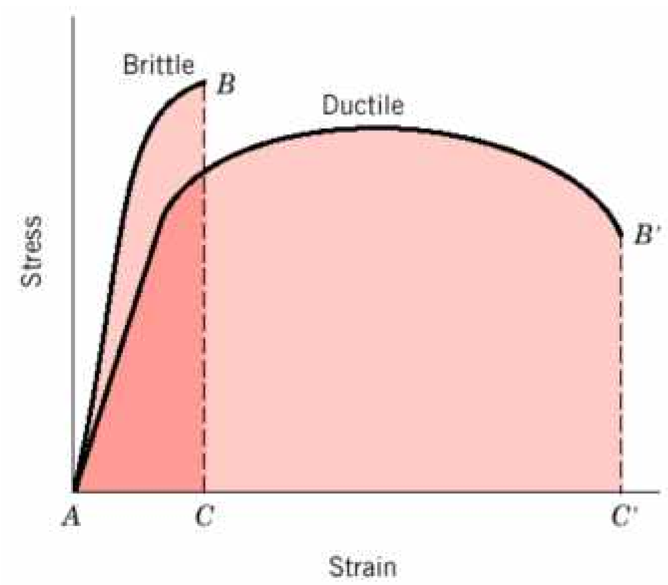


Figure 2.14 graphs of stress-strain for two materials. [13]

a- Ductile materials - extensive plastic deformation and energy absorption "toughness") before fracture. Ductile materials can be classified into various classifications; 1- Very ductile, soft metals (e.g. P_b, Au) at room temperature, other metals, polymers, glasses at high temperature.,

2- Moderately ductile fracture, typical for ductile metals, 3- Brittle fracture, cold metals, ceramics.

b- Brittle materials – has a little plastic deformation and low energy absorption before fracture

2.11 Fracture modes

In fracture mechanics, a distinction is made between different modes of fracture propagation, depending on the loading situation. There are three different fractures modes the stress intensity factor is usually given a subscript to denote the corresponding load and fracture mode (K , K , K).

Mode 1, as shown **in figure,** is caused from tensile stress normal to the plane of the crack these tensile stresses are in the context of adhesive bonding referred to as peel stresses and are highly undesirable.[12]

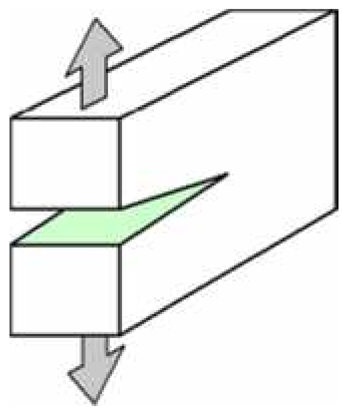


Figure 2.15 Mode1-opening. [14]

Fracture Mode 2, as shown in figure 2.17 is caused from in plane shear stress. This is the optimal fracture mode for bended joints in terms of load capacity. It is therefore desirable to design the joints so they fracture in pure Mode2.

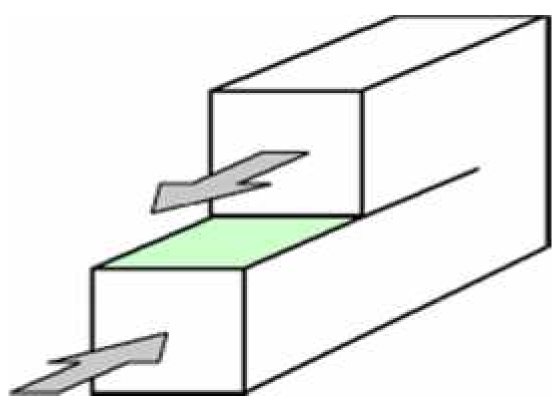


Figure 2.16 Mode 2 in plane Shear. [14]

Fracture Mode 3, as shown in figure, is caused from out of plane shear stress.

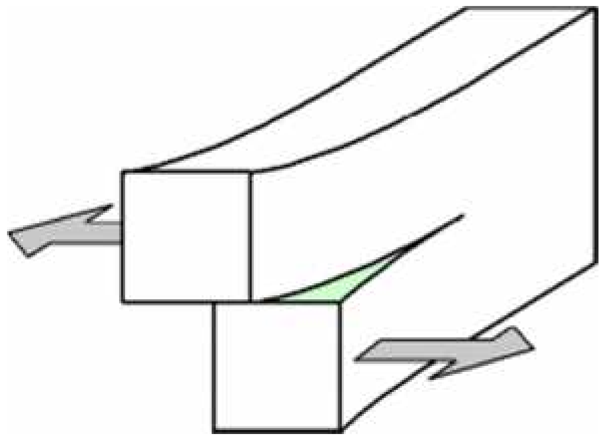


Figure 2.17 Mode -3 out of -plane shear. [14]

Figure 2.20 through -thickness crack in an infinite plate subject to a remote tensile stress.in practical terms. ‘infinite ‘means that the width of the plate is >> 2a. [15]

2.13 The stress intensity Approach

Figure (2.22) schematically shows an element near the tip of a crack in an elastic material, together with the in-plane stresses on this element. Note that each stress component is proportional to a single constant KI. If this constant is known, the entire stress distribution at the crack tip can be computed with the equations in Figure (2.22). This constant, which is called the stress-intensity factor, completely characterizes the crack-tip conditions in a linear elastic material. (The meaning of the subscript on *K)* If one assumes that the material fails locally at some critical combination of stress and strain, then it follows that fracture must occur at a critical stress intensityk_{I_I} . Thus, K_{I_I} is an alternate measure of fracture toughness. For the plate illustrated in Figure (2.21), the stress-intensity factor is given by. [13]

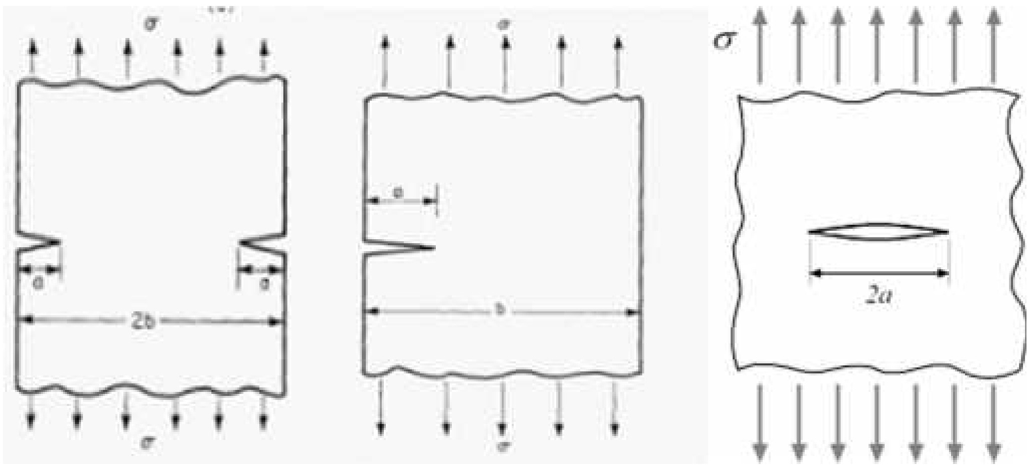
$$KI= \sigma\sqrt{\pi} \tag{40}$$

Equation gives a good accuracy for geometries where the crack length is small compared to the plates width ($a << \omega$)

For different types of geometries, it is in general convenient to express $k$as

$$k = FS\sqrt{\pi a} \tag{41}$$

Where the factor F includes the effects of geometry .as finite width, and loading configuration Solutions for F exist for a wide variety of configurations. Three of the most common, obtained From the “the stress analysis of cracks handbook «by Tada, Paris and Irwin are listed below



(a) (b) (c)

Figure 2.18 stress intensity factors for three cases of cracked plates under tension. [16]

$$\text{c)}.F = \frac{1-0.5\alpha+0.3 \quad \alpha^2}{\sqrt{1-\alpha}} \tag{42}$$

$$\text{b)}. = (1 + 0.1222\cos\frac{4\pi}{2})\sqrt{\frac{2}{\pi}}\tan\frac{\pi}{2} \tag{43}$$

$$\text{a)}.F = 0.265(1-\alpha)^4 + \frac{0.8 \quad +0.2 \quad \alpha}{(1-\sigma)^{\frac{3}{2}}} \tag{44}$$

2.15 Conclusion

This chapter has allowed us to understand the mechanical behaviour of composite laminate through these properties that are the young modulus and the shear modulus, subsequently our study based on failure mechanism with different criterion which are the Tsai-Wu and Tsai-hill.

The major problem in the composite is the delamination which caused by many factors which the defect of after measurement and cut, the defect in modelling .to understand well these phenomena we have chosen the fracture mechanism which is the separation of the parts due to a stress. many criteria are applied to determine some factor as the energy criterion which is a measure of the fracture toughness, and the stress intensity factor which who predict for the fracture. we also talking about the fracture modes and the crack chapes which plays an important role to determine many essential factors. [15]

Chapter III
Experimental Results

3.1Introduction

We have seen previously that the composite and laminate structures have a higher characteristic performance and to determine those characteristics there is some steps to follow and experiments to perform. In this chapter, we are going to see the behavior about the specimens (Carbon/epoxy) and (glass/ epoxy) used tensile test and demonstration of the experiments made by Abaqus software

3.2The aim this work

The aim of our work in this chapter is to compare and calculate experimentally the behaviour of the specimens glass/Epoxy -Carbone/EPOXY with different crack length and angles and how the specimens can resist of the tensile

We will talk about ZWICK ROELL, machine which can give us the variation of the force and deformation……. etc.

So, in our experiences we have three cases to calculate;

- without crack (glass /epoxy), and (Carbone/epoxy)
- with different angle (30°-45°-60°-90°) and crack length (15mm)
- with different crack size (3,6,9,12,15) mm and angle (45°)

3.3 Overview about the machine of traction (ZWIKC ROELL)

3.3.1 Description

This machine of traction electro mechanic is equipped of a training by ball screw and it is static Machine and for testing; tensile tests, compression and cycling …………etc. available in version: 300,400,600,1200 and 2000KN (30-200 tones).

The testing machines of materials are characterized by a large measuring range. small efforts can thus be determined accurately without modification of the machine.

The big race crosses and small footprint compared ensure easy mounting of test specimens And increased user comfort over a wide range of specimens.

Screw without pre-stress balls to low maintenance game ball ensures maximum long term measurement accuracy in the direction of tension and compression part test provides great strength and rigidity.

Standard tests with the test software test expert being reduced for use of type button modularity materials offering many prospects (e.g. mounting of different gauges, jaws and other testing tools.

Slide systems or screws for a very simple adaptation to other test tools (eg mounting a calibration slide) Adapts to the specific demands of the customers (dimensions of the work space, test speed, test software).

3.4 Use of the machine

- Maintenance/checks
- Repair/part substation
- Software
- Transfer Machines
- Contractual tests
- Calibration

3.5 Material tested by machine zwick roell

- Thermoplastic and thermosetting materials.
- Rubbers and elastomers.
- Rubbers and elastomers.
- Fiber reinforced composites.
- Flexible cellular plastics.
- Thin sheeting and plastic film. _ Adhesives and sealing.

Figure. 3 1 The machine of tensile test ZWICK ROELL

3.6 Tensile test

A tensile test is a physical experience which can allow to determine the elastic behavior of a material and measure the degree of rupture resistance of the material and in the case of uniaxial stress and it can also give the mechanical performance and some characteristics.

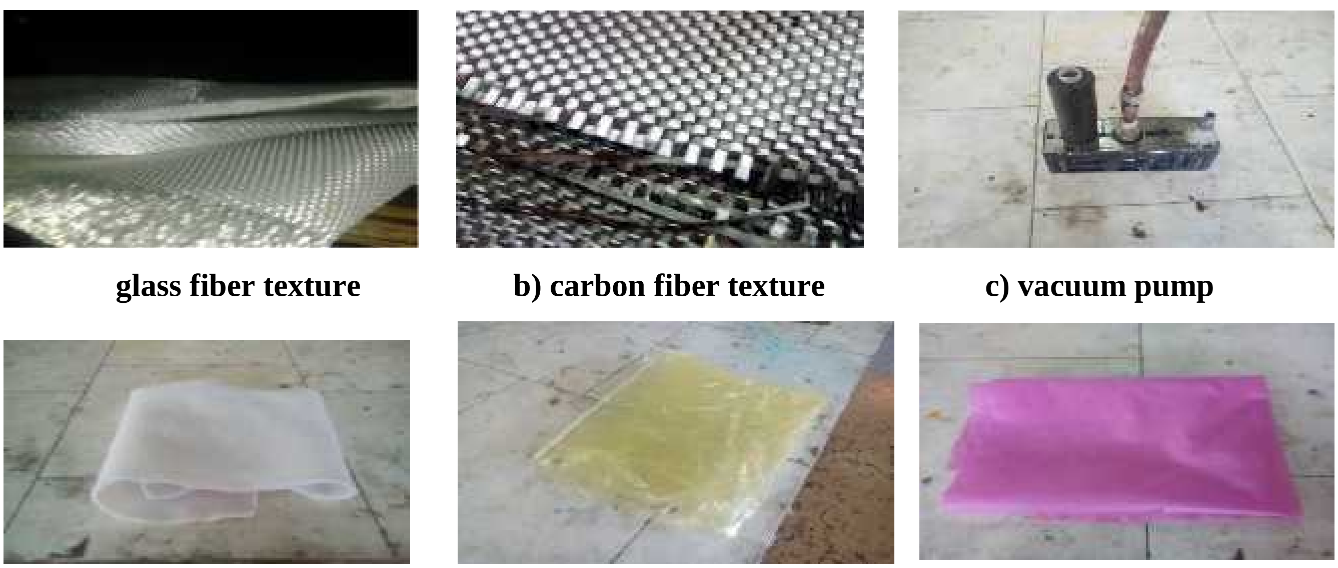
3.7 Material and geometry of Specimen used

The specimen used in this test is plates of glass/epoxy and Carbone/epoxy with specific geometry:

With length l= 200mm, width w= 30mm and depth b= 2mm.

- Glass/epoxy specimen produced by glass fiber 8 layups with orientation angle [0/90^{o}].
- Carbone/epoxy specimen produced by Carbone fiber 8layups with orientation angle [0/90^{o}].

We have in following figure epoxy with hardener matrix and glass fiber /Carbone fiber with orientation angle [0/90^{o}] and vacuum pump to absorb air and peeling film to absorb epoxy also use a pumping felt that decrease a temperature and special plastic called tarpaulin to isolate it from environment.



glass fiber texture **b) carbon fiber texture** **c) vacuum pump**

d) Pumping felt **e) Tarpaulin** **f) peeling film**

Figure .3.2 materials used for preparation specimen

Figure .3. 3 resin and hardener

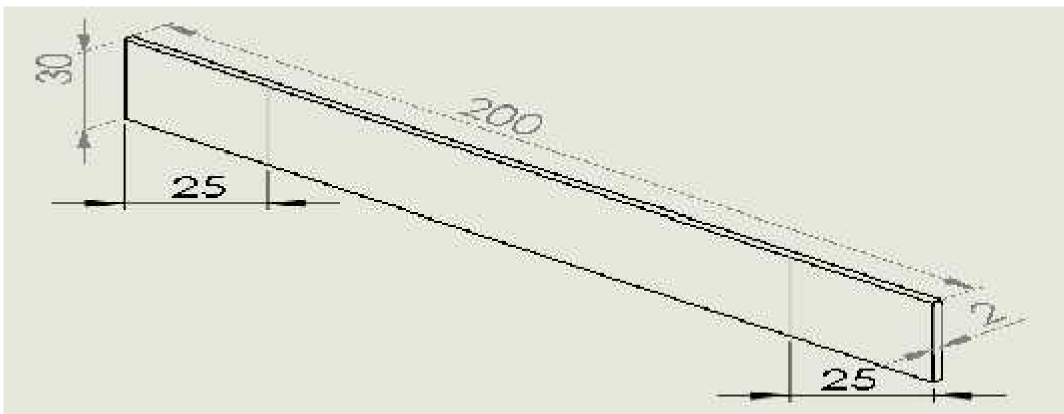


Figure. 3. 4 Geometry and dimension of specimen

3.8 Specimen preparation

We start with cleaned up the place of work and preparation of material needed for this process

First, Measure and cut the material's plies as we need (8 layups of each material) Mix the epoxy with hardener respecting the ingredients (hardener must be 15% of the epoxy)

On a clean plan, we put the mixed epoxy then we put the ply then the epoxy till we reach to the 8^{th} ply Then as a final often we put the epoxy on that last 8^{th} ply

We cover this obtained material by an epoxy absorber called peeling film and we cover that using another cover called pumping felt that decreases temperature

We cover all that using a special plastic called Tarpaulin material for this work to isolate it from the environment conditions We use the 'vacuum pump" to absorb air and create external pressure on the produced material to steak together

We left that from 7 to 8 hours to obtain the final form of our composite material

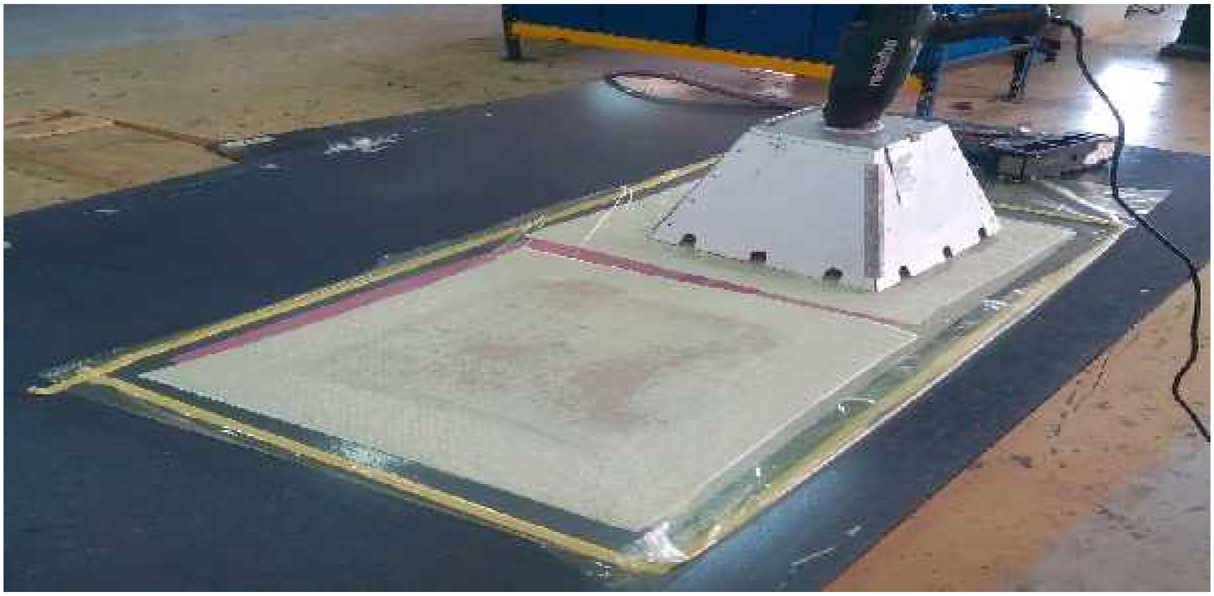


Figure 3.5the two specimens carbon/epoxy and glass/epoxy preparation

After we obtain that material we need to cut it into small measured specimens to be submitted to a tensile test.

Before we bring those specimens to tensile test machine (Zwick Roell) our work is to observe and calculate cracked specimens so that we scarf them into different lengths and angles

Figure .3.6simple specimens made of glass /epoxy after preparation

3.9 Propriety of Materials

3.9.1 Matrix

Table. 3.1 the epoxy resin properties

Properties	**RESINE EPOCAST 50_A1**
Color	straw
Density (g/cm^3)	1.21
Viscosity (mg/cm. s)	77.7
Temperature of life has 25c° and without opening container (less)	12

3.9.2 **The hardener**

The hardener used is reference hardener 964 it is compatible with EPOCAST Resin 50_A1

Table. 3.2 the hardener properties

Properties	**HARDENER 964**
Color	Orange Gold
Density (g/cm^3)	1.05
Viscosity (mg/cm. s	4000
Temperature of life has 25 c ° and without opening of container (less)	12

3.9.3 **Reinforcements**

The reinforcements used are carbon fabrics and bidirectional glass (see figure), these characteristics are mentioned in the tables below:

Table. 3.3 general property of carbon fiber

	Carbon HR
Density(kg/m*m*m)	1750
Modulus of longitudinal elasticity MPa	230000
Shear Modulus (MPa)	50000
Poisson v coefficient	0.3
Tensile Breaking Stress (MPa)	3200
Elongation at rupture (%)	1.3
Coefficient of thermal expansion	0.02
Temperature limit	>1500

Table. 3.4 general property of glass fiber

	Glass R
Density (kg/m*m*m)	2500
Longitudinal elasticity Modulus	86000
Shear Modulus (MPA)	36000
Poisson coefficient v	0.2
Tensile Breaking Stress (MPA)	3200
Elongation at rupture (%)	4
Coefficient of thermal expansion	0.3
Temperature limit	800

3.10 simple specimen

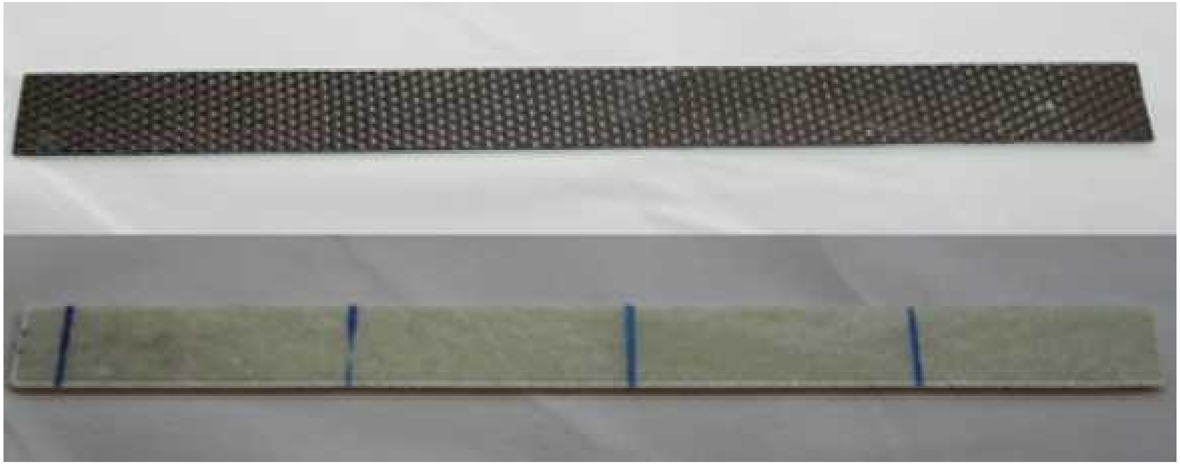


Figure. 3.7 simple specimen made of carbon fiber and glass fiber without crack

3.11 Specimens of glass fiber with crack (V Form)

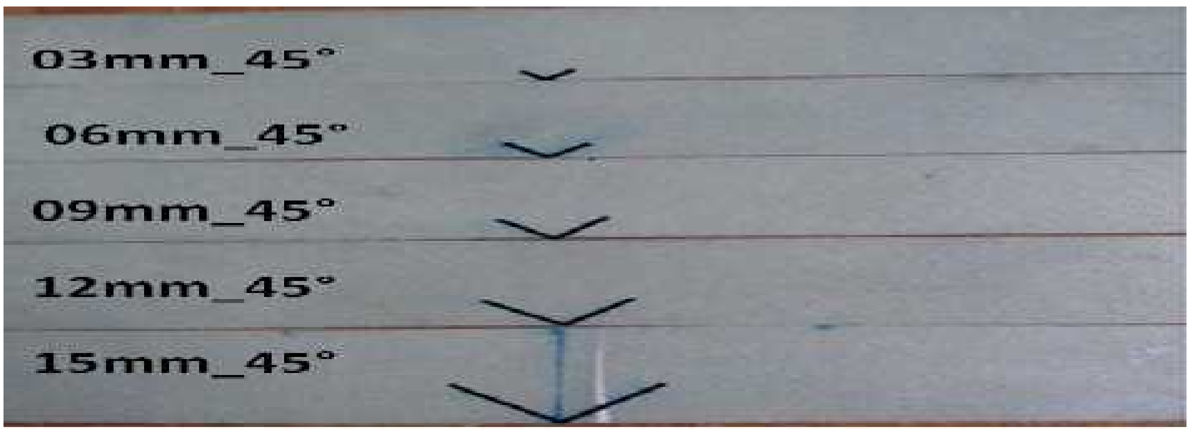


Figure .3.6 the specimen glass/epoxy with crack angle (45°)

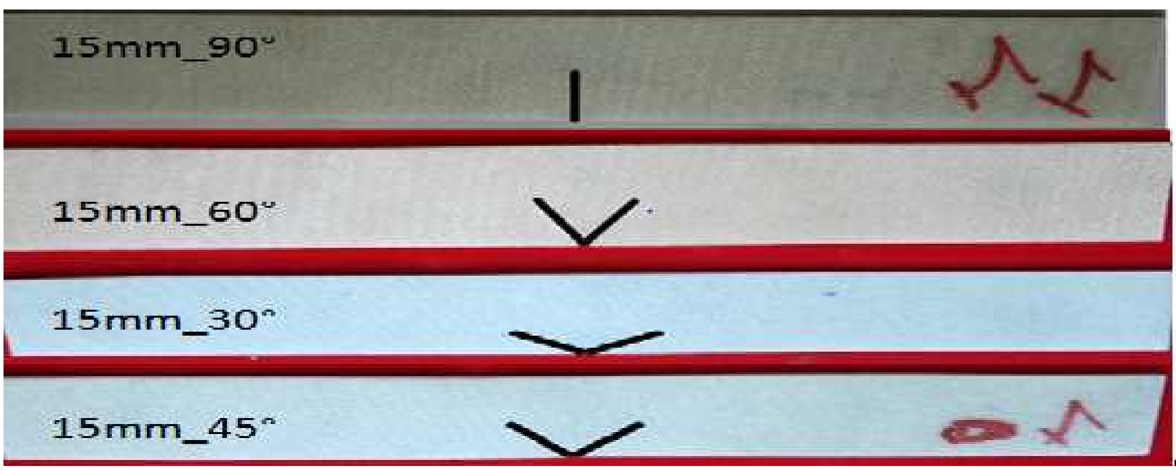


Figure .3.8 the specimen glass/epoxy with crack angle

3.12 Specimens Carbone fiber with crack (V Form)

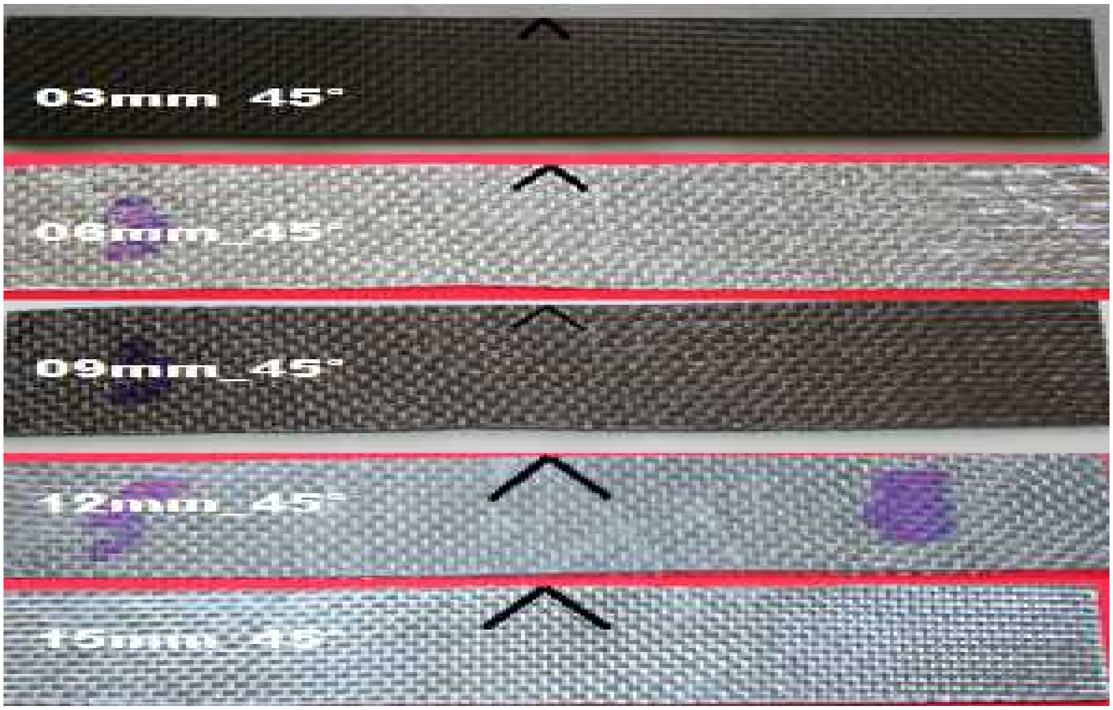


Figure. 3.9 the specimens carbon with different crack

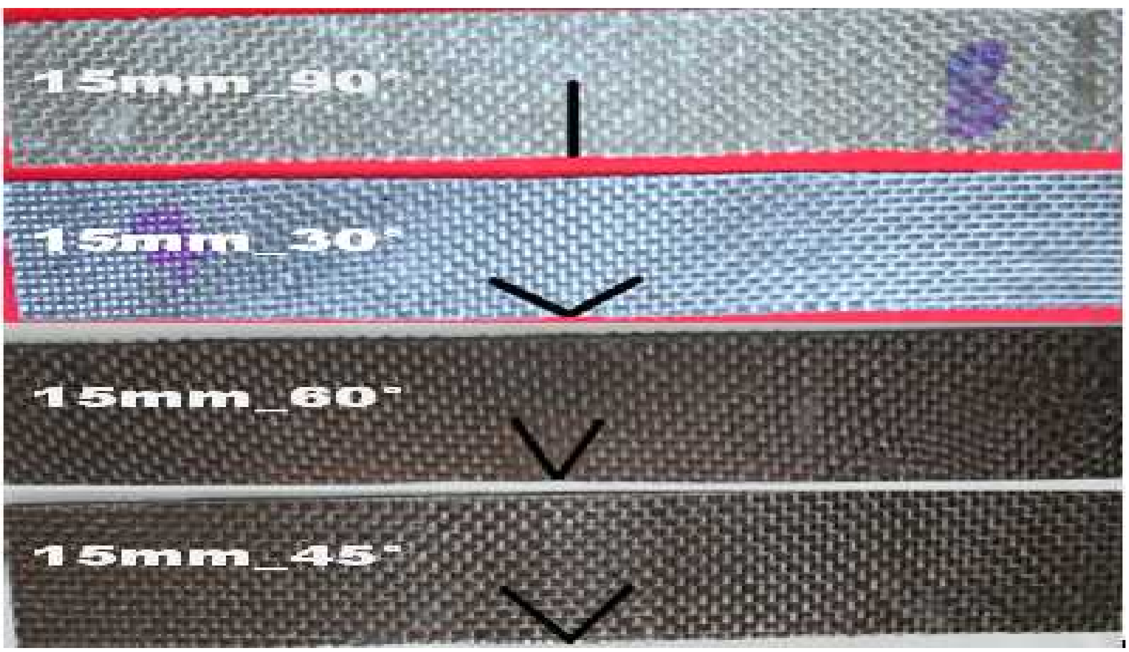


Figure .3.10 the specimens carbon/epoxy with crack angle

3.13 Analyses and technical experience

The tests are performed on a machine Zwick Roell ISO 527-4 with test speed =2mm/min

And P=250KN

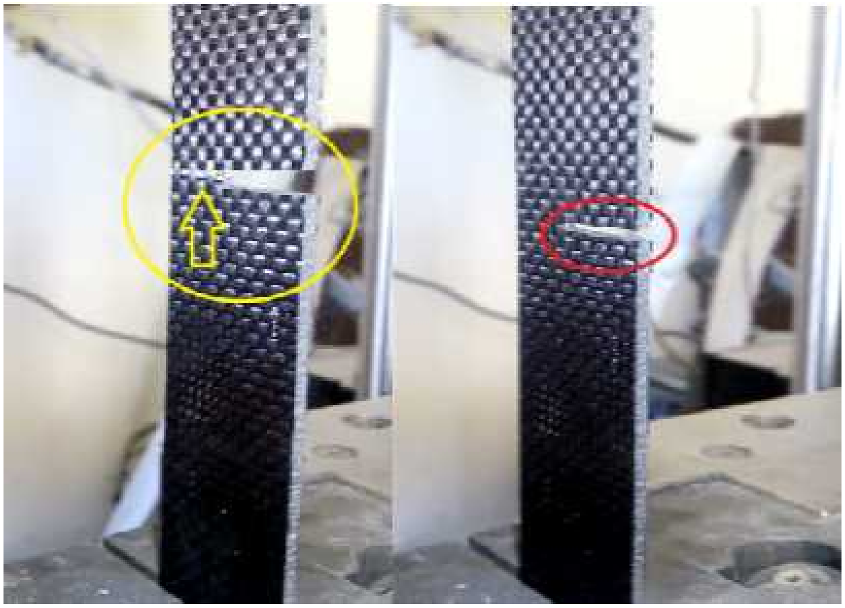


Figure .3.5 the specimen carbon /epoxy between the two jaws of the machine

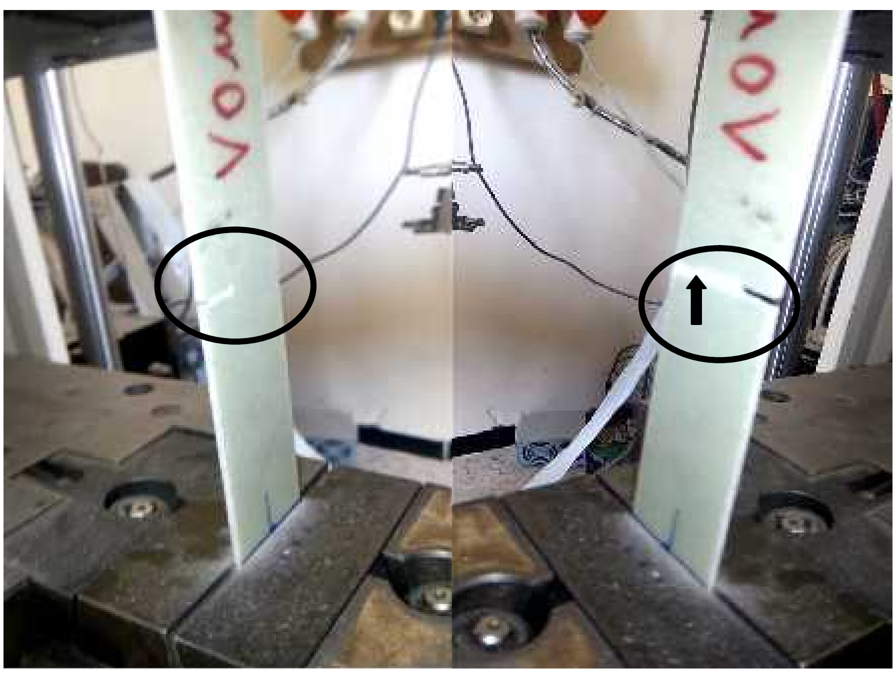


Figure .3.12 the test specimen glass/epoxy between the two jaws of the machine

3.14 Result for glass epoxy after tensile Test

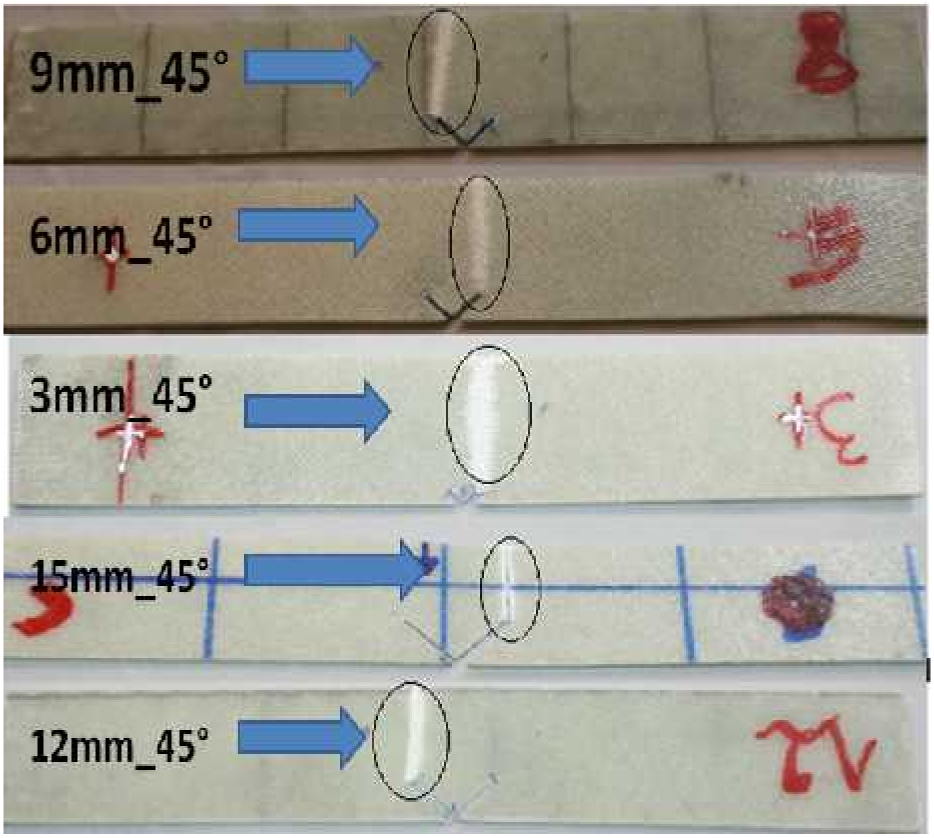
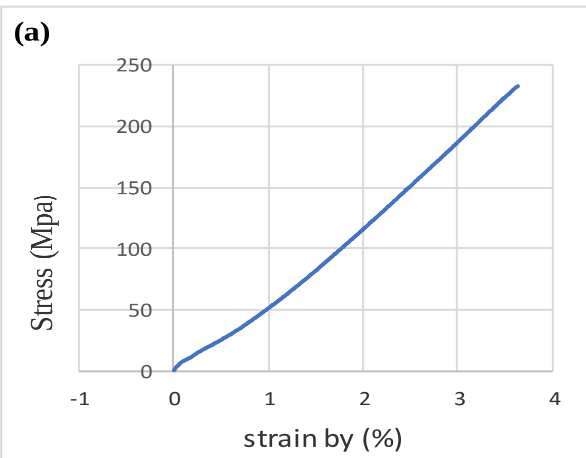


Figure .3.13 specimens glass/epoxy after tensile test with and without crack size



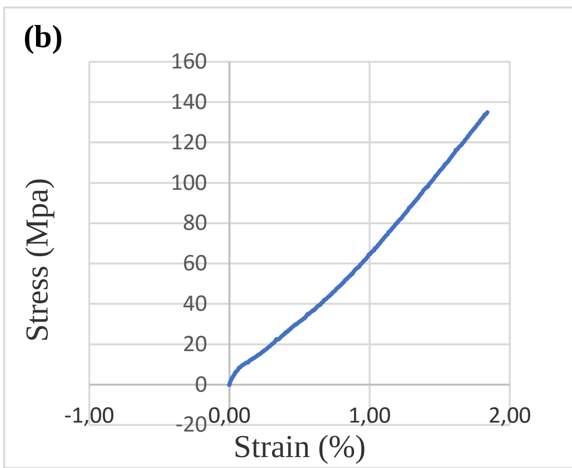


Figure 3.14 The graph a and b specimens glass/epoxy with and without crack size

(a): without crack, **(b)**: 3mm and 45°

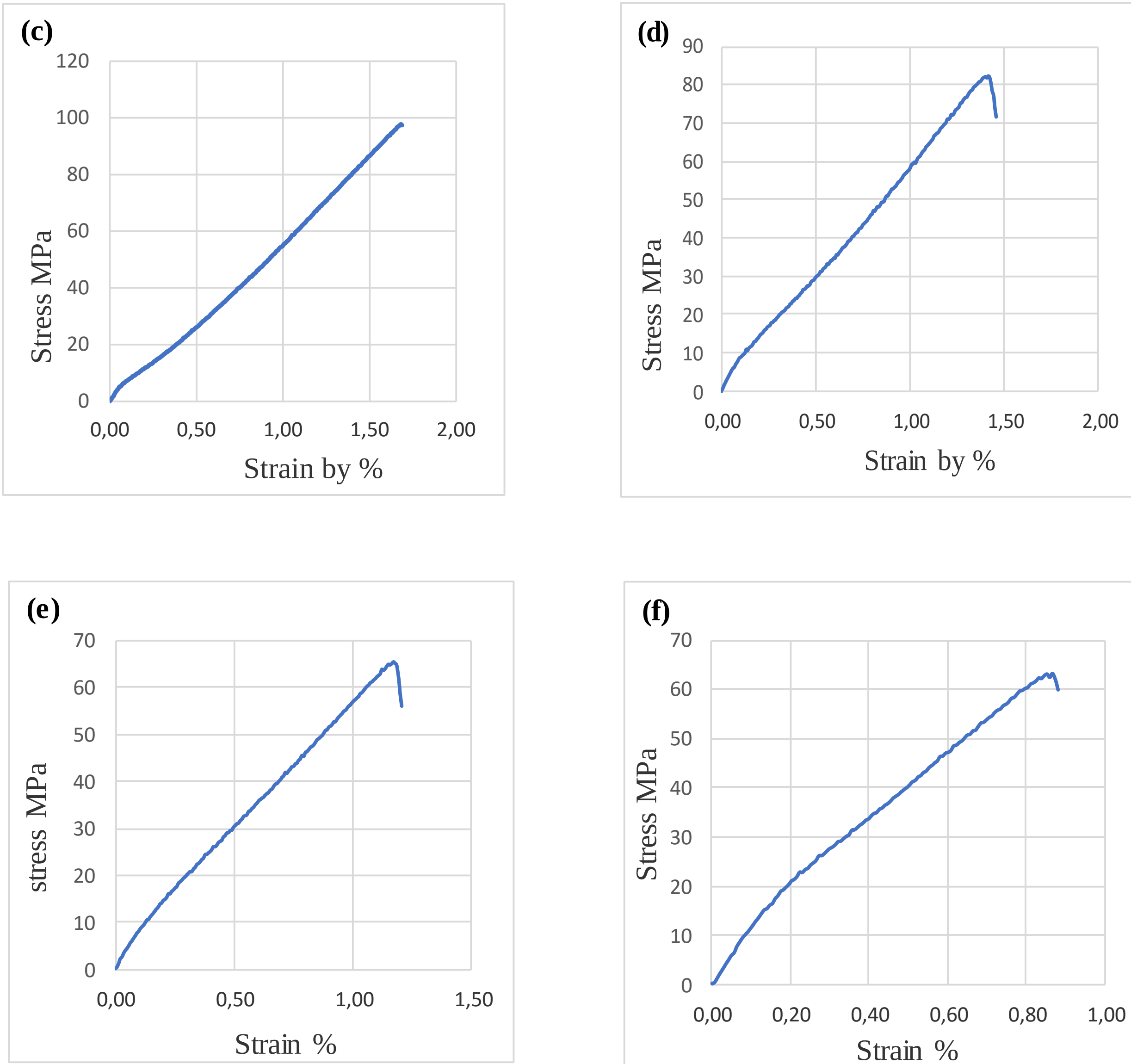


Figure. 3.15 graphs c, d, e, and f specimens glass/epoxy with crack size and angle fixed **(c):**6mm,45°, **(d):**9mm,45°, **(e):**12mm,45°, **(f):**15mm,45°.

Interpretation

1/From the tensile tests we have seen that the rupture takes the same direction in the majority of the test Specimens. From the graphs we noticed that the stress increase proportionally to the strain until the points of rupture. these points of rupture have a pick values which is the maximum stress. We can note that the variation of the stress with strain is not a linear composite material, which causes by production and defaults of cutting the specimens.

We can also notice that the rupture become fast after each test.

Table. 3.5 properties off specimen glass/epoxy with and without crack size

Test case	Crack angle	crack size	σ_{max} (MPa)	$F_{max}(N)$	ε_{max} (%)	ϑ
1	45°	0	244	14640	3.96	0.21
2	45°	3 mm	135	8100	1.84	0.21
3	45°	6 mm	97.4	5844	1.37	0.21
4	45°	9 mm	82.4	4944	1.17	0.21
5	45°	12 mm	65.5	3930	1.20	0.21
6	45°	15 mm	63.1	3786	0.86	0.21

3.15 Result for glass /epoxy after tensile test

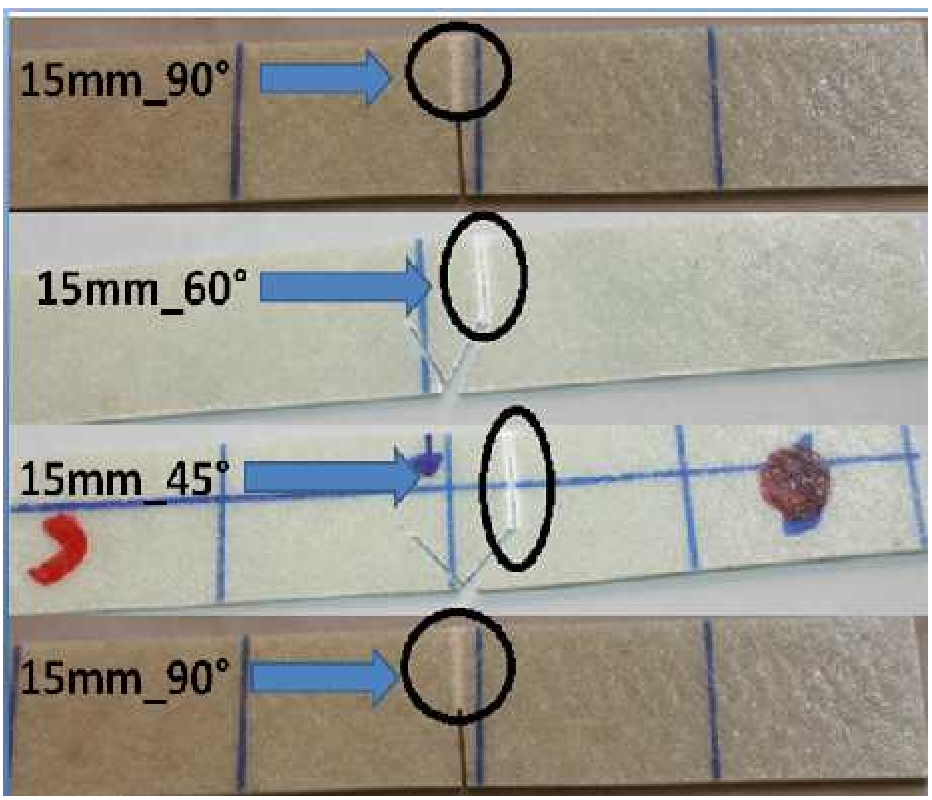


Figure 3.16 specimens glass/epoxy after tensile test with crack angle

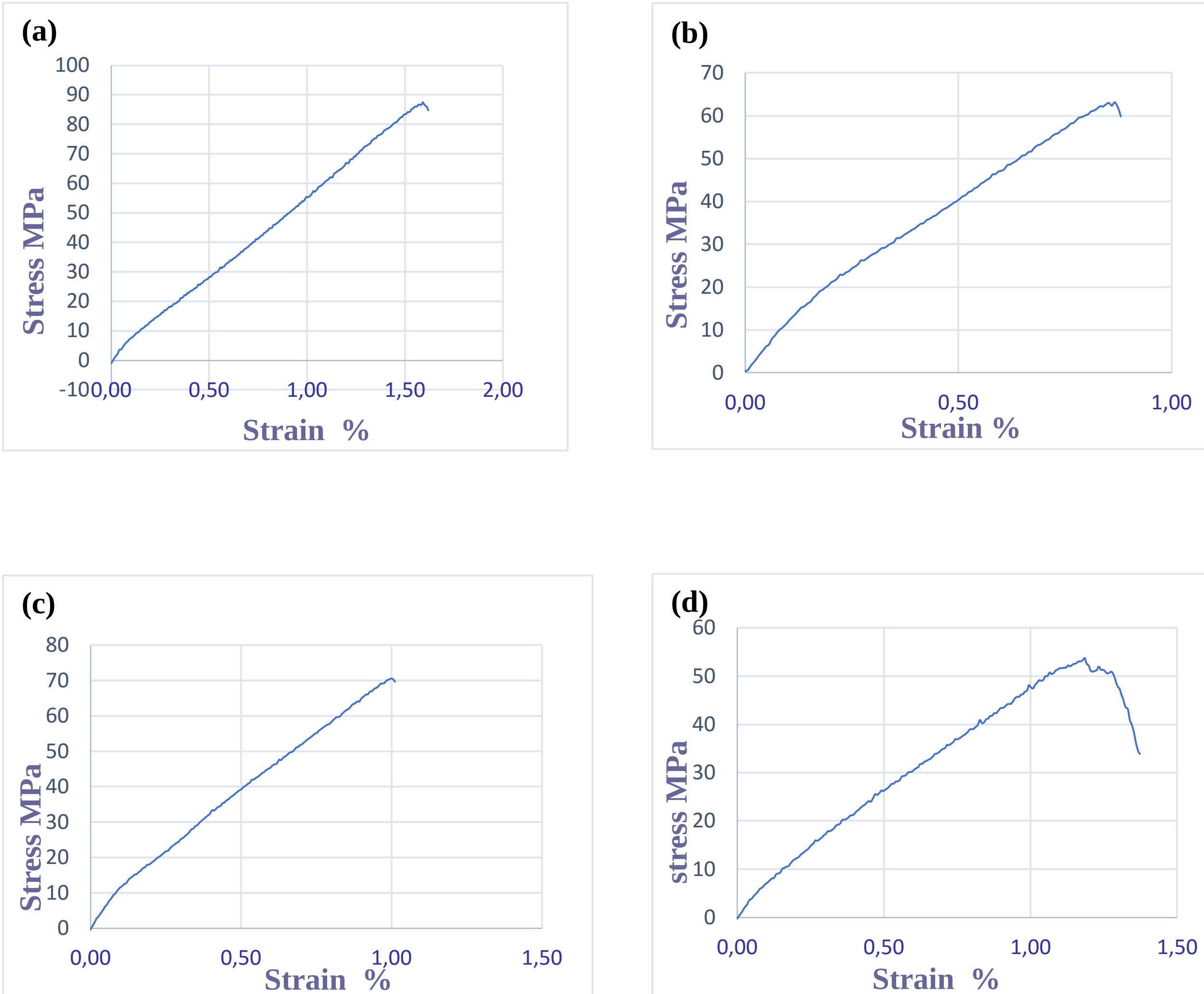


Figure .3.17 the graph a, b, c, and d specimens glass/epoxy with crack angle **(a):**15mm,30°,**(b):**15mm,45°,**(c):**15mm,60°,**(d):**15mm,90°

Interpretation

1/ from the graph (a) we observe that stress increases proportionally until the point of rupture.

We observe that the curve progressed parabolically in the interval [0.0.90] instead of a linear form and submitting some wiggles and that's due to the effect of the composite material proprieties and its defaults, also it refers to the weak adhesion fiber-matrix that caused micro crack in the matrix which is the reason of the curve's wiggles.

2/In the next graph (b) the point of rupture which is maximum stress has lower value than the previous

We observe that the curve progressed in a quick manner in the interval [0, 0.0485] and that due to a sliding between the specimen and the specimen's holders in the machine, then we note that the curve progressed linearly till it reaches to the point (1.02, 40.5) submitting some wiggles that are a result of a weak fiber-matrix adhesion and occurred because of a micro crack in the matrix

3/ In this figure (c) we notice that the maximum stress is higher than the graph (b)

We can see also wiggles on it as result of a weak adhesion of fiber-matrix that caused mini and micro crack in the matrix, then we note that the curve stabilized a little bit so the stress almost took a constant value when the strain was increasing till it reached to the value 1.91 % then the stress decreased and the curve submitted to some wiggles which are the result of the rupture of fiber group by group that means that the fiber didn't break at once for all and that occurred till the rupture of the whole material.

4/ we observe from the curve (d) that the stress increases proportionally to the elongation and have maximum stress value lower than the three previous graphs.

We note that the decrease region of the stress doesn't occurs linearly but we note that there is wiggle on the curves line and it increased its value at the point and that due to the weak adhesion fiber-matrix and the break of fiber one after one or group after group, that means that the whole material doesn't break together at one time

Table.3. 6 property of glass epoxy with crack angle

Test case	Crack size	Crack angle	F_{max}(N)	S_{max}(MPa)	$\varepsilon_{max}(\%)$	ϑ
1	15 mm	30°	5244	87.4	1.61	0.21
2	15mm	45°	3786	63.1	0.86	0.21
3	15 mm	60°	3942	65.7	1.91	0.21
4	15 mm	90°	3222	53.7	1.18	0.21

3.16 Result of (carbone /epoxy) specimens after tensile Test

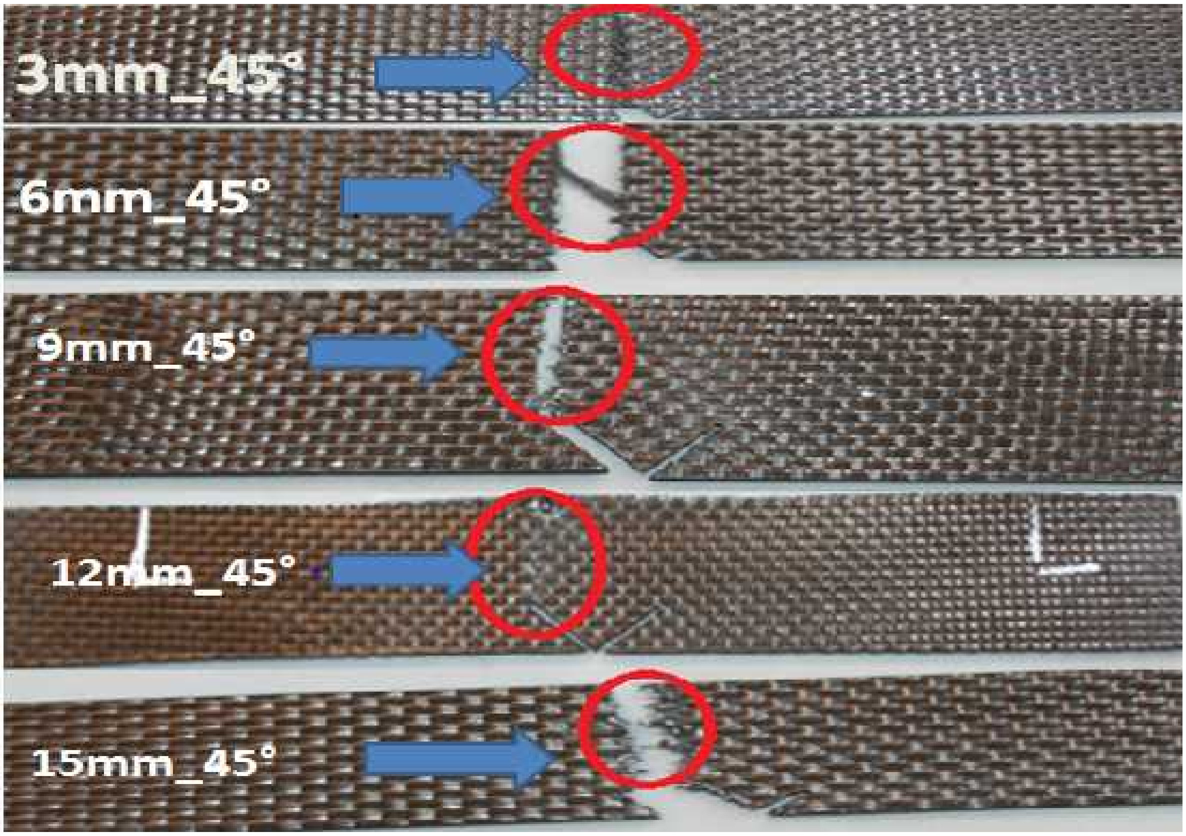


Figure .3.18 the specimens carbon/epoxy after tensile test with different crack size

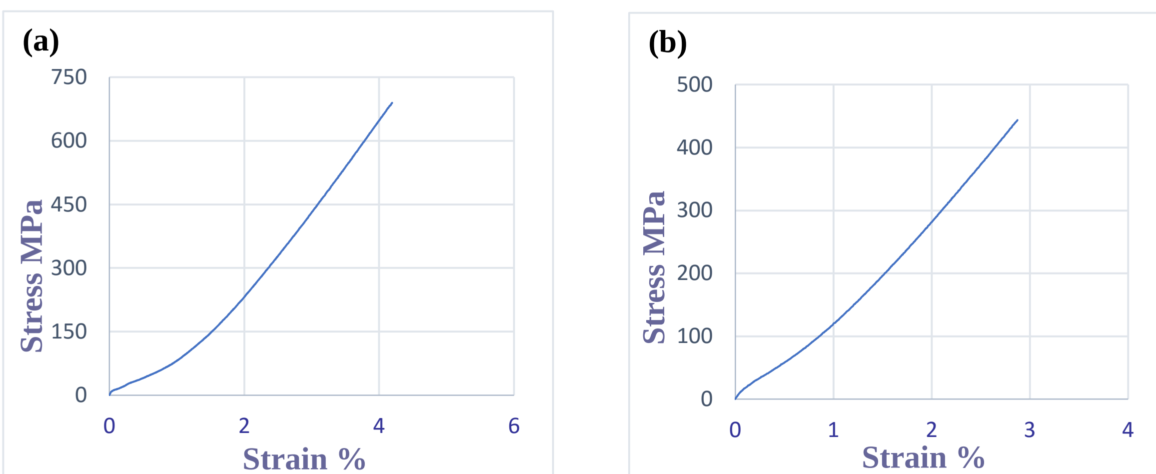


Figure 3.19 The graph a and b specimens carbon /epoxy with and without crack size

(a): without crack, **(b)**: 3mm and 45°

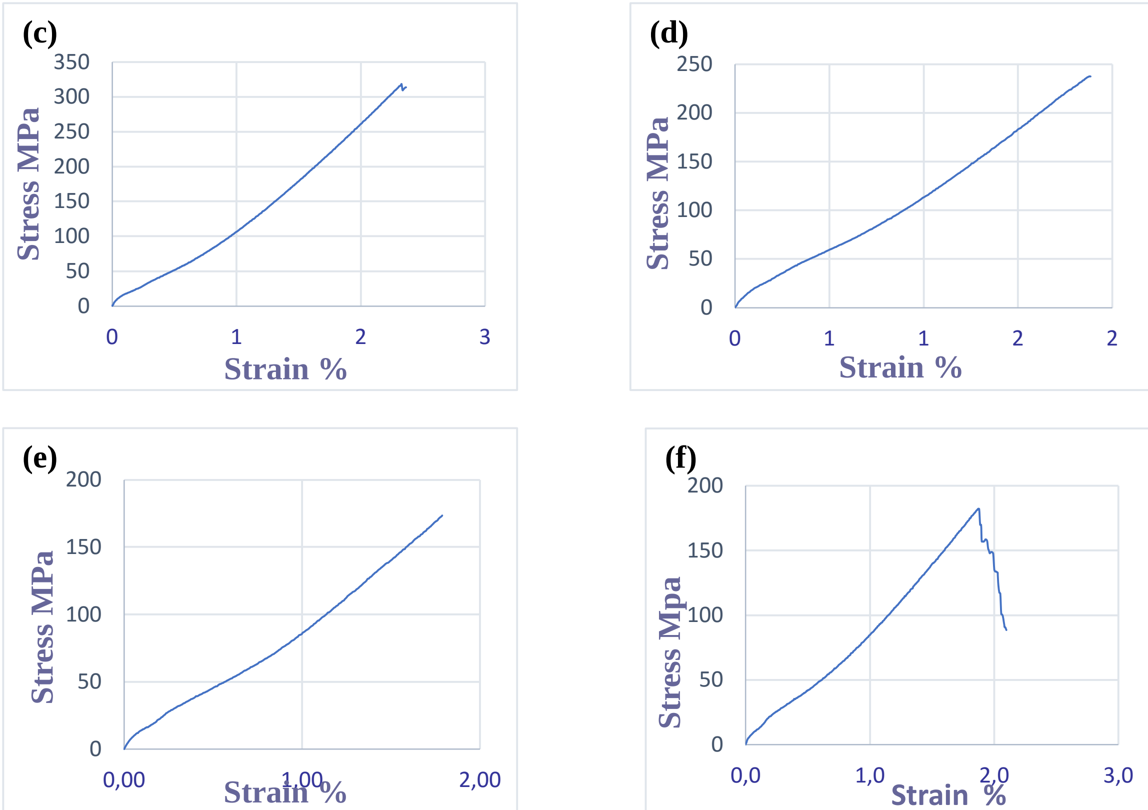


Figure. 3.20 graphs c, d, e, and f specimens carbon /epoxy with crack size and angle fixed **(c):**6mm,45°, **(d):**9mm,45°, **(e):**12mm,45°, **(f):**15mm,45°.

Interpretation

1/ From the graphs (a) we observe that the stress increases proportionally to the Elongation until the points of rupture which is the maximum stress.

We can see that the curve progressed parabolically then it progressed linearly till the end of the graph and that because of the proprieties of composite materials and its defaults of production, measure and cut.

2/ from the graph (b) In the last region [2.94, 3.1] the stress wiggled till the end of graph and that's because of the rupture of fiber and matrix before the total rupture of the specimen

3/from the graph (c) we observe the stress increase proportionally to the strain and have almost linear form due to default of production

4/from the graph (d) we observe a parabolically form that progress linearly till the end of graph

We can see also wiggles in the end of graph on it as result of a weak adhesion of fiber-matrix that caused mini and micro crack in the matrix

4/ the graph (e) and (f) have a same chapes and increase proportionally to the strain.

We can see also a wiggle in first of graph on its result of a weak adhesion of fiber _matrix that caused micro crack in the matrix.

Table .3.7 property of carbon/epoxy with and without crack

Test case	Crack size	Crack angle	υ_{max}(MPa)	F_{max}(N)	ε_{max}(%)	ϑ
1	0	45°	699.5	41970	4.19	0.3
2	3 mm	45°	444	26640	2.87	0.3
3	6 mm	45°	314	18840	2.63	0.3
4	9 mm	45°	238	14280	1.87	0.3
5	12 mm	45°	173	10380	1.60	0.3
6	15 mm	45°	182	10920	1.47	0.3

3.17 Result of (Carbone /epoxy) after tensile Test

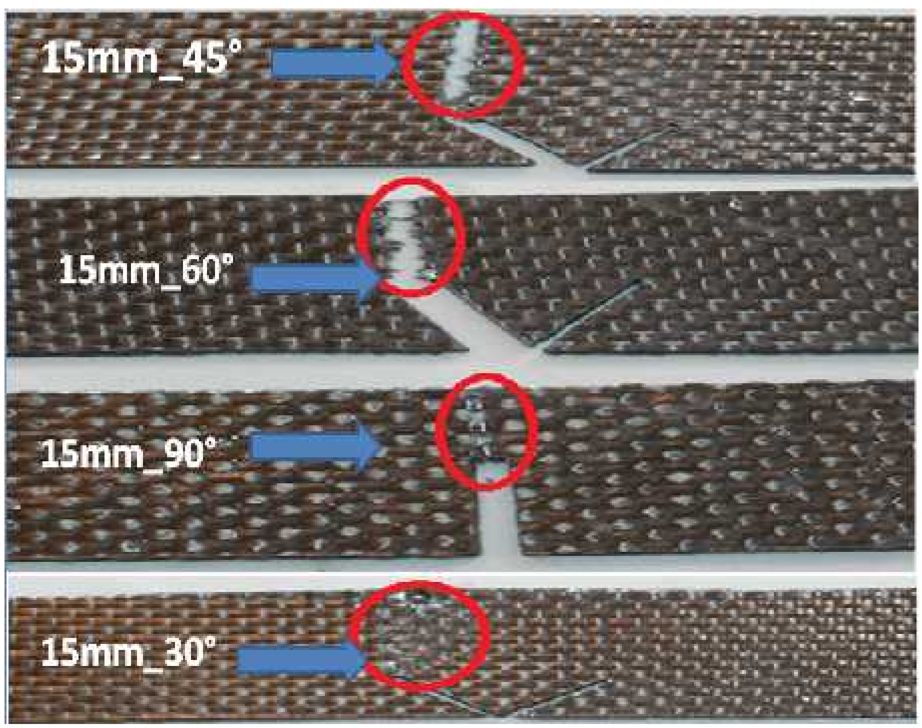


Figure.3.21 specimens carbon/epoxy after tensile tests with crack angle

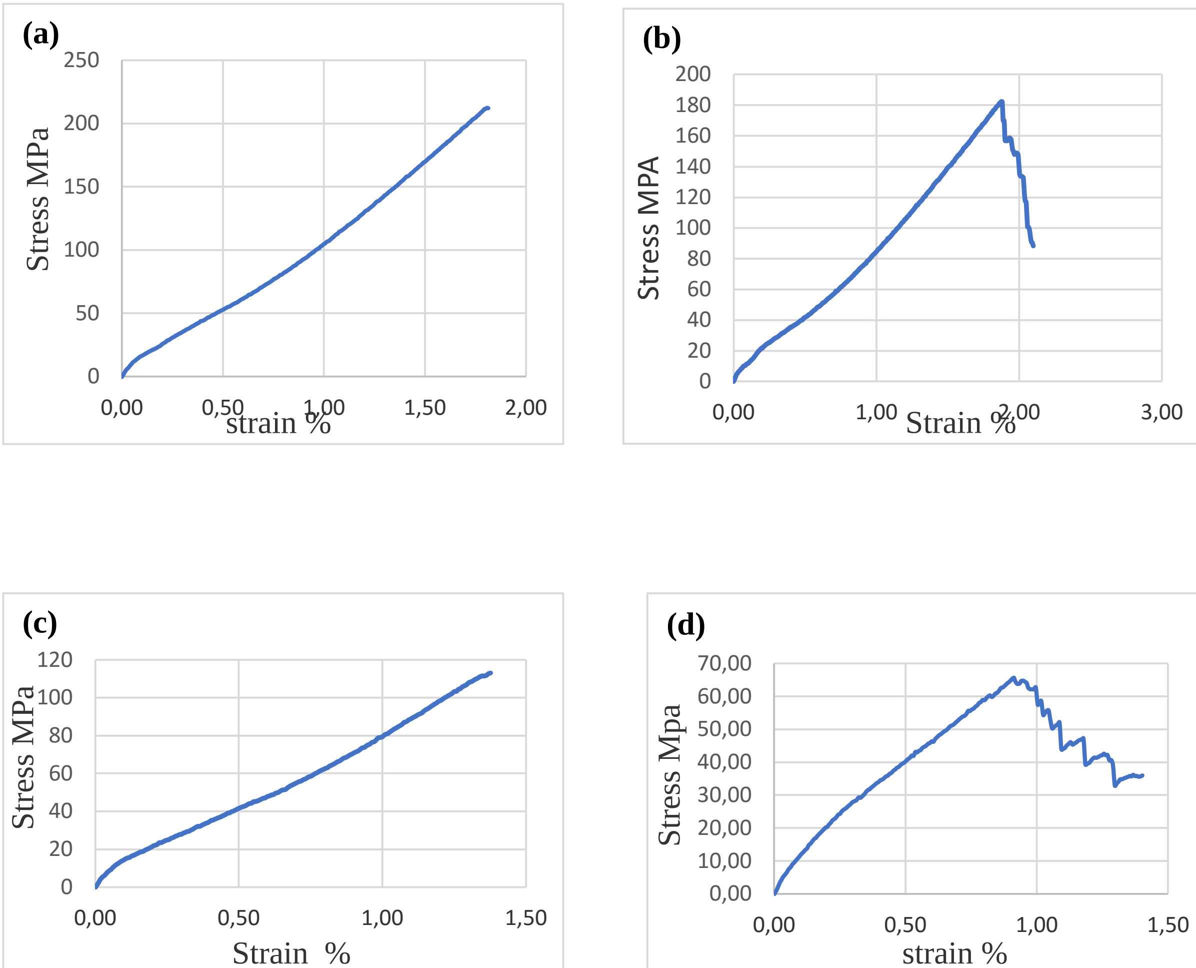


Figure .3.22 the graph a, b, c, and d specimens carbon /epoxy with crack angle **(a):**15mm,30°,**(b):**15mm,45°,**(c):**15mm,60°,**(d):**15mm,90°

Interpretation

1/from the graphs (a) we observe that the stress increases proportionally to the strain until the point of rupture which is the maximum stress equal S_{max}=212MPa

2/We observe from graph (b) that the stress increases proportionally with strain until it reaches the value of the stress max equal=182Mpa then it decreases with increase of strain till the rupture. We note that the curve progressed parabolically from the beginning of the curve till the point (2,09; 163,43) then it wiggled till it reached the maximum stress then it generally decreased and submitted so many wiggles until it reached the point of rupture of the whole material

3/from the graph (c) we observe that the stress increase proportionally to the strain until the point of the rupture which is the maximum stress.we can see also a parabolically form in the first graph and a little wiggled in the end.

4/ in the last graph(d) We can see that the curve proceeded in a quick manner at the start of the graph in the interval [0;0.08] and this is because a slid happened between the specimen and its holders in the machine, we also note that the curve progressed parabolically from the beginning of the curve till the point (1.59; 65.49) then it generally decreased and submitted so many wiggles until it reached the point of rupture of the whole material.

those wiggles are a result of a weak adhesion of fiber-matrix which made a mini and micro crack in the matrix, also it was because of the rupture of both fibers and matrix.

The rupture of fibers wasn't a total rupture but the fibers was breaking group by group till the end of the curve.

2/we notice that the rupture becomes faster after each tensile test specimens

Table .3.8 property of carbon/ epoxy with crack angle

Test case	Crack size	Crack angle	$F_{max}(N)$	$\upsilon_{max}(MPa)$	$\varepsilon(\%)$	ϑ
1	15 mm	30°	12720	212	1.81	0.3
2	15 mm	45°	10920	182	1.88	0.3
3	15 mm	60°	6780	113	1.38	0.3
4	15 mm	90°	2160	36	1.40	0.3

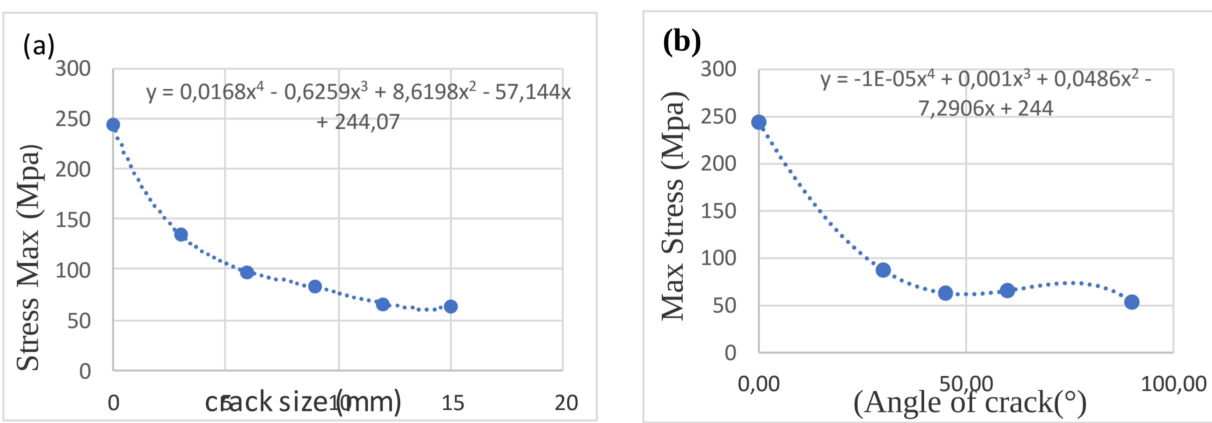


Figure. 3. 23 the graphs a, and b the maximum stress of glass/epoxy on function of size and angle of crack

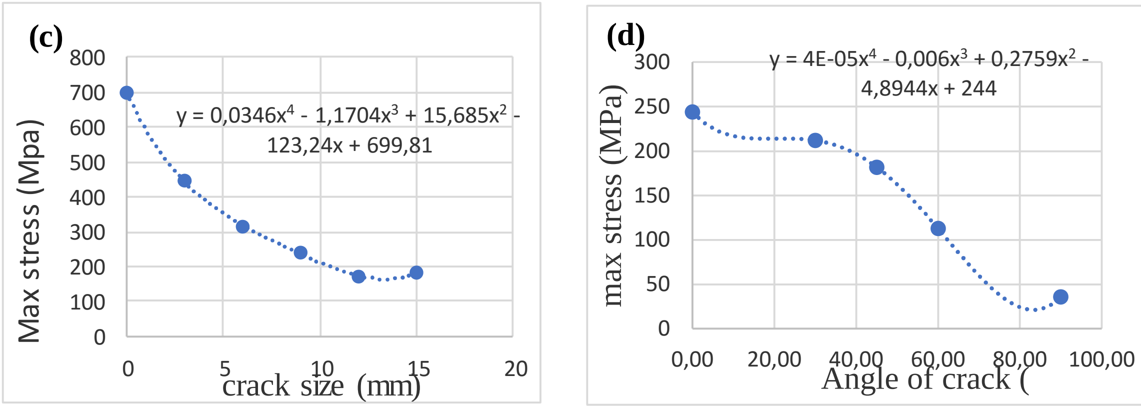


Figure .3.6 the graphs c, and d the maximum stress of carbon/epoxy on function of size and angle of crack

Interpretation

1/We notice that the variation of stress is proportionally to the crack size from the two graphs of (Carbone and glass) epoxy

2/We also observe that the graphs of carbon and glass epoxy on function of crack size have a same form and decreases exponentially

The curve approximately proceeded following the equation below.

$F(x)= 0.168x^4 – 0.6259x^3 + 8.6198,7x^2$ 57.144-x. (Glass/epoxy)

$F(x)= 0.0303\ x^4 – 1.047x^3 + 14.32x^2 – 116.63x +690.13$ (carbon /epoxy)

The strain has been reduced more than two times from the smallest to the biggest crack size.

3/From the graph of a glass epoxy on function of crack angle we observe that the stress decreases until the angle 45°and we notice a slight increase between 45° and 60°after decrease until the 90°

The curve approximately proceeded following the equation below

$F(x) = - 1^{E}\text{-}05x^4 + 0.001x^3 + 0.0486x^2 – 7.2906x + 244$

4/ in the graph of carbon epoxy on function of crack angle we observe that the stress decreases until the 15° we notice a slight stability form between 15° and 30° after it continue to decrease until the 85° and increase until the angle of 90°.

The curve approximately proceeded following the equation below

$F(x) = 4E\text{-}05x^4 - 0.006x^3 + 0.2759x^2 - 4.8944x + 244$

Table. 3.9 characteristics of specimen's carbon and glass epoxy

Carbon fiber	9840	10	0.82	0.76	0.01
Resin Epoxy Carbon	2160	0.3	0.18	0.23	0.0013
Composite Carbon	12000	13	1	1	0.012
Glass fiber	10560	14.4	0.88	0.75	0.013
Resin glass	1440	4.2	0.12	0.25	0.029
Composite glass	12000	19	1	1	0.015

Table. 3.10 Material properties of specimens

Properties of materials	Carbone/epoxy	Glass / epoxy
E_1(Map)	188603.5	75682.38
E_2(Mpa)	26.18	226.06
ν_{12}	0.3	0.21
G_{12} (Mpa)	7115.51	9328.09
G_{23} (Mpa)	7115.5	9328.09
G_{31} (Mpa)	1142.32	127757.8

3.18 Conclusion

Experiments were conducted on glass fiber/epoxy and carbon fiber/epoxy laminates with the fiber orientation (0°.90°) with and without angle and size of crack to characterize the tensile properties. The following conclusions were drawn and recorded.

1/The glass fiber fail more quickly than the carbon fiber

2/The mechanical properties of composite materials depend upon the structure of the material, and also depend on the volume fraction, interfaces between components

4) Failures of composite materials include the fracture of fiber, fracture of matrix in tension normal to the fiber. And the nature of failure also depends on the angle ply between the fiber and specimen's axis

Chapter IV

Numerical Simulation

4.1 Introduction

The aim of this chapter is a numerical simulation of plate (glass/epoxy) and (Carbon/epoxy) with and without crack by Abaqus software which can give the distribution of the stress and field of the displacement also we will see the deformation of the specimen., fluid flow an electromagnetism analysis. ABAQUS has a complete new look with a multiple window incorporating graphical user interface (GUI) pull down menus, dialog boxes and tool bar. Today we find ABAQUS in the whole engineering field

4.2 Design and geometry of specimen

The geometry of specimen was created with Abaqus software for carrying out static structural analysis which is shown in figures bellow.

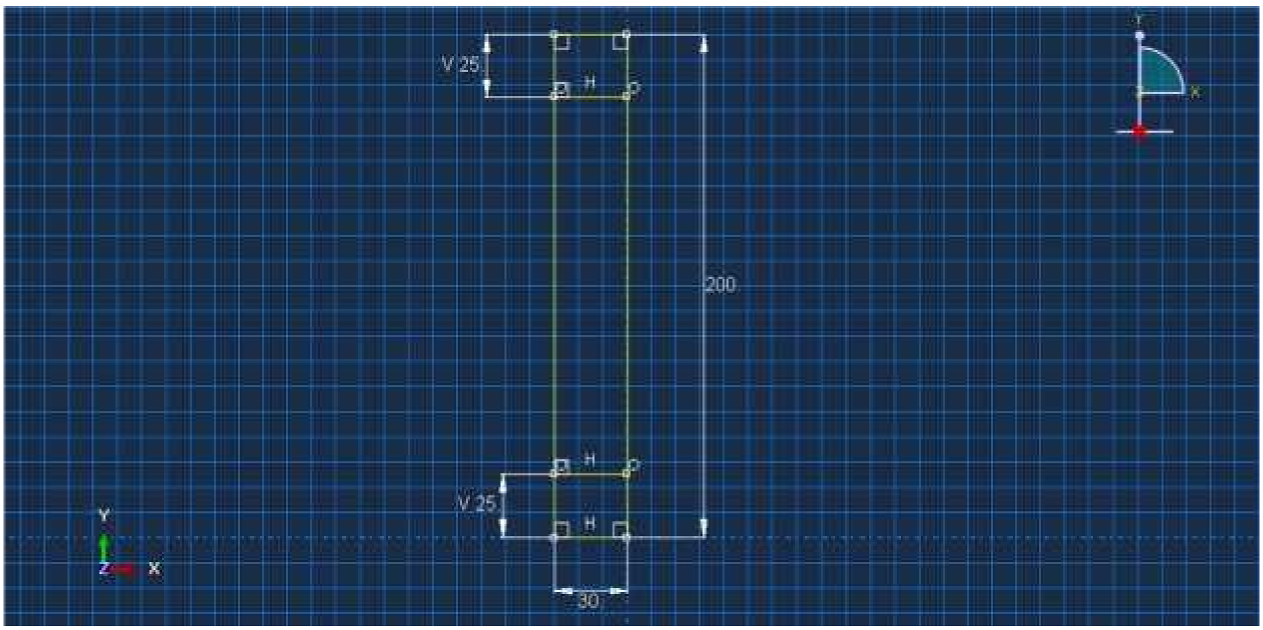


Figure.4.1 geometries of specimen

4.2.1Gemometry of specimen

Total length= 200mm

Thickness of specimen=2mm

Length at the extremities=150mm

Weight of specimen =30 mm
Distance between the two Gripps =25mm

4.3Abaqus software simulation

4.3.1 Part of modelling

The part in which used to create geometry required (area, volume, lines, key, point)

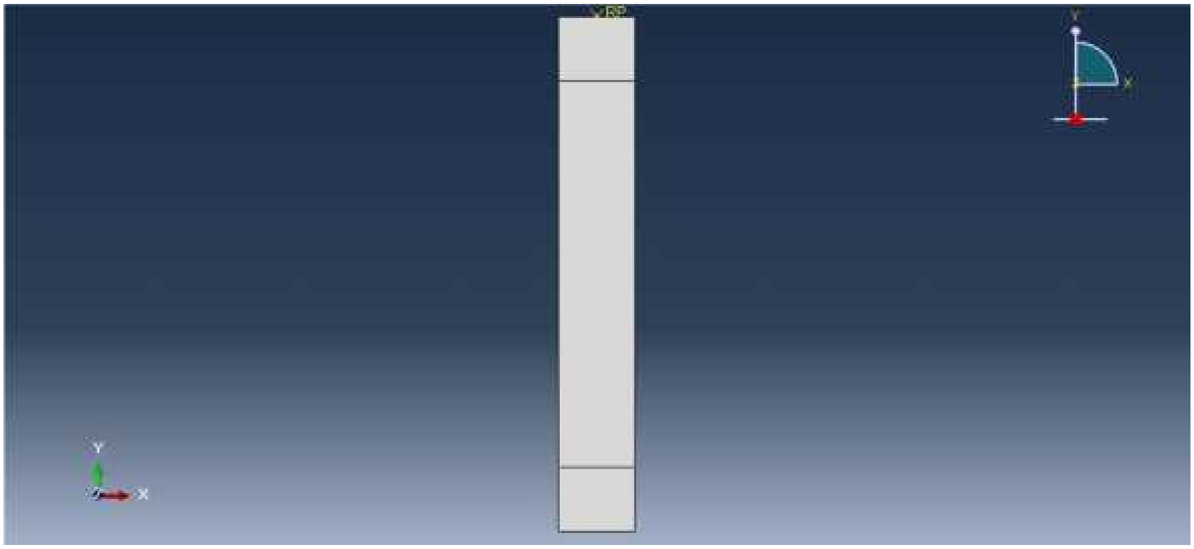


Figure.4.2 modelling specimen

4.3.2 Property function

Orientation of fiber (0°.90°) for sixteen layers

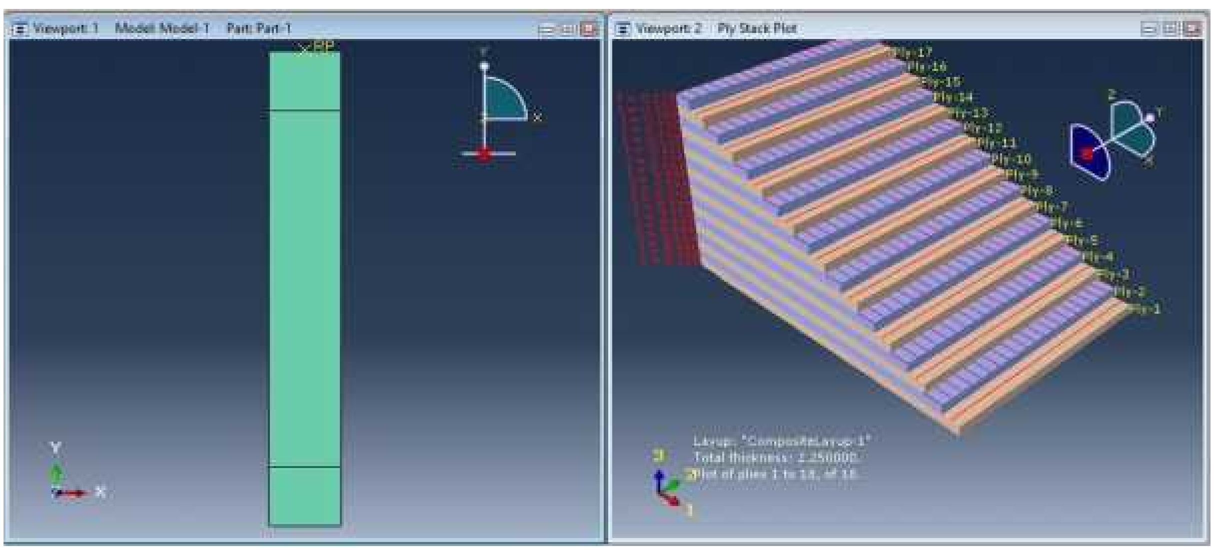


Figure.4.3 specimen property

4.3.3 Assembly

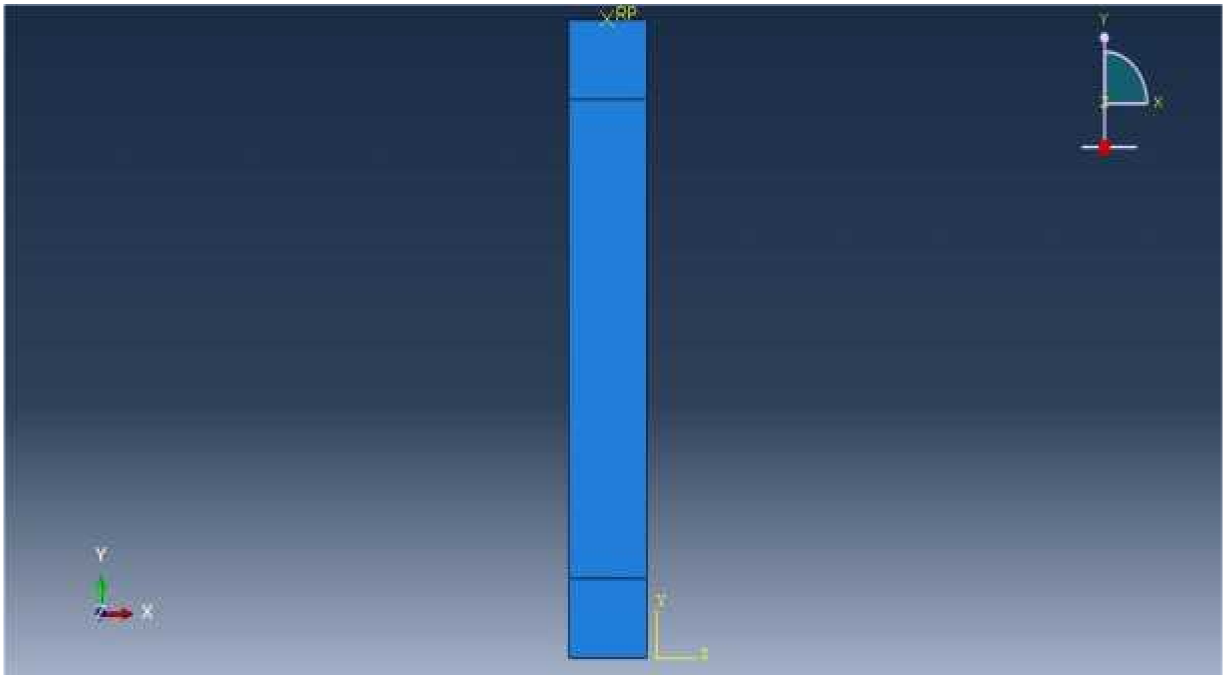


Figure.4.4 Assembly specimen

4.3.4 Interaction we create a constraints type coupling kinematic where we apply load.

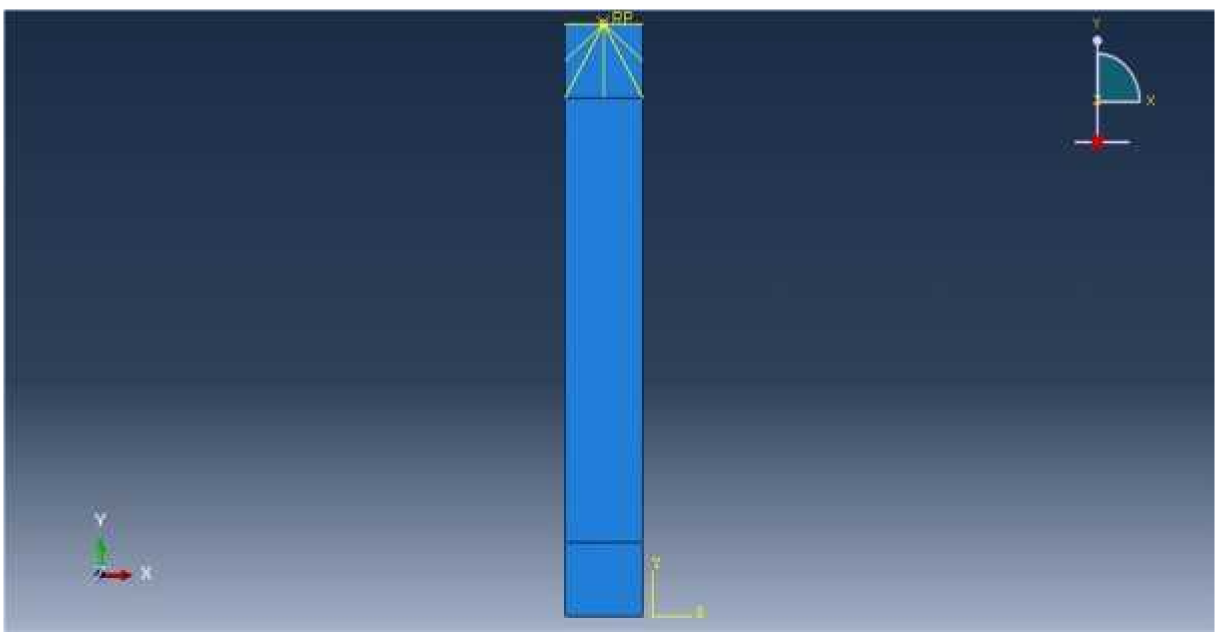


Figure.4.5 interaction of specimen

4.3.5 Loads and boundary conditions

- For the displacement we have ENCASTRE $U_1=U_2=U_3=UR_1=UR_2=UR_3=0$.
- displacement and rotation $U_1=U_3=UR_1=UR_2=UR_3=0$.

Load type concentrated force .CF1 $=CF_3=0$ and $CF_2=14640$ N

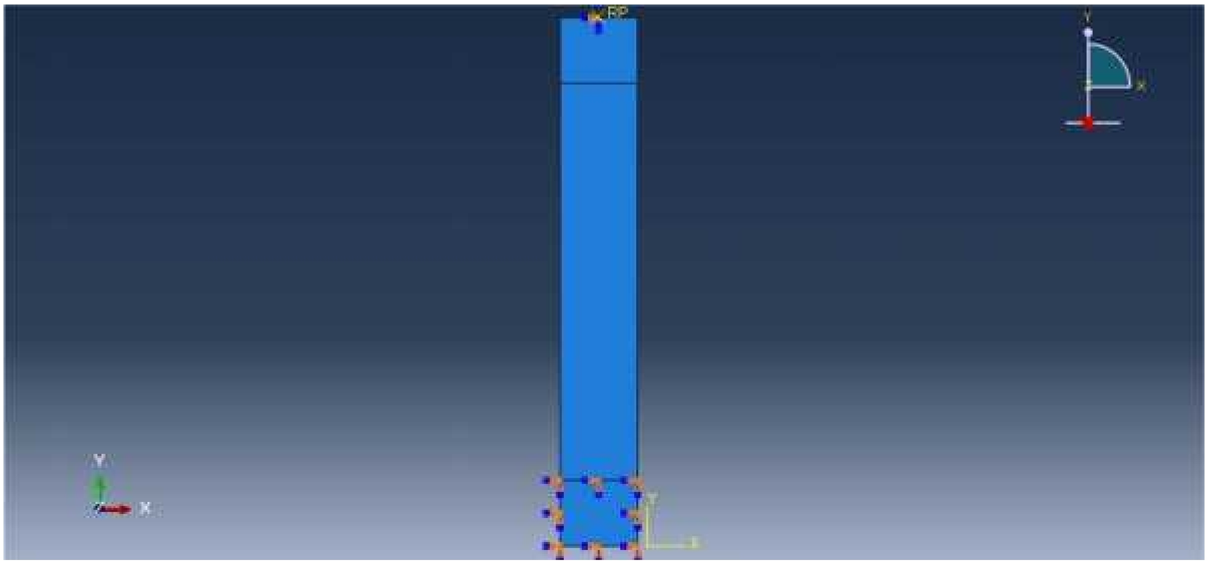


Figure.4.6 load and boundary conditions

4.3.6 Mesh Function

Here the specimen is meshed in order to define the elements size

Approximate global size =1

Number of elements .6000 element, type of material: Quadratic

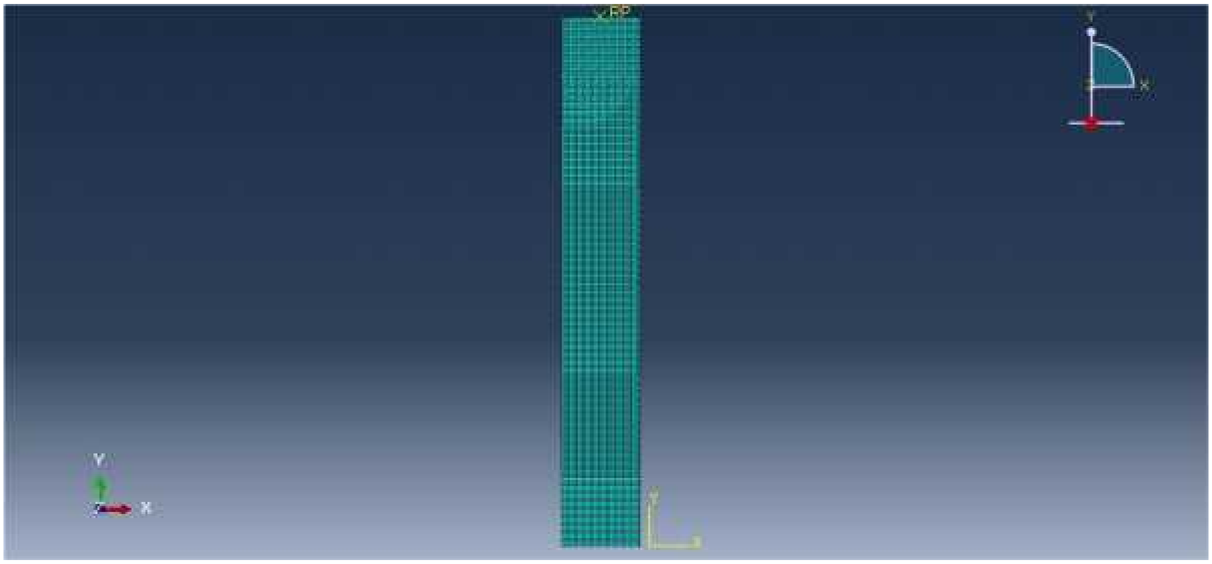


Figure.4.7 Mesh of specimen

4.4 Results of specimens without crack

a) Displacement

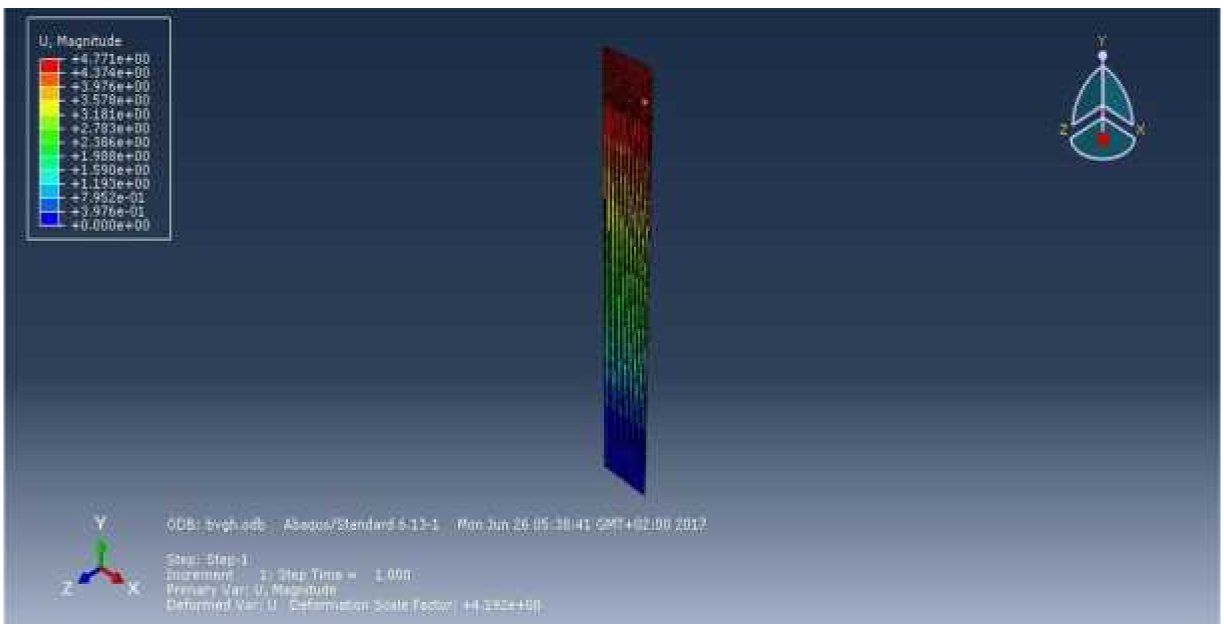


Figure.4.8 Displacement maximum U_{max}=4.771mm.

b) Strain

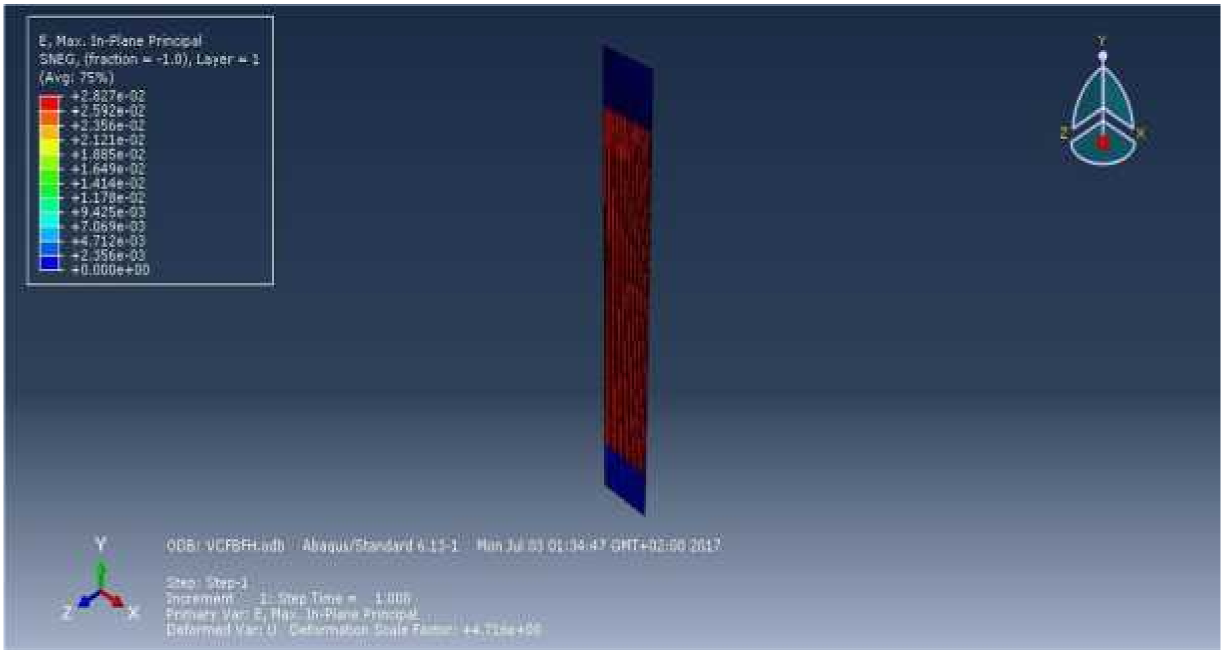


Figure.4.9 maximum strain E_{max}=2.827mm

c) Stress

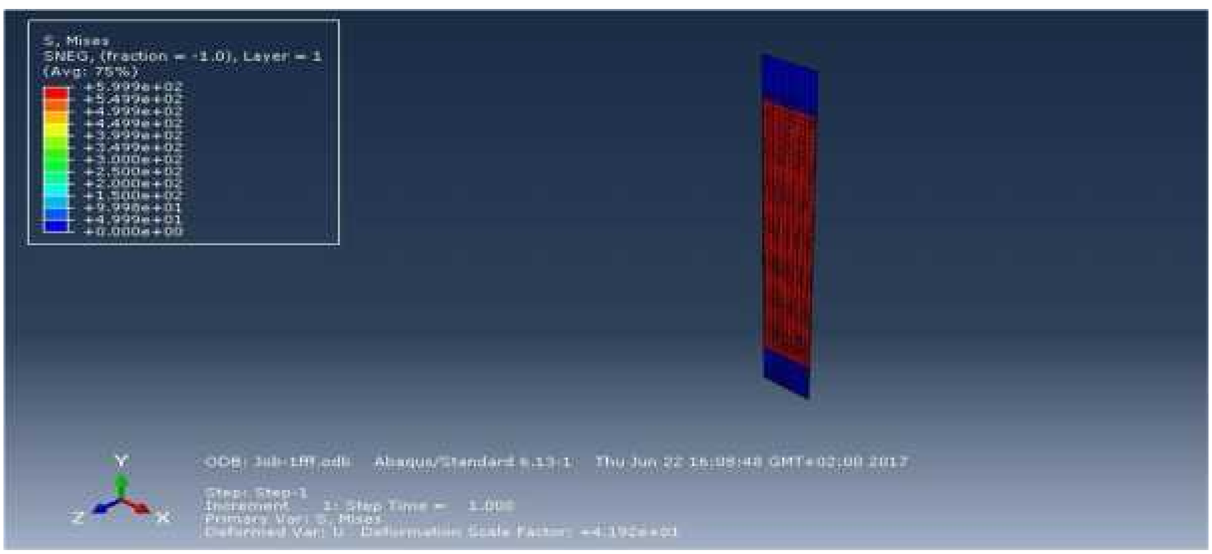


Figure.4.10 Von Mises stress maximum Smax =5.999e+2

4.5 Calculate the stress (S_{max}), and strain (E_{max}), and displacement (U_{max})

Table
.4.1 static parameters of various specimens without crack

Without Crack	S_{max} (MPa)	E_{max}	U_{max} (mm)
Carbon/epoxy	599.9	4.821e-2	4.771
Glass/epoxy	250	3.65e-2	5.93

4.6 Result of crack specimen Carbon/epoxy with different crack size and angle fixed (45°)

a) Displacement

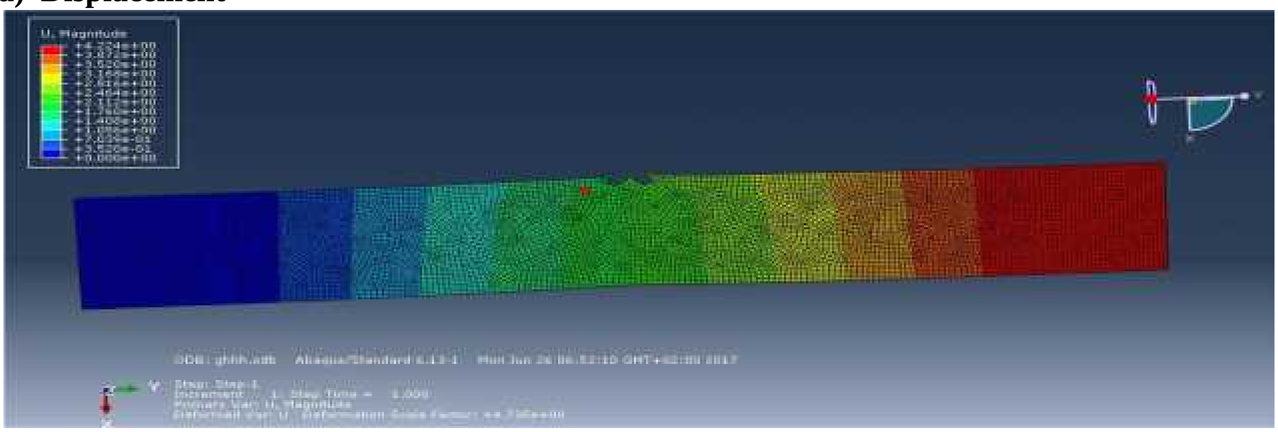


Figure.4.11 Displacement maximum U_{max}=4.224mm

b) Strain

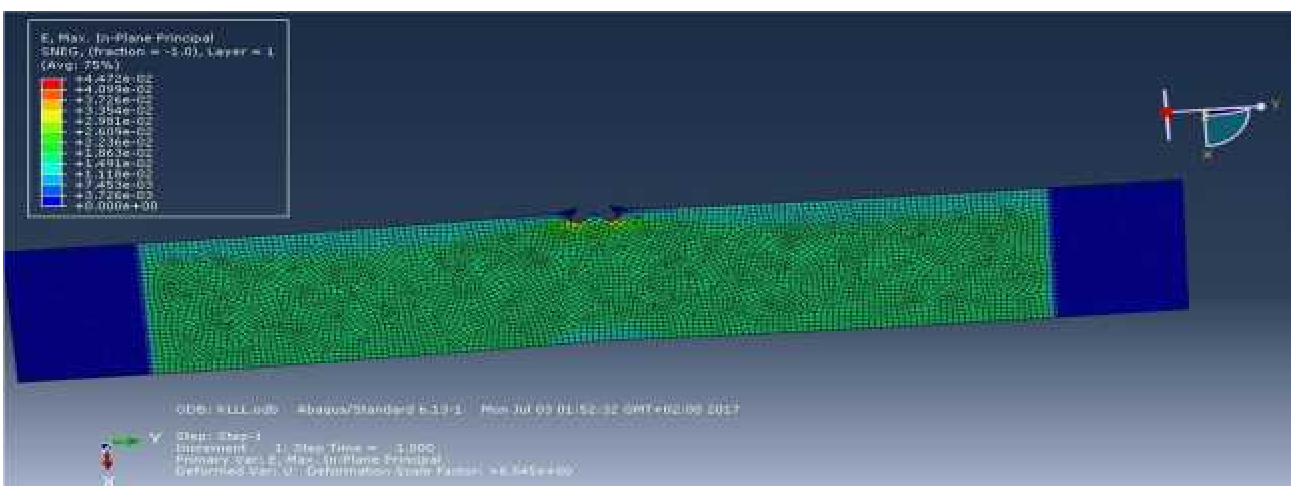


Figure.4.12 Strain maximum E_{max}= 4.472e-2

c)Stress

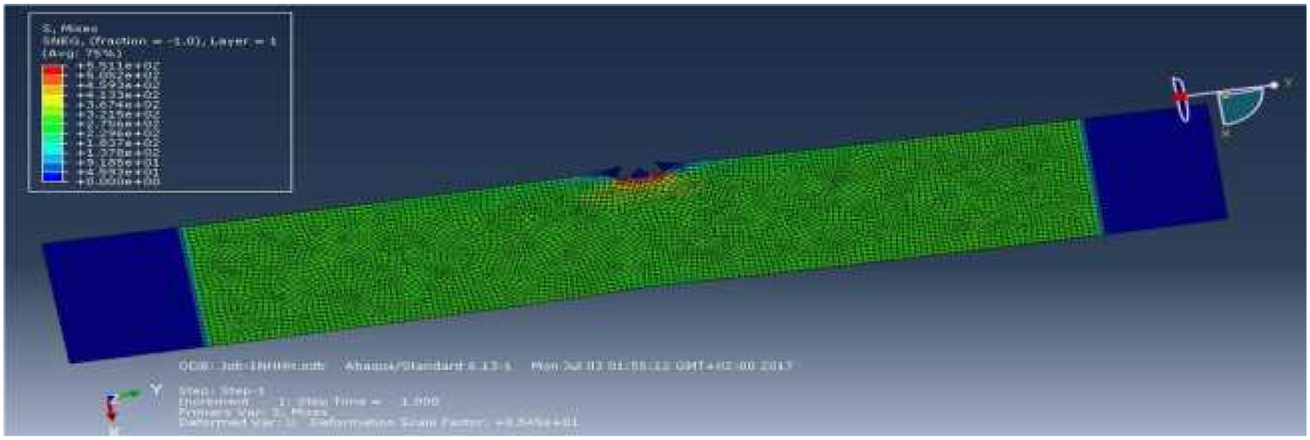


Figure. 4.13 Von Mises maximum stress S_{max} =5.511e+2 MPA

4.7 Calculate stress S_{max}, strain E_{max}, displacement U_{max}

The results obtained shown in tables below

Table.4.2 stress max (S_{max} MPa) versus crack size of specimens

Crack size (mm) Materis		3	9	12	15
Carbon/epoxy	5.511e+2	3,702e+2	2,381e+2	1,803e+2	1,375e+2
Glass /epoxy	1.40e+2	0,97e+2	0.832e+2	0,623e+2	0,555e+2

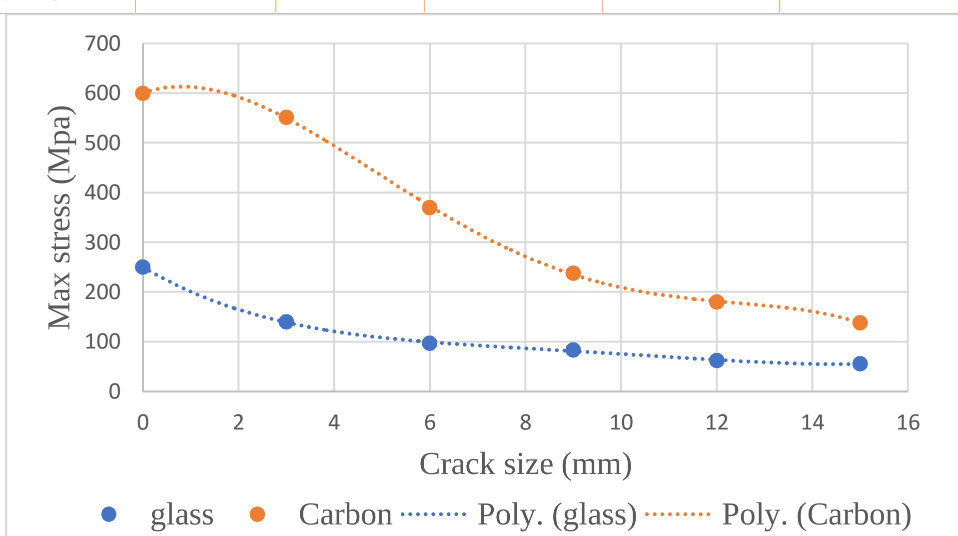


Figure.4.14 the graphs of carbon and glass /epoxy on function of crack size

Table.4.3 strain max Emax versus crack of specimens

Crack Size mm Materials	3	6	9	12	15
Carbon /epoxy	3.02 9e-2	2.361e-2	1.735e-2	1.653e-2	1.446e-2
Glass/epoxy	1.90e-2	1.63e-2	1.401e-2	1.20 e-2	1.04 e-2

From the table 4.3 , we have this graph

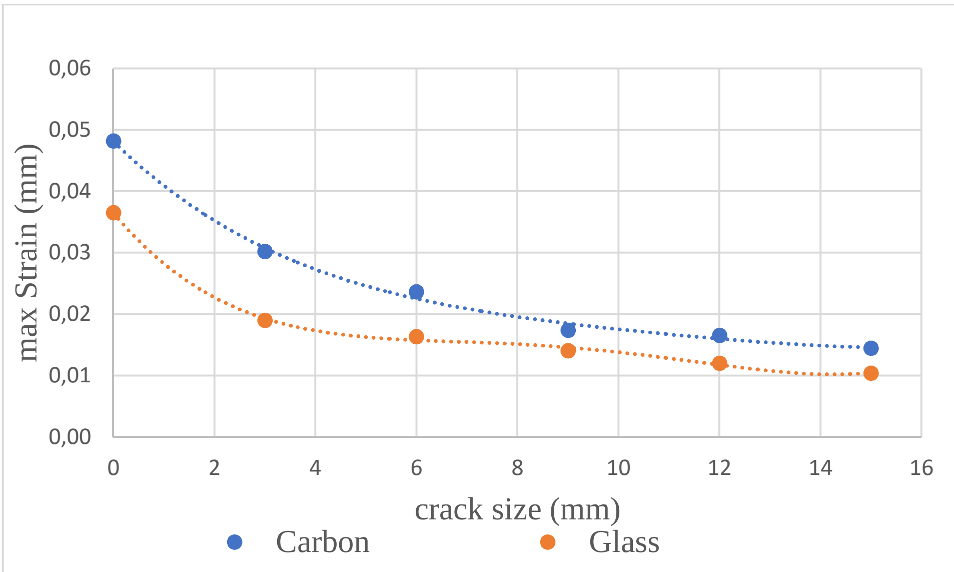


Figure.4.15 the graph of strain on function of crack size

Table.4.4 displacement Umax(mm) versus crack of specimens.

Crack size mm Materials	3	6	9	12	15
Carbon/epoxy	4.224	3.501	2.703	2.502	2.451
Glass/epoxy	2.76	2.5	2.11	1.75	1.27

From the Table 4.4, we obtain this graph

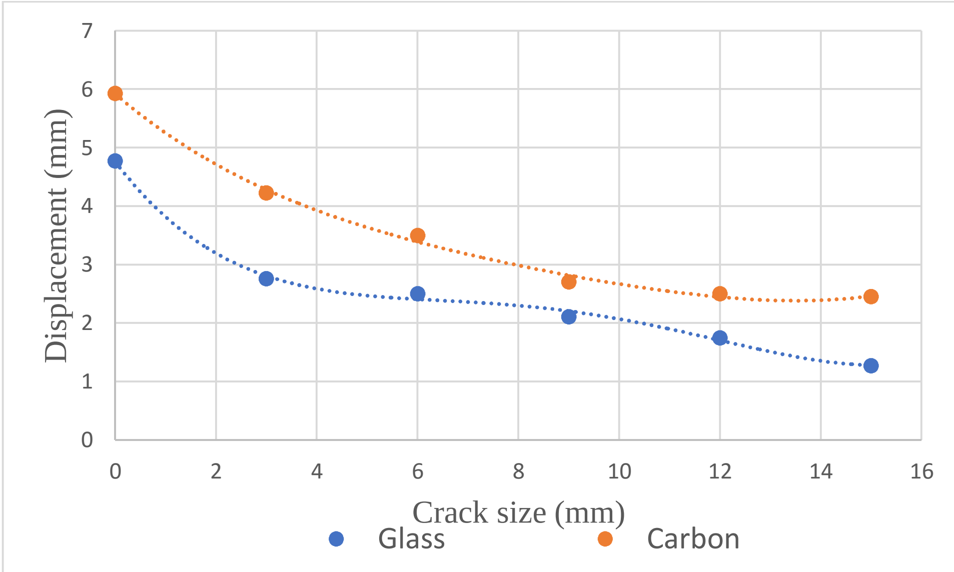


Figure.4.16 the graph of displacement on function of crack

4.8 Result of crack specimens (carbon /epoxy) with different angle and crack fixed (15mm)

Calculate the stress, strain and displacement

a) Displacement

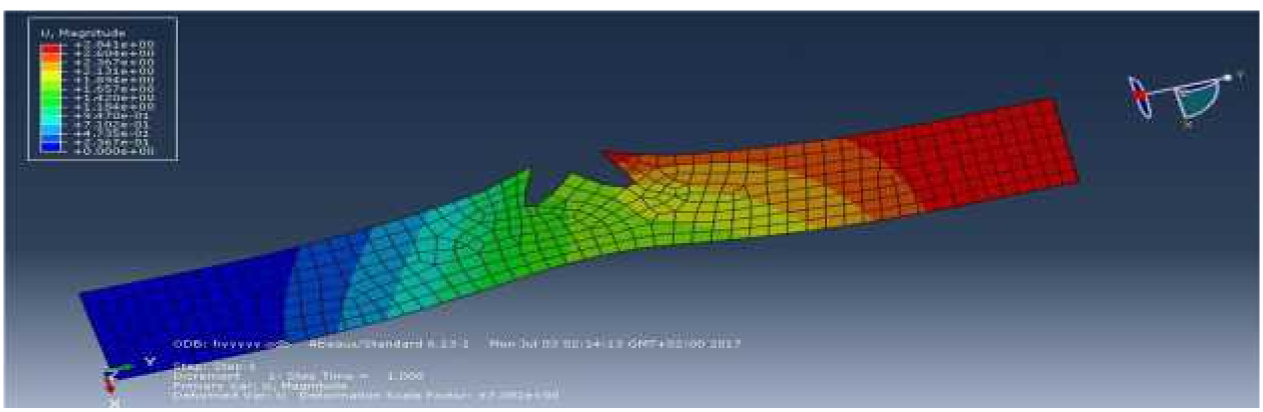


Figure.4.17 maximum strain Umax =2.84mm

b) Stress

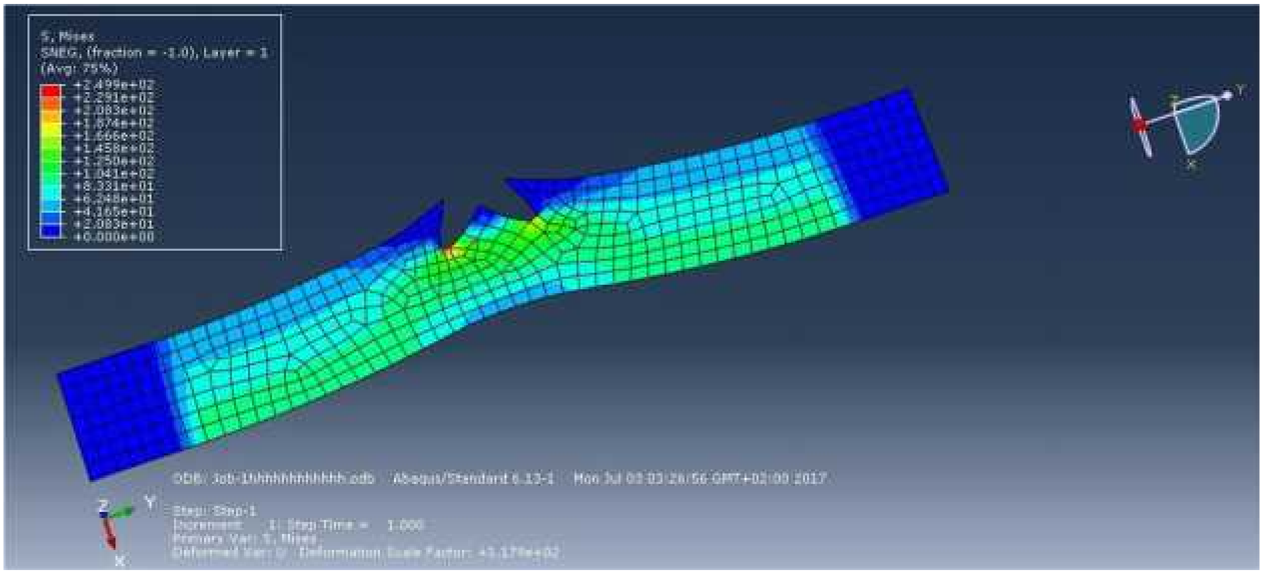


Figure.4.18 Von Mises maximum stress S_{max}=249.4MPa

c)Strain

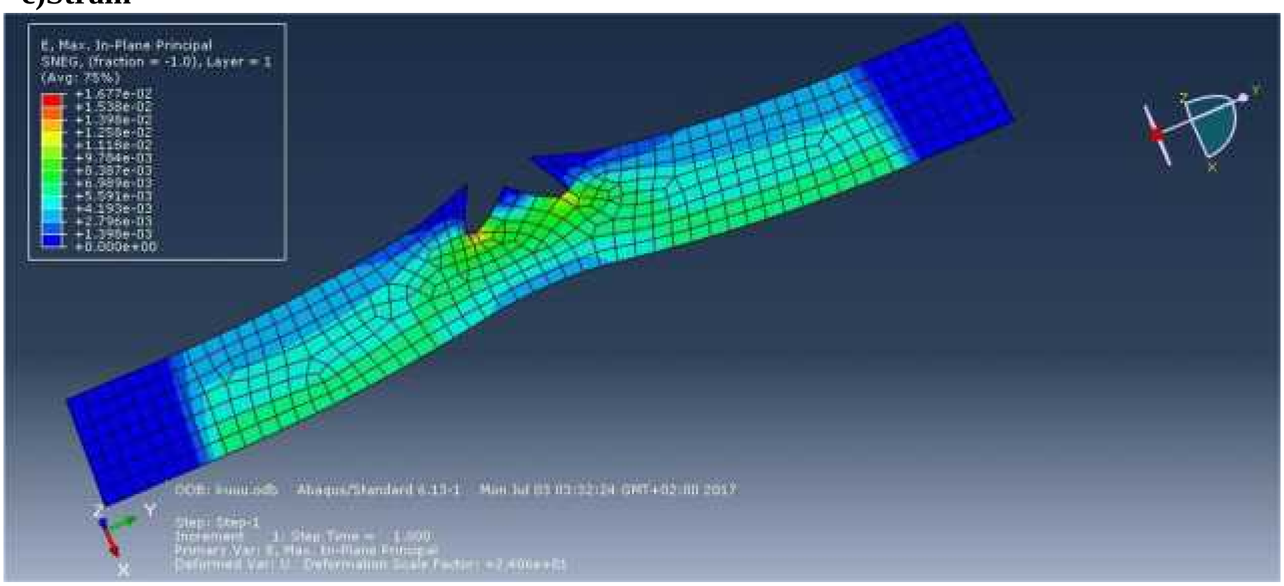


Figure.4.19 the Maximum strain E_{max} =1.67e-2

4.9 Calculate the stress, and the strain and the displacement

The results obtained shown in the Table below

Table.4.1 maximum strain specimen versus angle of crack.

Crack angle / Materials	30°	45°	60°	90°
Carbone/epoxy	1.672e-2	1.446e-2	1.37e-2	1.02e-2
Glass / epoxy	1.59e-2	9.35e-3	9.9e-3	5.5e-3

From the table, we can get this graph

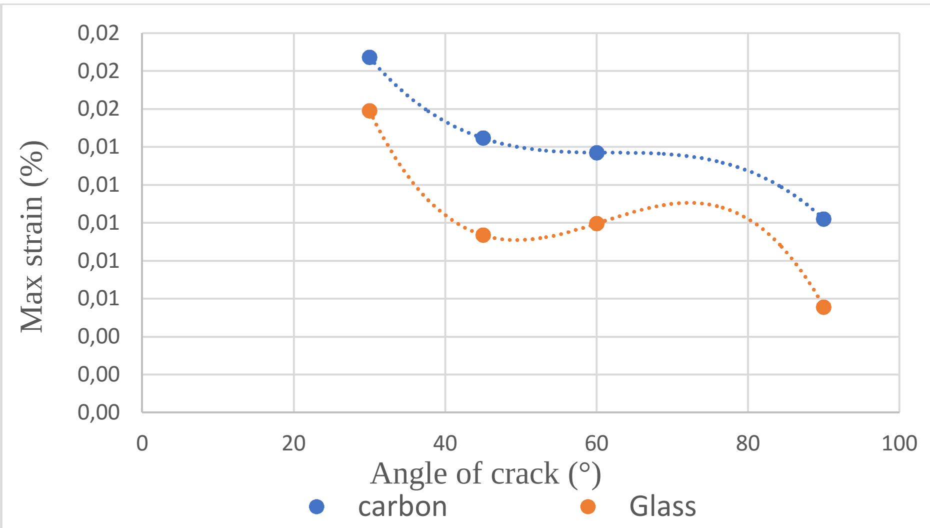


Figure.4.20 the graphs of specimens on function of angle of crack

Table. 4.2 stress max (Smax MPa) versus crack angle of specimen

Crack angle / Materials	30°	45°	60°	90°
Carbone /epoxy	2.495e+2	1.37e+2	1.132e+2	0.825e+2
Glass/ epoxy	0.871	5.552e+2	0.613e+2	0.482e+2

From the table of stress max by angle of crack, we obtain this graph

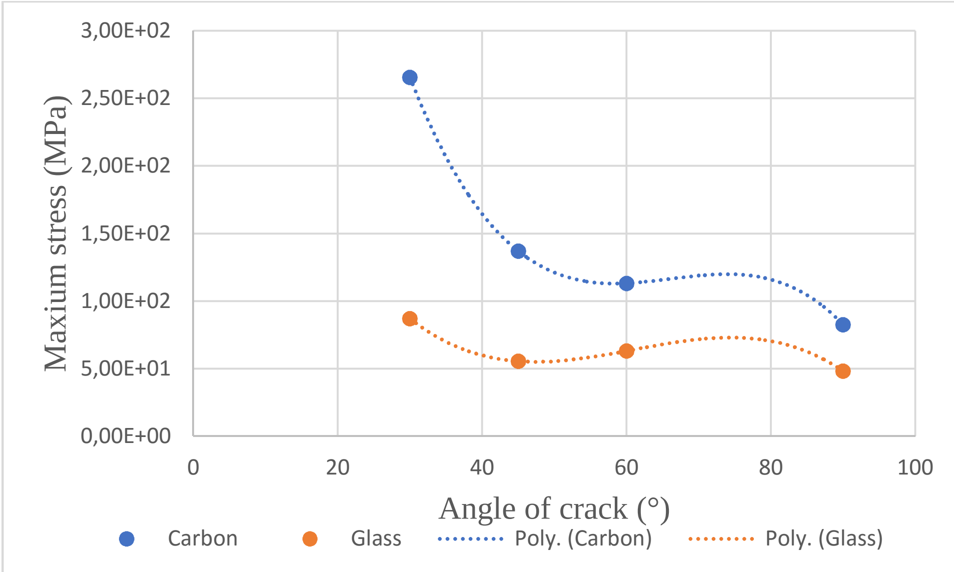


Figure.4.21 The graph of specimens on function angle of crack

Table .4.7 the maximum displacement Umax versus angle of crack

Displacement	**30°**	**45°**	**60°**	**90°**
Carbone/epoxy	2.845	2.451	2.03	1.452
Glass / epoxy	2.301	1.276	1.542	0.783

From the Table we get this graph

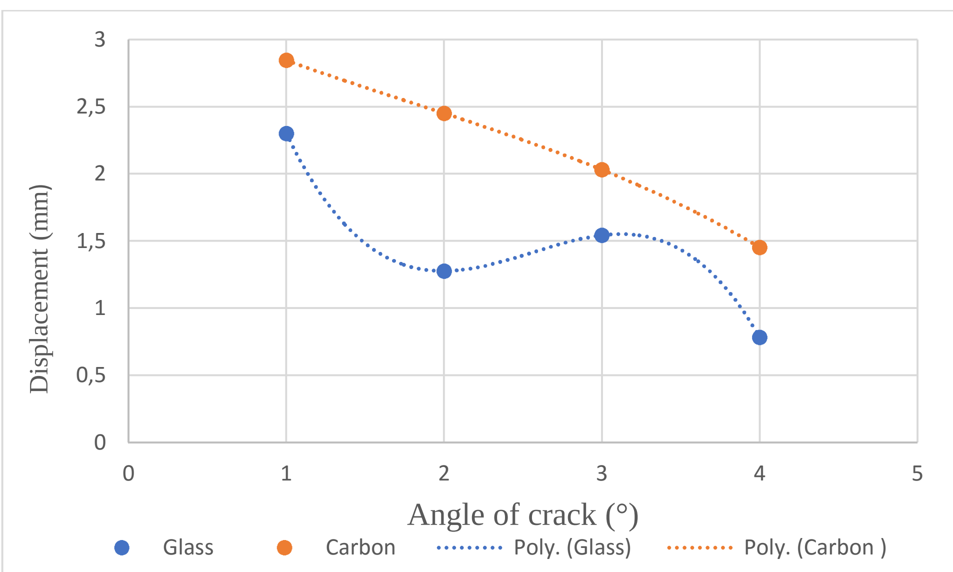


Figure .4.22 The graph of specimens on function angle of crack

Note and interpretation

1/From the graphs we notice that the stress and strain and displacement decreases proportionally to the crack size and angle

2/ from the simulation we observe that the stress in consented in the crack

4.10 Conclusion

In this chapter we can conclude after the result by the Abaqus software we deduce the maximum stresses are concentrated around of the crack .and also cites the behavior during deformation of the plate we also deduce that the displacement which is decrease with increases the crack size from the graph we can conclude that the orientation and size of crack influence on the mechanic behavior of laminate that decreases the stress and the strain and displacement.

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