FABRICATION AND PERFORMANCE EVALUATION OF LOW COST HIGH IMPACT RESISTANT COMPOSITE

MD. ANISUR RAHMAN

M.Sc. ENGINEERING THESIS

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M Sc Engineering Thesis

By

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FABRICATION AND PERFORMANCE EVALUATION OF LOW COST HIGH IMPACT RESISTANT COMPOSITE

DECLARATION

I hereby declare that the study reported in this thesis entitled as above is my own original work and has not been submitted before anywhere for any degree or other purposes. Further I certify that the intellectual content of this thesis is the product of my own work and that all the assistance received in preparing this thesis and sources have been acknowledged and/or cited in the reference section.

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FABRICATION AND PERFORMANCE EVALUATION OF LOW COST HIGH IMPACT RESISTANT COMPOSITE

A Thesis

By

Md. Anisur Rahman

DEDICATION

Dedicated to my wife, my late father and my mother.

ABSTRACT

Fabrication and Performance Evaluation of Low Cost High Impact Resistant Composite

In this thesis low cost composite laminates were fabricated and their effectiveness against high impact was assessed. Glass fiber was used as the fiber and epoxy resin as the binder to create composite laminates. For enhanced binding properties, hardener and 6% cobalt were additionally included with the binder. The laminates vary in terms of layer count, glass fiber type (woven or matt), and curing time. For better comparison between same type of laminates, a few more variables, including the percentage of hardener, the quantity of matrix, and the curing time, were held constant. The mechanical properties were measured giving the Impact test more importance. The mechanical property tests such as the tensile test, compression test, bending test, Charpy impact test, Izod test, and free fall impact tests were done according to the different standardized test method. A laminate with greater performance was found after comparing all the attributes. The production costs were successfully reduced by the thesis because all the materials were readily available and locally manufactured with simple setups. The thesis successfully suggested a possible low-cost production setup for high impact resistant materials.

সারসংক্ষেপ

Fabrication and Performance Evaluation of Low Cost High Impact Resistant Composite

এই গবেষণা কার্যে স্বল্প খরচে কম্পোজিট লেমিনেট তৈরি করা হয় এবং উচ্চ গতির কারণে সৃষ্ট প্রভাবের বিরুদ্ধে এর কার্যকারিতা মূল্যায়ণ করা হয়েছে। ফাইবার (Fiber) হিসেবে গ্লাস ফাইবার (Glass Fiber) এবং বাইন্ডার (Binder) হিসেবে ইপক্সি রেজিন (Epoxy resin) ব্যবহারের মাধ্যমে কম্পোজিট লেমিনেট তৈরি করা হয়েছে। পারস্পরিক বাঁধন আরও মজবুতকরণের জন্য বাইন্ডারের সাথে হার্ডেনার ও ৬% কোবাল্ট মিশ্রিত করা হয়। বিভিন্ন বৈচিত্রের লেমিনেট তৈরির জন্য লেমিনেটের স্তর সংখ্যা, বিভিন্ন প্রকৃতির গ্লাস ফাইবার (উভেন অথবা ম্যাট) ব্যবহার এবং কিউরিং সময় পরিবর্তন করা হয় এই গবেষণায়। আবার একই প্রকৃতির লেমিনেট এর মধ্যে তুলনা করার জন্য কিছু বিশেষ উৎপাদক যেমন হার্ডেনার এর পরিমাণ, ম্যাট্রিক্স এর পরিমাণ এবং কিউরিং সময় অপরিবর্তিত রাখা হয়। উচ্চগতির কারণে সৃষ্ট প্রভাবকে গুরুত্ব প্রদান করতঃ তৈরিকৃত লেমিনেট সমূহের যান্ত্রিক বৈশিষ্ট্যসমূহ পরিমাপ করা হয়। যান্ত্রিক বৈশিষ্ট্য মাপার জন্য অনুমোদিত স্ট্যান্ডার্ড পরীক্ষার ধাপ মেনে টেনসাইল টেস্ট (Tensile Test), কম্প্রেশন টেস্ট (Compression Test), বেন্ডিং টেস্ট (Bending Test), চার্পি ইম্প্যাক্ট টেস্ট (Charpy Impact Test), আইজড টেস্ট (Izod Test) এবং ফ্রি ফল টেস্ট (Free fall Test) সমূহ করা হয়েছে। সকল বৈশিষ্ট্য বিবেচনা করে সবচেয়ে ভাল ফল প্রদানকারী লেমিনেট বের করা হয়েছে। যেহেতু এখানে স্থানীয়ভাবে প্রাপ্ত এবং সহজলভ্য সকল কাঁচামাল ব্যবহার করা হয়েছে তাই এই লেমিনেট তৈরির খরচ সফল্ভাবে হ্রাস করা সম্ভবপর হয়েছে। এই গবেষণা কার্য সফল্ভাবে স্বল্প মূল্যে উচ্চ গতির কারণে সৃষ্ট প্রভাবকে মোকাবেলা করার উপযোগী লেমিনেট তৈরির একটি কর্মপদ্ধতি প্রদান করতে সমর্থ হয়েছে।

ACKNOWLEDGEMENTS

The author firstly thanks Almighty Allah for His relentless blessings to complete this thesis work. The author would like to thank Professor Dr. Afsar Ali, who oversaw his thesis, for his advice, support, and assistance with this study work. The author would like to thank his co-supervisor, Prof. Dr. Enamul Hoque, for his consistent oversight, passionate observations, and direction throughout the thesis. The department's Dean, Brig Gen Md Humayun Kabir Bhuiyan, psc, whose guidance and support allowed the author to labor tirelessly and introduce new ideas, is also noteworthy. The author would also like to recognize the efforts of the lab staff, in particular Sub Asst Engr Mr. Md. Raju Ahmed and Sub Asst Engr Mr. Dibakar Tarafdar, who assisted with the setup and execution of experiments for the research work. Last but not the least, the author would like to express his utmost gratitude to his family members who has been patient and supportive all through this journey.

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LIST OF MAIN NOTATIONS

σ	Engineering Stress
ε	Engineering Strain
ΔL	Change in length of the specimen
L_0	Original length of the specimen
σ_f	Flexural strength
F	Load at fracture
L	Distance between supports
b	Width of the specimen
h	Thickness of the specimen
E_f	Flexural modulus
δ	Deflection of the specimen at the center of the span
V	Velocity of the pendulum
h	Height of the pendulum
A	Cross-sectional area of the specimen
$\bar{v}$	Average velocity of a projectile
v_s	Velocity after impact
v_r	Velocity before impact
σ_x	Stress in x- direction
τ_{xy}	Shear Stress in x-y plane
τ_{xz}	Shear Stress in x-z plane

ε_x	Normal strain in x-direction
ε_y	Normal strain in y-direction
V_f	Volume fraction of fiber
v_f	Total volume of fiber
v_c	Total volume of composite
V_v	Volume Void Fraction
σ_{TS}	Peak yield strength
σ_f^f	Fracture strength of fiber
σ_y^m	Fracture strength of matrix
σ_{TS}	Peak yield strength
σ_f^f	Fracture strength of fiber
σ_y^m	Fracture strength of matrix.
E_f	Modulus of elasticity of bending
ε	Strain in the elastic deformation limit

CHAPTER 1

INTRODUCTION

1.1 General

Composite materials are widely used for different purposes for their easy fabrication process, desired property and wide application area. Impact resistant materials are used in different applications like armor, vehicles, vessels, helmets etc. The impact resistant properties are achieved by using high profile lightweight Kevlar material. Kevlar being expensive and not readily available in the market makes it difficult to use for wider applications. For special military application, using Kevlar is necessary. But for general application where costing should be controlled, Kevlar can't be used. So finding out an alternative solution is required.

1.2 Problem Statement

The composite materials used in different applications can be made of high density polymers (Ignatova, n.d.), ceramic (Crouch, 2019), rubber inserts (Medina et al., 2018) or natural fibers (Ali et al., 2019b). Different fabrication processes are used i.e. hand layup (Nurhadiyanto and Mukhammad, 2017) , injection molding (Ye et al., 2008) or nano particle mix (Kovács et al., 2018) etc. Most of the fabrication process contains rigorous steps and requires high end machines. The complexity and complication of those processes has made fabrication more expensive. Moreover without the high end machines and processes, the performance of composites drops down (Naik et al., 2013) and thus it creates a problem to be addressed or solved. This research concentrates to solve this issue by preparing a composite with better impact resistance with a simplified fabrication process and in lower cost. The research tried to prepare the composites with readily available materials also.

1.3 Objectives of the Research Work

The research has the following objectives:

(i) To fabricate high impact resistant composite.
(ii) To formulate easier fabrication process.
(iii) To fabricate the composite in lower price.

(iv) To fabricate the composite with readily available materials.

(v) To investigate the impact resistance performance of the composites.

1.4 Organization of the Thesis

This thesis is divided into five chapters. The chapters are designed in following manner.

Chapter 1 will give a general idea about the thesis and introduction to problem statement along with the objectives of the thesis.

Chapter 2 discusses relevant previous works done by different researchers. The required equation, graphical models, methodology and results of the previous works will be focused.

Chapter 3 will describe the methodology followed by this research. The chapter describes the fabrication process, the mechanical tests done on the composites in details.

The results of the tests are shown and compiled in chapter 4. The relevant data, charts and graphs are presented, compiled and analyzed.

The chapter 5 analyzes the results and tries to draw a conclusion from the achieved result.

CHAPTER 2

LITERATURE REVIEW

2.1 General

The purpose of this study is to present the different forms composites fabrication process, composite made of glass fibers, effectiveness of fabricated composite against high velocity projectiles, calculations of fiber and matrix. The fabricated composite in this research will follow the previous works and evaluation of their performance will be done.

2.2 Fiber Composites

Ali et al., (2019) fabricated a composite made of bamboo- woven E glass fiber-unsaturated polyester. The bamboo strips were cut into specific length and width to convert it into a woven form of bamboo. The woven e glass fiber and bamboo woven fiber was bonded by epoxy resin. The layers were placed one over another brushing the epoxy in between the layers as matrix. Two combinations of composites were made where one combination had 4 layers of woven bamboo/ 18 layers of e glass fiber and another combination had 9 layers of e glass fiber/ 4 layers of woven bamboo/ 9 layers of e glass fibers. The composites then were tested against ballistic impacts.

Braga et al. (2017) made a composite of ceramic, aramid fiber and steel plate. The ceramic material was used as front part of the composite, then second layer was made of curaua or aramid fiber and last layer was steel plate. All the layers were bonded by epoxy resin. The curaua fibers used here was non-woven type. The composite was exposed to blast and the condition of composite after the blast was investigated.

A composite made of Kevlar 29, metal sheet and fiber cement was investigated against for ballistic performance by Soydan et al. (2018). Here 200 g/m^2 Kevlar 29 fabrics were used. 10 layers of Kevlar 29 and 8 mm of fiber cement were used in all the samples whereas the thickness of steel plate was changed from 1 mm, 1.5 mm and 3 mm. As binder epoxy resin L285 with H160 haredner was used in the study. The composites were then was tested against 9 mm projectiles.

Ramie fiber is a natural fiber with high tensile strength. The fibers can be processed and weaving can be done to make it a fabric. Mujiyono., Nurhadiyanto and Mukhammad, (2017) developed a composite made of rami fiber and epoxy. The layers were oriented in

0º and 90º direction to maintain the fiber direction uniform. The 12 layers were placed one over another alternating the direction of fibers. Epoxy was used to bind and solidify the composite. The composite then tested against high velocity projectile.

Kenaf fiber is another natural fiber which was used by Azmi et al. (2018) with X ray films to fabricate a composite of higher impact resistant properties. Total 7 layers of X ray film and kenaf fiber woven fabric were used to fabricate the composite. The resin used here was mixed with hardener at a ratio of 2:1. Mechanical properties i.e. tensile, flexural were investigated as well as high velocity impact tests were also done.

Chatys et al. (2019) developed a composite made of glass woven fabric, carbon bi-axial woven fabric and ceramic tiles with epoxy resin binder. The glass fiber fabric had 6 layers, then 4 layers of matte glass fabric then ceramic tiles and then steel plate. The epoxy with a hardener mixing ratio of 100:33 is used in this study. The composite was fabricated by vacuum bagging method. The mechanical and physical properties were also investigated for this composite.

2.3 Fabrication process

Ali et al. (2019) used hand lay-up method to make the composites. The E-glass fibers were first woven into a fabric, and after that, unsaturated polyester resin was applied to the fabric. The bamboo fibers were weaved into a fabric in a similar manner, and the fabric was then impregnated with the resin. By alternately stacking E-glass reinforced fabric and bamboo reinforced fabric and employing resin as an adhesive, the hybrid composites were created. Three distinct weight ratios of bamboo and E-glass fibers—10:90, 20:80, and 30:70—were combined to create the hybrid composites. For all the composites, the fiber volume fraction was held constant at 0.4. Following the lay-up procedure, the composite panels were cured in a hot press for 4 hours at 60°C and 10 MPa of pressure. The cured composite panels were then sliced into specimens for tensile, flexural, and impact testing, among other mechanical evaluations. In order to create the hybrid composite panels, unsaturated polyester resin was impregnated, bamboo and E-glass fibers were weaved together, and then the panels were hand-layed. The hybrid composites are a viable alternative material for ballistic applications because of their straightforward and affordable construction procedure.

Fig 2.1: Bamboo-E glass fiber composite made by Ali et al. (2019)

Doddamani and Kulkarni (2012) prepared jute/epoxy composite face sheets, the functionally graded rubber core is made, and then the face sheets are bonded to the core as part of the construction process. To create the face sheets, the jute fibers are first impregnated with epoxy resin and then laminated together. The procedure of creating the rubber core involves mixing different rubber particle concentrations into the core at different thicknesses. To ensure that the rubber particles are properly bonded, the core is next heated and pressurized to cure. Next, a vacuum bagging procedure is used to properly attach the face sheets and functionally graded rubber core together. This entails compressing the sandwich panel with a vacuum to ensure a tight bond between the layers. The resulting sandwich panel is then put through ballistic testing to determine how well it can withstand being penetrated by fast bullets. A functionally graded rubber core sandwich panel made of jute and epoxy performed better in ballistic tests than a conventional solid rubber panel.

Fig 2.2: Jute/ Epoxy composite with rubber core produced by Doddamani and Kulkarni, (2012)

The fabrication of a bulletproof panel composed of Ramie Fiber Reinforced Epoxy (RFRE) composite is discussed in the study done by Mujiyono., Nurhadiyanto, and Mukhammad (2017). The procedure entails a number of phases, including panel molding, composite production, and fiber treatment. To get rid of contaminants and strengthen the bond between the fibers and the matrix, the ramie fibers are first exposed to an alkaline solution. Upon drying, the fibers are impregnated with epoxy resin using a vacuum-assisted method. After placing the coated fibers in a mold and compressing them under heat and pressure to achieve good bonding between the fibers and the epoxy matrix, the RFRE composite is created. Using a hot press molding procedure, the resulting RFRE composite is cut into the proper shapes and sizes and formed into a bulletproof panel. The efficiency of the final bulletproof panel's resistance to penetration by high-speed projectiles is assessed after it has undergone a high-speed ballistic test to assess its ballistic performance.

Fig 2.3: Ramie Fiber Reinforced Epoxy (RFRE) prepared by Mujiyono., Nurhadiyanto, and Mukhammad, (2017)

The manufacturing of a bulletproof vest employing hybrid composites made of Kenaf and X-ray film is described by Azmi et al., (2018). Fiber treatment, composite fabrication, and panel assembly are a few of the phases in the fabrication process. To get rid of contaminants and enhance fiber-matrix adhesion, the Kenaf fibers are first cleansed and treated with an alkali solution. After being treated, the fibers are dried and impregnated with an epoxy resin using a vacuum-assisted technique. After being appropriately sized and shaped, the X-ray film is then impregnated with the same epoxy resin. The hybrid composite is then heated and pressurized to cure, ensuring that the X-ray films and fibers are properly bonded. A bulletproof vest is constructed using panels of the finished hybrid composite. The efficiency of the final bulletproof vest's resistance to penetration by high-speed bullets is assessed after it has undergone a high-speed ballistic test to assess its ballistic performance.

The manufacture of ceramic composite armor intended for ballistic protection is described by Liu et al., (2016). The fabrication process entails a number of phases, such as panel assembly, composite fabrication, and ceramic preparation. The ceramic is first made by creating slurry by combining alumina powder with a binder. The ceramic tiles are then created by casting the slurry into the correct shape and firing it at a high temperature. In the composite fabrication process, a fabric layer is impregnated with a resin matrix before being covered in ceramic tiles. The composite is then heated and pressurized to cure, ensuring that the fabric layer and ceramic tiles are well bonded. The last stage is to put the panels together by joining several ceramic composite layers to produce a thick and durable armor panel.

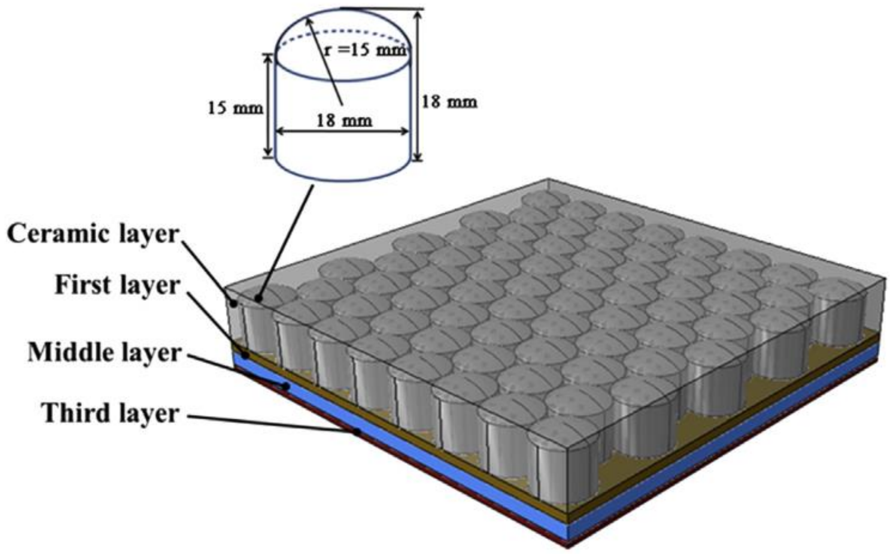


Fig 2.4: Schematic diagram of ceramic composite fabricated by Liu et al., (2016)

Chatys et al., (2019) prepared a composite of 25 layers with ceramic tiles, glass fiber and carbon fiber by vacuum bagging method. There are multiple stages to the fabrication process, including fiber preparation, composite manufacture, and curing. To enhance adhesive and mechanical qualities, fibers are subjected to a variety of chemical treatments during the fiber manufacturing process. The composite is created by weaving the treated fibers into a fabric that is coated in a resin matrix. The coated fiber fabric is layered to the necessary thickness during the composite fabrication process, and the composite is then cured under particular temperature and pressure conditions. Following the curing procedure, the composite structure is constructed and cut to the required size and shape for military purposes. The composite structure's mechanical characteristics are then modeled using a variety of software tools to make sure they adhere to the precise military specifications.

Soydan et al., (2018) made a comparison of the ballistic performance of several laminates. A Kevlar/epoxy laminate and a carbon/epoxy laminate are specifically compared. Several layers of Kevlar fibers woven into a fabric and impregnated with epoxy resin make up the Kevlar/epoxy laminate. On the other hand, the carbon/epoxy laminate is made of several layers of carbon fibers woven into a fabric and covered with epoxy resin. By putting the laminates through high-speed ballistic impact testing and measuring how well they can withstand being penetrated by projectiles traveling quickly, the laminates are compared. The findings indicate that the Kevlar/epoxy laminate outperforms the carbon/epoxy laminate in terms of ballistic performance.

Braga et al., (2017) illustrated how multilayered armor systems are made utilizing aramid laminates and non-woven curaua fabric composites. The curaua fibers are impregnated with a thermosetting resin before being carded and needled to create a nonwoven fabric, which is how the nonwoven curaua fabric composites are made. The cloth is then stacked to create a multilayered composite after being cut to the required size and shape. Kevlar or other aramid fibers layered in many layers and treated with epoxy resin are used to create the aramid laminates. To acquire the necessary mechanical qualities, the layers are layered in a particular orientation and then cured under pressure and heat. In order to obtain the appropriate level of ballistic protection, the multilayered armor systems are then put together by stacking numerous layers of the non-woven curaua fiber composite and aramid laminate in a certain order. The effectiveness of the resulting armor systems in resisting penetration by fast projectiles is assessed after they have been put through high-speed ballistic impact testing.

Fig 2.5: Curaua Fiber Composite illustrated by Braga et al., (2017)

2.4 Property Tests

Different tests of the fabricated composites are done for finding out the performance against impact. The tests were done by following some standards. From the preparation of sample to deriving the data and drawing a conclusion all the steps were followed according to the standards.

2.4.1 Tensile Test

Tensile test was done according to the ASTM A 370-19 was followed. ASTM A370-19, (2019) specifies the steps of tensile test which is as below:

(i) Specimen Preparation: A bigger sample of the material is machined into the test specimen, which is then cut to the standard's required measurements. Usually rectangular in shape, the specimen has a predetermined gauge length and gauge width.

(ii) Mounting the specimen: Using grips that hold it firmly without causing damage, the specimen is mounted into the testing device. The specimen's gauge length is meticulously measured and noted.

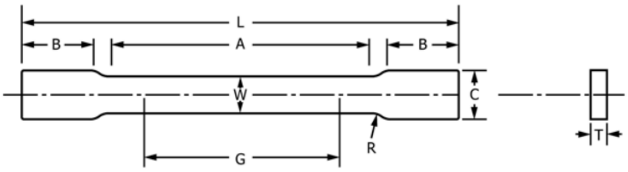
(iii) Applying load: Typically, a hydraulic or electromechanical testing machine is used to provide a regulated tensile load to the specimen. The load is steadily increased until the specimen breaks or fractures.

(iv) Measuring the load and deformation: During the test, a load cell is used to measure the load applied to the specimen, and an extensometer or strain gauge is used to measure the specimen's deformation. Throughout the test, the load and deformation data are continually logged.

(v) Calculating tensile properties: After the test is finished, the load and deformation data are utilized to compute the material's tensile properties, including ultimate tensile strength, yield strength, elongation, and area reduction.

(vi) Reporting results: The specimen dimensions, test parameters, and tensile characteristics are recorded in accordance with the criteria of the standard.

The dimension of the specimen for the tensile test for different shaped specimen is shown in the figure below:



DIMENSIONS

	Standard Specimens						Subsize Specimen	
	Plate-Type, 1½-in. (40-mm) Wide							
	8-in. (200-mm) Gauge Length		2-in. (50-mm) Gauge Length		Sheet-Type, ½ in. (12.5-mm) Wide		¼-in. (6-mm) Wide	
	in.	mm	in.	mm	in.	mm	in.	mm
G—Gauge length (Notes 1 and 2)	8.00 ± 0.01	200 ± 0.25	2.000 ± 0.005	50.0 ± 0.10	2.000 ± 0.005	50.0 ± 0.10	1.000 ± 0.003	25.0 ± 0.08
W—Width (Notes 3, 5, and 6)	1½ + ⅛ − ¼	40 + 3 − 6	1½ + ⅛ − ¼	40 + 3 − 6	0.500 ± 0.010	12.5 ± 0.25	0.250 ± 0.002	6.25 ± 0.05
T—Thickness (Note 7)	Thickness of Material							
R—Radius of fillet, min (Note 4)	½	13	½	13	½	13	¼	6
L—Overall length, min (Notes 2 and 8)	18	450	8	200	8	200	4	100
A—Length of reduced section, min	9	225	2¼	60	2¼	60	1¼	32
B—Length of grip section, min (Note 9)	3	75	2	50	2	50	1¼	32
C—Width of grip section, approximate (Notes 4, 10, and 11)	2	50	2	50	¾	20	⅜	10

Fig 2.6: The standard specimen dimension given in ASTM A370-19 (2019)

2.4.2. Bending Test

Bending test was done according to ASTM D7264. The steps of the bending test under ASTM D7264 (2016) is given below:

(i) Specimen Preparation: The composite specimen should be cut to the required dimensions in accordance with the standard. The specimen must be level, straight, and deformed-free.

(ii) Test Setup: According to the standard's recommended span-to-depth ratio, the specimen is mounted in the testing apparatus. The specimen is set up so that the loading point sits squarely in the middle of it.

(iii) Pre-test Measurement: The specimen's width and thickness is measured several times to make sure they are within the allowed tolerances.

(iv) Testing: With the help of the testing device, a controlled load at a steady rate is applied on the specimen. The load should be applied up until the specimen fails or obtains the desired deflection.

(v) Data Collection: At regular intervals throughout the test, the specimen's load and deflection are noted. Various parameters including strain, flexural strength, and flexural modulus are computed with the readings taken.

(vi) Analysis: Test findings are analyzed according to the standard specification.

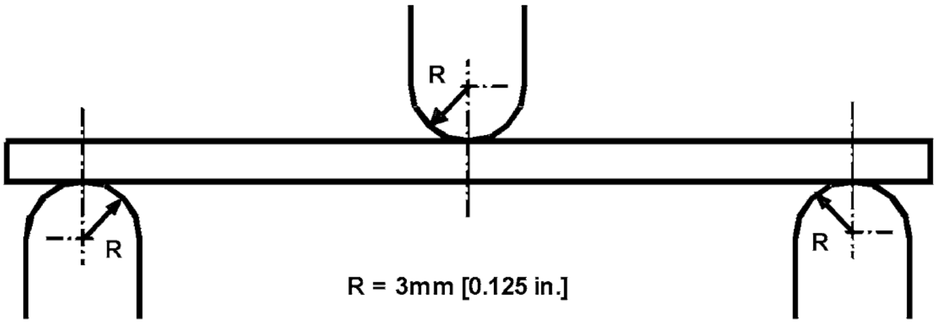


Fig 2.7: Three point loading configuration for bending test as specified in ASTM D7264(2016)

2.4.3. Charpy Impact Test

Chapry Impact Test is a common form of test to measure the material's resistance to high impact. For the conduct of Impact test ASTM E 23 has been followed. The steps of ASTM E23, (2016) Charpy Imapct V-Notch test is given below:

(i) Specimen Preparation: Samples should be cut from the material in accordance with the standards' detailed instructions. The specimens should have exact measurements and be thoroughly checked for flaws or damage.

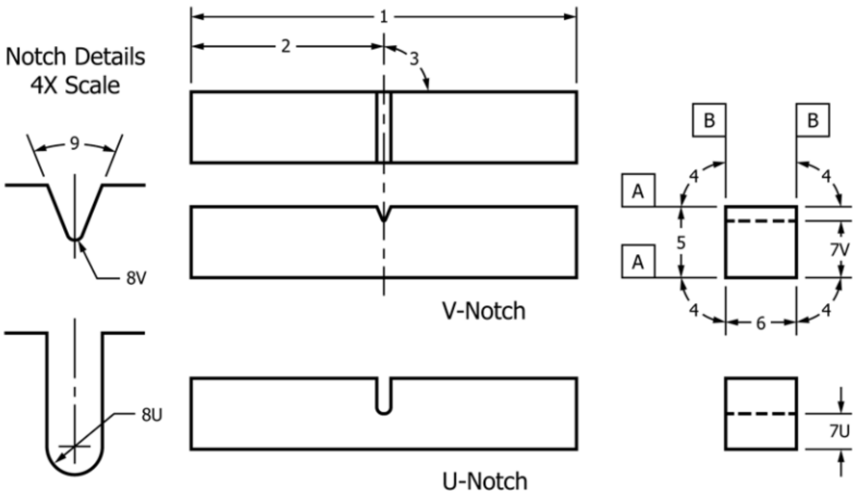
(ii) Specimen Conditioning: Before testing, the specimens must be prepared in a controlled setting in accordance with the standard. This is to guarantee that the test samples are at the proper temperature and humidity level.

(iii) Test Setup: The testing equipment, which normally consists of a pendulum impact tester, a notched specimen, and a specimen container, should be set up. The test tool needs to be calibrated in accordance with the standard.

(iv) Test Execution: After carefully aligning the notch with the impact direction, the specimen is placed into the holder. To hit the test subject, the pendulum was released and the greatest force and amount of energy absorbed is noted down.

(v) Result Calculation: Based on the maximal force and the energy absorbed during the test, the material's impact strength is determined.

The ASTM E23 standardized V notch specimen dimension for Charpy Test is given below:



ID Number	Description	Dimension	Tolerance
1	Length of specimen	55 mm	+0/-2.5 mm
2	Centering of notch		±1 mm
3	Notch length to edge	90°	±2°
4	Adjacent sides angle	90°	±0.17°
5	Width	10 mm	±0.075 mm
6	Thickness	10 mm	±0.075 mm
7V	Ligament length, Type V	8 mm	±0.025 mm
7U	Ligament length, Type U	5 mm	±0.075 mm
8V	Radius of notch, Type V	0.25 mm	±0.025 mm
8U	Radius of notch, Type U	1 mm	±0.025 mm
9	Angle of notch	45°	±1°
A	Surface finish requirements	2 µm (Ra)	≤
B	Surface finish requirements	4 µm (Ra)	≤

Fig 2.8: Charpy Test specimen dimension specified in ASTM E23 (2016)

2.4.4. Izod Impact Test

Similarly as Charpy Impact Test the Izod Impact Test is followed as per ASTM E23. The steps involved in ASTM E23, (2016) is given below:

(i) Specimen Preparation: The test specimen should be prepared using the standard's recommended dimensions. Usually rectangular in shape, specimens have a predetermined thickness, breadth, and length. The middle of one of the large faces of the specimen is then machined with a notched or V-shaped groove.

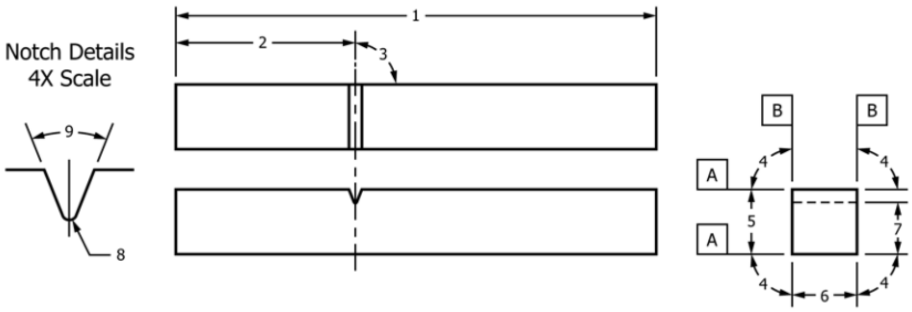
(ii) Test Apparatus Set-Up: The test equipment should be set up in accordance with the standard's specifications and the manufacturer's instructions. A pendulum hammer, an anvil, and a specimen support make up the test equipment.

(iii) Calibration: The techniques indicated in the standard should be used to calibrate the test equipment.

(iv) Test Procedure: The specimen is placed into the specimen support with the notched face facing away from the hammer. The pendulum is released so that it lands on the specimen at the notch. The force necessary to break the specimen is noted as well as any additional information that may be pertinent, such as the test's temperature.

(v) Result Calculation: The necessary calculations from the standard are used to determine the impact energy needed to break the specimen.

The ASTM E23 standardized V notch specimen dimension for Izod Test is given below:



ID Number	Description	Dimension	Tolerance
1	Length of specimen	75 mm	+0/-2.5 mm
2	Notch to top	28 mm	
3	Notch length to edge	90°	±2°
4	Adjacent sides angle	90°	±0.17°
5	Width	10 mm	±0.025 mm
6	Thickness	10 mm	±0.025 mm
7	Ligament length	8 mm	±0.025 mm
8	Radius of notch	0.25 mm	±0.025 mm
9	Angle of notch	45°	±1°
A	Surface finish requirement	2 µm (Ra)	≤
B	Surface finish requirement	4 µm (Ra)	≤

Fig 2.9: Izod Test specimen dimension specified in ASTM E23 (2016)

2.4.5. Free fall Impact Test

In case of free fall impact test, the specimen is tested against a free falling semi-circular bob released from a definite height and falling over the test specimen. The physical damage was investigated and penetration degree was measured. The laminar dislocation and penetration effect indicates the amount of energy absorbed by the specimen. In this testing system no established standard was followed. But the lab tested apparatus was used against the different specimen. Each time the bob was released a timer recorded the amount of time required to hit the test sample. Hence indicating the energy hit by the bob on the specimen. The test is conducted as a lab standard arrangement. This test is done only to investigate the penetration effect physically not for any specific calculation.

2.4.6. High velocity Impact Test

The high velocity impact test was conducted in this thesis by the help of firing 9 mm projectile fired from a specific distance. All the tests were done from a specific distance to compare the penetration effect of the same bullet on different specimen. The firing was done by the expert firer to hit the sample in specific zone over the plate. The steps of this test procedure are given below:

(i) Specimen Preparation: The laminates are cut or prepared in specific dimension to fit those in the target plate. The dimension of this plate is 6” x 6”. All the specimens are prepared according to this dimension.

(ii) Setting up the sample in Target plate: The target plates are available in the firing range. The plates hold up the sample by the help of small hooks attached to it. The samples are then placed and hooked to the target plate.

(iii) The projectile release: The projectile is released from a specific distance. The projectile is then kept in the specified distance and released to hit the specimen.

(iv) Data collection: Each time the projectile hits the specimen, the time required is recorded and specimen is taken out from the target plate to investigate the penetration effect.

(v) Investigation: The specimens are detached from the plate and penetration of the projectile on the specimens are investigated and compared.

2.5 Governing Equation and Calculation of Property Tests

The property tests are done under the standardized procedures specified in the standard manual. The properties are calculated in the same way the manual suggests. The different governing equations and calculation procedures are described in this section.

2.5.1 Tensile Test

ASTM A370 (2019) describes the calculation procedure of finding out the stress vs strain diagram. The yield strength for each lamina is found from the diagram which indicates the maximum strength can be imparted over. The yield strength is determined from the graph plot of stress vs strain diagram. The typical way of specifying the yield strength is to use the offset method from the graph. ASTM A370 (2019) provides a graph for ideal stress-strain diagram.

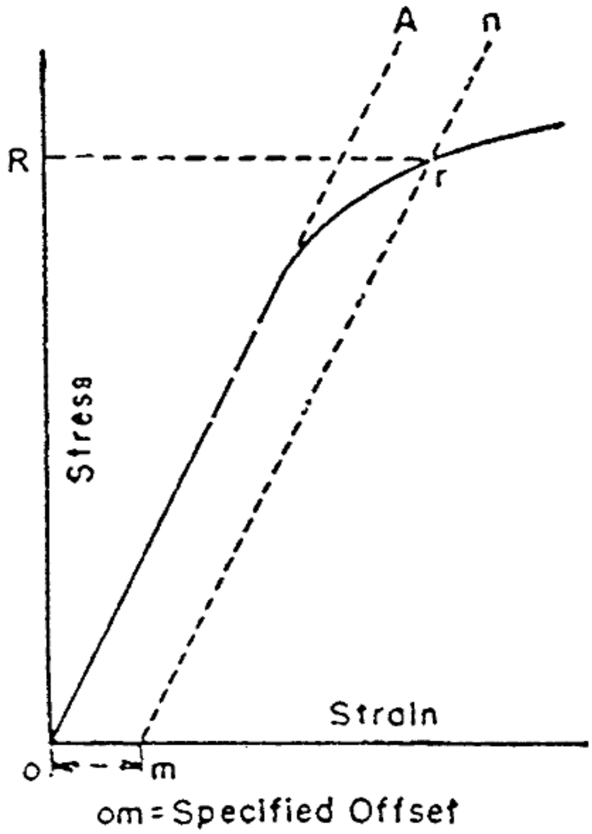


Fig 2.10: Stress-strain diagram, yield strength determined by offset Method described in ASTM A370 (2019)

According to Gibson (2012), the yield strength, which specifies the stress level at which the material will start to bend plastically, or outside of its elastic range, is a crucial mechanical parameter of composite materials. The tension at which a material begins to permanently distort or yield is known as the yield strength. The yield strength of composite materials is a crucial factor since it establishes the material's capacity to transport loads and its capacity to withstand applied stresses without irreversible deformation or failure. The material's longevity and resistance to damage under various loading circumstances can both be inferred from the yield strength. Moreover, structural components are frequently designed using the yield strength of a composite material to make sure they can sustain the projected loads and stresses. In the creation of predictive models for composite structures, such as finite element models, which are used to optimize the design of composite components for diverse applications, it is also a crucial component.

The equation followed for the calculation of yield strength is as following:

$$\sigma = \frac{F}{A} \tag{2.1}$$

Where, σ = Engineering Stress; F = Applied Force; A = Original Cross sectional area of the specimen

$$\varepsilon = \frac{\Delta L}{L_0} \tag{2.2}$$

Where, ε = Engineering Strain; ΔL = Change in length of the specimen; L_0 = Original length of the specimen

The diagram drawn with the engineering stress and strain is then used to find the yield strength. A material's yield strength is the stress at which it demonstrates a certain deviance from the proportionality of stress and strain. The standard deviation from the linear-elastic region of the stress-strain curve is 0.2% strain offset. The equation for calculating yield strength is as follows:

$$\sigma_y = (0.2\%\ \text{offset yield strength}) \tag{2.3}$$

$$= (\text{Stress at } 0.2\%\ \text{strain offset})$$

The standard method for calculating the 0.2% offset yield strength is to draw a line parallel to the linear-elastic region of the stress-strain curve and intersect it at the 0.2% strain value. The yield strength is then determined by looking at the stress value where this line and the curve connect. (Gibson, 2012)

2.5.2 Bending Test

The bending test, commonly referred to as the flexural test, is a vital test procedure used to assess the mechanical qualities of composite materials. The bending test is used to evaluate the material's stiffness and flexural strength. In order to conduct the test, a sample of the composite material that is supported at two places must have its center loaded. The material will flex as the force is applied, and the degree of deflection is gauged. The material's flexural strength and modulus are then determined using the load and deflection information. The significance of the bending test lies in the useful information it offers regarding the material's capacity to bear bending loads and how it will react under various bending scenarios. For designing and constructing composite materials for particular purposes, such as aircraft, automotive, and construction, this knowledge is essential. Also, the bending test can shed light on the consistency and quality of the composite material. The bending test can identify any such changes that may affect the material's performance. Variations in the composition of the material or in the manufacturing process can affect its bending capabilities. In conclusion, the bending test is crucial for figuring out a material's bending properties, which are crucial for designing and constructing composite materials for different purposes (ASTM D7264, 2016).

The bending test gives two important parameters of the material. They are flexural strength and flexural modulus. The maximum stress a material can endure while bending before breaking is known as flexural strength. According to Gibson (2012) Flexural strength in composite materials refers to a composite's capacity to withstand bending loads. It is a crucial factor in determining how well and how long-lasting composite materials function in diverse applications. The equation of flexural strength is given in Equation (2.4):

$$\sigma_f = \frac{3\,FL}{2\,bh^2} \tag{2.4}$$

Where, σ_f = Flexural strength; F = Load at fracture; L = Distance between supports; b = width of the specimen; h = Thickness of the specimen

The ratio of stress to strain in bending for a material is known as the flexural modulus. According to Gibson (2012) flexural modulus in composite materials refers to a composite's capacity to withstand deformation under bending pressures. In many applications, it is a crucial characteristic to assess the stiffness and rigidity of composite materials. The equation of flexural strength is given in Equation (2.5):

$$E_f = \frac{FL^3}{4bh^3\delta} \tag{2.5}$$

Where, E_f = Flexural modulus; F = Load at fracture; L = Distance between supports; b = width of the specimen; h = thickness of the specimen; δ = deflection of the specimen at the center of the span

The flexural modulus is used to calculate the deflection of a composite material under a given load, which is important for designing and optimizing composite structures.

2.5.3 Charpy Impact Test

The Charpy impact test can simulate impact or shock loads that a material could encounter in service and is particularly helpful in evaluating the behavior of composite materials under dynamic and abrupt loading circumstances. In order to create and design composite materials for use in a variety of industries, including aerospace, automotive, and construction, this understanding is essential (ASM International, 2000).

The impact strength of the is measured with the help of Equation (2.6)

$$\text{Impact Strength} = \frac{V(h/2)}{A \times d} \tag{2.6}$$

Where, V = Velocity of the pendulum; h = Height of the pendulum; A = Cross-sectional area of the specimen; d = Deflection of the specimen at fracture

2.5.4 Izod Impact Test

Izod impact and charpy impact test provide similar parameter of the composite material. There are some significant variations between the two procedures, even though they both involve striking a specimen that has been notched with a pendulum. The position of the notch in the specimen differs between the Charpy and Izod impact tests. In the Izod test, the notch is positioned on the same side as the point of impact as opposed to the Charpy test, where the notch is on the other side of the specimen from the point of impact. This variation may have an impact on the specimen's stress and strain distribution and result in various outcomes.

Another difference is the shape of the specimen. The Izod specimen is a cantilever beam with a triangular cross-section, whereas the Charpy specimen is normally rectangular in shape. This distinction may also have an impact on the specimen's stress and strain distribution, which may produce various outcomes. Overall, both tests provide important information on the impact resistance of composite materials, but the choice of test method may depend on the specific application and material properties being evaluated (Gibson, 2012). The Equation (2.6) is also applicable to Izod Test.

2.5.5. Free fall Impact Test

A common technique for assessing the impact resistance of composite materials is the free fall impact test. It is especially helpful for analyzing how composite materials behave when subjected to high-velocity impact stresses, such those found in aerospace and defense applications. In the test, an impactor is dropped onto a specimen with or without notches, and the amount of energy received by the substance prior to failure is measured. These details can be used to analyze the material's impact strength and fracture toughness, two crucial characteristics for determining if it is suitable for usage in high performance applications (Gibson, 2012).

The equation of free fall impact test is given in Equation (2.7) given by (Callister, 2007)

$$E = \frac{1}{2} mv^2 \tag{2.7}$$

Where, E = Energy of the impact; m = Mass of the impactor; v = Impact velocity

The energy needed to fracture a material under an impact load, such as in a free fall impact test, is determined using this equation. The test measures the energy absorbed by the substance prior to failure.

2.5.6. High velocity Impact Test

High velocity impact testing is a crucial technique for assessing the impact resistance of composite materials, especially those used in aerospace, defense, and other high-performance applications. This method of testing is subjecting the material to high velocity impact loads, generally using a gas gun or other specialized apparatus, and measuring the resulting damage or deformation. The ability to examine how composite materials behave under extreme loading circumstances and to pinpoint probable failure modes or weaknesses makes high velocity impact testing crucial.

The high velocity projectile is observed before hitting the target plate and after hitting the target plate. Before hitting the plate, the energy and acceleration kept increasing. After hitting, energy decreases and declaration occurs. Given that the velocity is constant time and velocity keeps a simple relationship when a projectile leaves the muzzle. According to Nikmatin et al., (2020) the equation is very simple for average velocity given in Equation (2.8)

$$\bar{v} = \frac{x - x_0}{t - t_0} \tag{2.8}$$

Where, $\bar{v}$ = Average velocity of a projectile; x = Displacement amount; t = Time

Kinetic energy of a projectile is given by (Nikmatin et al., 2020) as

$$KE = \frac{1}{2} mv^2 \tag{2.9}$$

Where, m = Mass of the projectile; v = Velocity of the projectile

For the impact after the hit, Nikmatin et al., (2020) explained a simple set of equation for finding out the distance travelled and velocity after hit.

$$x = x_0 + \left(\frac{v + v_0}{2}\right) t \tag{2.10}$$

$$v^2 = v_0^2 + 2a(x - x_0) \tag{2.11}$$

Where, x = Displacement; t = Time; v = Velocity; a = Acceleration

Energy lost after hit is also explained by (Nikmatin et al., 2020) as

$$E.L. = \frac{1}{2} m \left(v_s^2 - v_r^2\right) \tag{2.12}$$

Where, v_s = Velocity after impact; v_r = Velocity before impact

The physical investigation of the fiber deformation after the impact is also taken. The penetration depth is measured and the damage was measured against the impact energy.

2.6 Related Definitions

Few related definitions are discussed for clarification of different parameters.

2.6.1 Composite material and related definition

2.6.1.1 Composite material

When two or more constituents are combined at a macroscopic level and are not soluble in one another, the result is a structural material known as a composite. The matrix refers to both the component in which a constituent is embedded and the reinforcing phase, which is one of them. The material used in the reinforcing process can take the shape of fibers, particles, or flakes. Materials used in the matrix phase are typically continuous (Kaw, 2006).

2.6.1.2 Fiber

Fibers in composite materials are often characterized as high-strength, high-modulus components that are added to a matrix material to give reinforcement. A polymer, metal, or ceramic can be used as the matrix substance. Glass, carbon, aramid, ceramic, and other elements can all be used to make fibers. The total mechanical characteristics of the composite material can be significantly influenced by the characteristics of the fibers and how they are arranged in the matrix (Gibson, 2012).

2.6.1.3 Matrix

The substance that holds the reinforcement fibers together and distributes the load among the fibers is referred to as the matrix in a composite material. The matrix is typically a relatively ductile and weak material, such as a metal, ceramic, or polymer, that is selected to give the composite toughness, durability, and environmental resistance. The entire performance of the composite material depends heavily on the matrix's characteristics and how those interact with the reinforcing fibers (Kaw, 2006).

2.6.1.4 Lamina

A thin layer or sheet of material made up of reinforcing fibers and a matrix is referred to as a lamina. To offer the appropriate mechanical properties in various directions, the fibers and matrix are often organized in a layered pattern. The stress-strain relationship, which depends on the characteristics of the fibers and the matrix as well as the orientation of the fibers with regard to the applied load, describes the behavior of a lamina under load (Kaw, 2006).

2.6.1.5 Stress and strain of composite material

Stress is defined as the load per unit area. The internal force developed by the material against the load applied per unit area is called as stress. To determine stress one infinitesimal cuboid is defined. A cross section in parallel to y-z plane is taken to find the stress over the body.

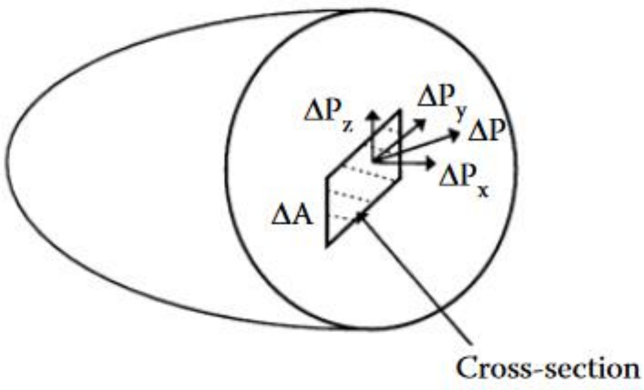


Fig 2.11: Forces in infinitesimal area on y-z plane described in Kaw (2006)

The stresses along the plane are

$$\sigma_x = \lim_{\Delta A \to 0} \frac{\Delta P_x}{\Delta A} \quad (2.13)$$

$$\tau_{xy} = \lim_{\Delta A \to 0} \frac{\Delta P_y}{\Delta A} \quad (2.14)$$

$$\tau_{xz} = \lim_{\Delta A \to 0} \frac{\Delta P_z}{\Delta A} \quad (2.15)$$

Similarly these stresses can be found out in x-y and z-x planes.

For defining all these stresses, the stress at a point is defined generally by taking an infinitesimal cuboid in a right-hand coordinate system and finding the stresses on each of its faces. Nine different stresses act at a point in the body as shown below:

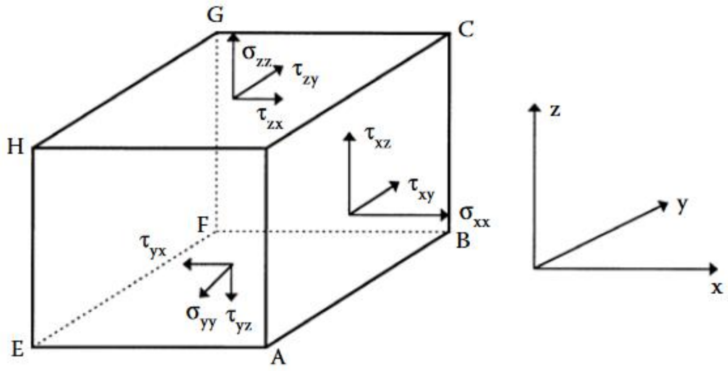


Fig 2.11: Stresses on infinitesimal cuboid described in Kaw (2006)

The shear stresses are related to each other by the relation given below (Kaw, 2006)

$$\tau_{xy} = \tau_{yx} \tag{2.16}$$

$$\tau_{yz} = \tau_{zy} \tag{2.17}$$

$$\tau_{zx} = \tau_{xz} \tag{2.18}$$

The strains and displacements are related to each other. The displacements of a point (x,y,z) defined as

u = u(x,y,z) = displacement in x-direction at point (x,y,z)

v = v(x,y,z) = displacement in y-direction at point (x,y,z)

w = w(x,y,z) = displacement in z-direction at point (x,y,z)

In accordance with x-y plane the normal strain in x direction and y direction are given below (Kaw, 2006):

$$\varepsilon_x = \frac{\partial u}{\partial x'} \tag{2.19}$$

$$\varepsilon_y = \frac{\partial v}{\partial y'} \tag{2.20}$$

The shearing strain is given by

$$\gamma_{xy} = \frac{\partial v}{\partial x} + \frac{\partial u}{\partial y'} \tag{2.21}$$

Similarly y-z plane and z-x plane strains can be found out towards x and y direction. That makes six strains and three shearing strains.

2.6.1.6 Elastic Moduli

Three equilibrium equations cannot define all six stress components simultaneously. Hooke's law describes how stresses and strains at a place are related by six simultaneous linear equations for a body that is linearly elastic and has minor deformations. Six stresses, six strains, and three displacements are at a position where there are 15 unknown parameters (Kaw, 2006).

The Hooke's law stress-strain relationships at a location in an x-y-z orthogonal system for a linear isotropic material in a three-dimensional stress state are shown in matrix form in Figure 2.9.

$$\begin{bmatrix} \varepsilon_x \\ \varepsilon_y \\ \varepsilon_z \\ \gamma_{yz} \\ \gamma_{zx} \\ \gamma_{xy} \end{bmatrix} = \begin{bmatrix} \frac{1}{E} & -\frac{v}{E} & -\frac{v}{E} & 0 & 0 & 0 \\ -\frac{v}{E} & \frac{1}{E} & -\frac{v}{E} & 0 & 0 & 0 \\ -\frac{v}{E} & -\frac{v}{E} & \frac{1}{E} & 0 & 0 & 0 \\ 0 & 0 & 0 & \frac{1}{G} & 0 & 0 \\ 0 & 0 & 0 & 0 & \frac{1}{G} & 0 \\ 0 & 0 & 0 & 0 & 0 & \frac{1}{G} \end{bmatrix} \begin{bmatrix} \sigma_x \\ \sigma_y \\ \sigma_z \\ \tau_{yz} \\ \tau_{zx} \\ \tau_{xy} \end{bmatrix} \quad (2.22)$$

Where, ε_x = Normal strain at x direction; ε_y = Normal strain at y direction; ε_z= Normal strain at z direction; γ_{yz} = Shearing strain at yz plane; γ_{zx} = Shearing strain at zx plane; γ_{xy} = Shearing strain at xy plane; E = Elastic modulus; v = Poisson's ratio; G = Shear modulus; σ_x = Stress at x direction; σ_y = Stress at y direction; σ_z = Stress at z direction; τ_{yz} = Shearing stress at yz plane; τ_{zx} = Shearing stress at zx plane; τ_{xy} = Shearing stress at xy plane.

2.6.1.7 Volume Fiber Fraction

The volume fiber fraction of a composite material is the percentage of fibers that are present in the composite material. This equation can be used to calculate it:

$$V_f = \frac{v_f}{v_c} \tag{2.23}$$

Where, V_f = Volume fraction of fiber; v_f = Total volume of fiber; v_c= Total volume of composite

The volume fiber fraction is a key factor in defining the mechanical behavior of composite materials since it directly impacts the material's ability to support loads. A composite material has increased stiffness and strength as a result of a higher volume fiber fraction (Kaw, 2006).

2.6.1.8 Volume Matrix Fraction

The ratio of a composite material's overall volume to the volume of its matrix material is known as the volume matrix fraction. It is stated as a percentage (Kaw, 2006).

The equation of matrix volume fraction is given below:

$$V_m = \frac{v_m}{v_c} \times 100\% \tag{2.24}$$

Where, V_m = Volume Matrix Fraction; v_m = Total Volume of Matrix; v_c = Total Volume of Composite.

2.6.1.9 Volume Void Fraction

In composite materials, voids are the regions where the matrix material is absent and has been replaced by air or other gases. The volume of voids in relation to the overall volume of the composite material is known as the void volume fraction. This is also referred to as the substance's porosity (Kaw, 2006). The equation of Void volume fraction is given below:

$$V_v = \frac{v_v}{v_c} \tag{2.25}$$

Where, V_v = Volume Void Fraction; v_v = Total Volume of Void; v_c = Total Volume of Composite

The relation between void volume fraction, fiber volume fraction and matrix volume fraction is given below:

$$V_v = 1 - V_f - V_m \tag{2.26}$$

2.6.2 Property Tests related definition

2.6.2.1 Tensile Strength

A more ductile polymer matrix surrounds strong, brittle fibers in many fiber composites. The stress-strain curve will therefore resemble the thick line in Figure 28.2. The graph describes itself very well. Up until the matrix yields, the stress-strain curve is linear and has a slope of E (Equation 28.1). The fibers continue to extend elastically until they fracture, at which point the majority of the additional stress is carried by them. When they do, the tension decreases until it reaches the matrix's yield strength, though not as abruptly as the image depicts due to the fact that not every fiber breaks at once. When the matrix breaks, the composite collapses (Ashby and Jones, 2013)

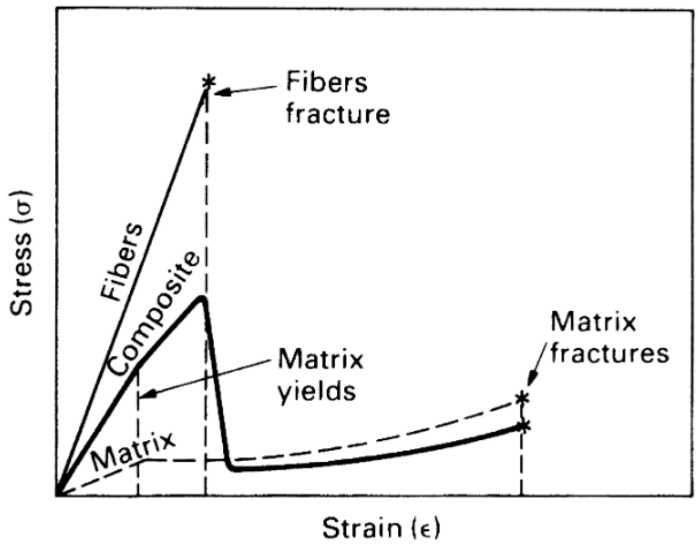


Fig 2.13: Stress-Strain diagram for Fiber, Matrix and Composite (Ashby and Jones, 2013)

The peak stress is important in all structural applications.

The stress is determined by the yield strength of the matrix, σ_y^m, and the fracture strength of the fibers σ_f^f,, combined using a rule of mixing at the peak, where the fibers are just on the verge of breaking and the matrix has yielded.

$$\sigma_{TS} = V_f\sigma_f^f + (1 - V_f)\sigma_y^m \qquad (2.27)$$

Where, σ_{TS} = Peak yield strength; σ_f^f = Fracture strength of fiber; σ_y^m = Fracture strength of matrix.

Once the fibers have fractured, the strength rises to a second maximum determined by the fracture strength of the matrix (Ashby and Jones, 2013),

$$\sigma_{TS} = (1 - V_f)\sigma_y^m \qquad (2.28)$$

2.6.2.2 Strength to Weight Ratio

According to Kaw (2006) strength to weight ratio is considered as one of the important factors for composite materials. A measurement of a material's strength in relation to its weight or density is called the strength-to-weight ratio. It is calculated by dividing the strength of a material by its density. The strength-to-weight ratio of composite materials, which are created by mixing various components, can be significantly higher than that of conventional materials like steel or aluminum. This is so that composite materials, which have a better strength-to-weight ratio, can be tailored to have particular features by changing the kinds and quantities of materials employed.

$$\text{Strength to weight ratio} = \frac{\sigma_{\text{Ult}}}{\rho g} \qquad (2.29)$$

2.6.2.3 Specific Modulus

The specific modulus is calculated by dividing the material's modulus by its density. It is a way to compare the performance of various materials in structural applications and measures the stiffness of a material in relation to its weight. Because composite materials are created to have high stiffness and strength at low weight, the specific modulus is a crucial metric. The usage of composite materials in aerospace and other weight-sensitive applications makes the specific modulus for composite materials crucial. In these applications, it's critical to keep weight as low as possible while preserving adequate stiffness and strength to sustain operational loads.

$$\text{Specific Modulus} = \frac{E}{\rho g} \qquad (2.30)$$

2.6.2.3 Flexural Modulus of Elasticity

The ability of a material to resist deformation in response to an applied bending load is expressed by a metric known as the modulus of elasticity in flexure (E_f) in bending tests. It is determined by the stress-strain curve's linear portion's slope, which is derived from the bending test's results. The ratio of stress to strain within the elastic deformation range of the material is known as the modulus of elasticity in flexure (E_f). It indicates the material's capacity to withstand bending and other forms of deformation, which makes it an essential parameter in the design and analysis of structures constructed of composite materials (ASTM-D-790,2017).

$$E_f = \frac{3\ FL}{2\ bd^2\varepsilon} \tag{2.31}$$

Where, E_f = Modulus of elasticity of bending; F = Applied force; L = Span length; b = Width of the span; d = Thickness of the specimen; ε = Strain in the elastic deformation limit

2.6.2.5 Velocity and Deceleration of Projectile calculation of High Speed Impact

Naik et al., (2013) described the equations of projectile velocity calculations. The velocity of the projectile after *i*th time interval is given below

$$v_i = \sqrt{\frac{\frac{1}{2}m_{i-1}^{p}v_{i-1}^{2} - \Delta E_i}{\frac{1}{2}m_i^{p}}} \tag{2.32}$$

Where, v_i = Velocity of projectile after ith time; m_i^p = Mass of the projectile after ith time; ΔE_t = Energy absorbed by the target and projectile during ith time interval.

Deceleration of the projectile during ith time interval (Naik et al., 2013)

$$dc_i = \frac{v_{i-1} - v_i}{dt} \tag{2.33}$$

Where, dt = Time interval

2.6.2.6 Distance Travelled By Projectile

Naik et al., (2013) established the equation of distance travelled by projectile as below

$$S_i = v_{i-1}dt - \frac{1}{2}dc_i dt^2 \tag{2.34}$$

Where, S_i = Distance travelled by projectile

CHAPTER 3

METHODOLOGY

3.1 Introduction

Fabrication of composite can be done by following different methods i.e. ply layup, injection molding, vacuum bagging, polymer induced or fiber reinforced method. To keep the fabrication process simpler and easier ply hand lay-up method was selected for this thesis. A special set of fabrication set up was built for this research work. As material fiber glass of two types i.e. woven and matt type was used with epoxy resin as matrix for the composite. All samples went through mechanical property testing i.e. tensile, bending, charpy test and free fall impact test. Additionally, the samples were tested against high velocity projectile to have ultimate test of its impact resistance. The penetration effect and mechanical properties suggested the best suited combination for the desired composite.

3.2 Fabrication of the composite

3.2.1 Raw Materials

3.2.1.1 Fiber Glass

The material that was used in this research for the composite is S Glass Fiber of two types.

i. Woven type
ii. Matt type

Woven type fiber glass holds the FG threads in two interfacing layer with right angle. In case of Matt type, FG threads are randomly distributed.

(a) (b)

Figure 3.1: Type of FG used (a) Woven type (b) Matt type

3.2.1.2 Epoxy Resin

Epoxy resins are the most commonly used thermoset plastic in polymer matrix composites. Epoxy resins are a family of thermoset plastic materials which do not give off reaction products when they cure and so have low cure shrinkage. They also have good adhesion to other materials, good chemical and environmental resistance, good chemical properties and good insulating properties. The epoxy resins are generally manufactured by reacting epichlorohydrin with bisphenol (Singla and Chawla, 2010). In this research the epoxy resin used is known as LY 556. The epoxy has some distinct characteristic i.e. pale yellow in color, visibly clear, viscosity at 250ºC is 10000-12000 MPa, density at 250ºC is 1.15-1.20 gm/cm^3 (Ebewele, 2000). The epoxy along with hardener acts as binder in the composite.

3.2.1.3 Hardener

For getting the properties to be improved, the resin should undergo curing reaction in which the liner epoxy resin structure changes to form three-dimensional cross-linked thermo set structure. This curing reaction takes place by adding a curing agent called hardener in a ratio of 10:1 to Epoxy resin (Goodman, 2012.). In this research the hardener used is known as HY 951. It has a density of 0.95 gm/cm^3. The hardener is mixed with a ratio of

10:1 to the epoxy. The ratio is changed according to different applications and to vary fiber-matrix ratio of the composite.

3.2.1.4 Cobalt 6%

Cobalt 6% is an abbreviation for the compounds cobalt napthenate and cobalt octoate, usually supplied as a 6% solution. These compounds are promoters used in the curing of polyester and vinyl ester resins with methyl ethyl ketone peroxide (MEKP) type catalysts. Promoters are also called accelerators. They can be added to the resin by the supplier, in which case the resin is said to be pre-promoted. Alternatively, promoters can be added by the manufacturer prior to adding catalyst to the resin. The purpose of cobalt-based promoters is to speed up the curing reaction of polyester and vinyl ester resins and allow them to cure at room temperature. The cobalt-based promoter helps the catalyst to start the chemical reaction between the resin and styrene monomer and form a cured solid. The promoter or accelerator is used in a proportion of 0.1% of the epoxy resin. This is done to fabricate the composite in room temperature.

3.2.2 Fabrication Setup

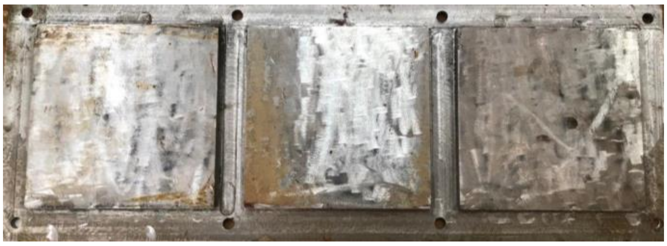
The fabrication setup was made for this research work with three distinct MS Plate parts. They are:

(a) Base Plate
(b) Cavity Part
(c) Male Part

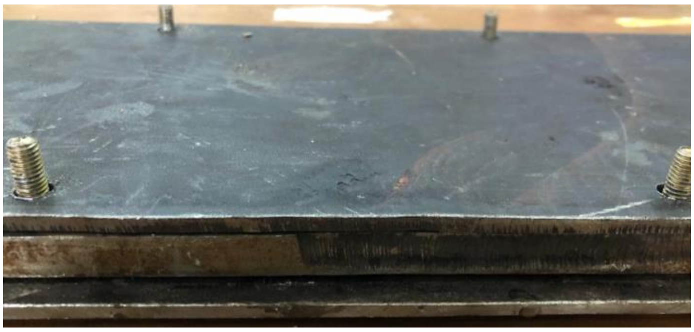
The base plate is the bottom most part where all the fibers and matrix are poured. The female part holds a cavity of the sample size. The male part is placed over the female part after the fibers and resin are poured inside it. There are removable bolts which can be tightened with the help of screwing nuts for applying equal pressure over the sample. There are other essential elements in the fabrication setup i.e. wax, polythene film, brush, measuring beaker etc. Each of the elements was used to fabricate the composite using hand layup process.

(a)

(b)



(c)

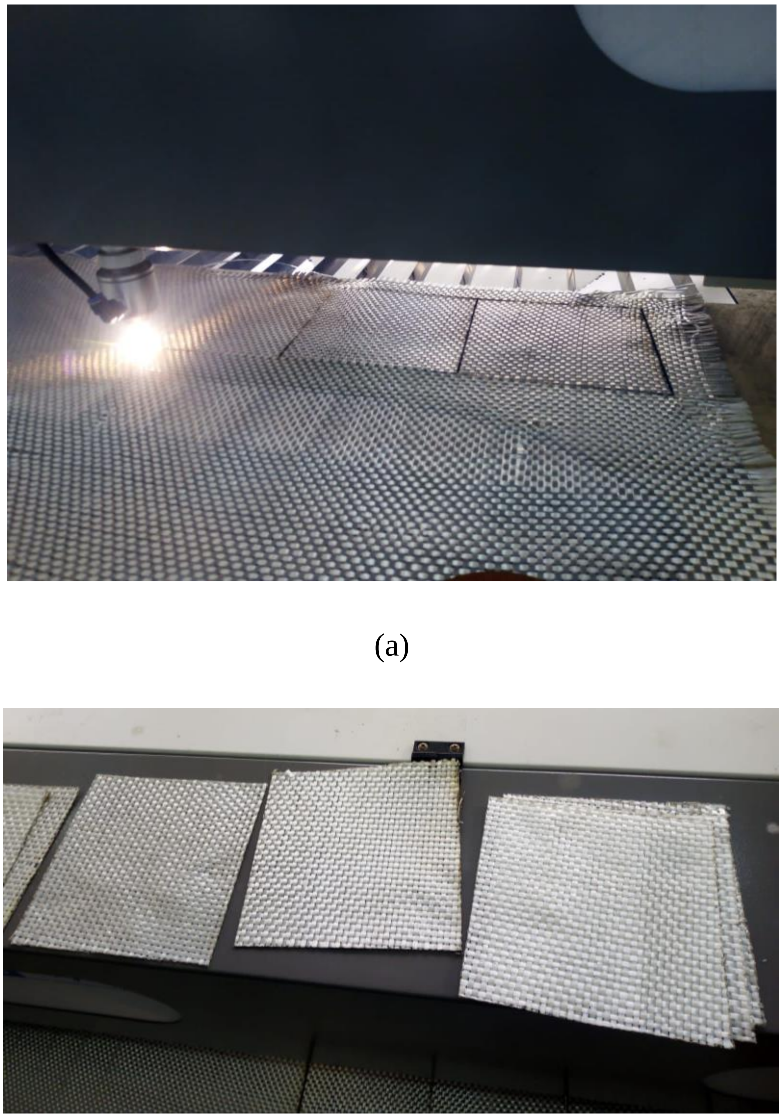


(d)

Fig 3.2: Main parts of fabrication setup (a) Base plate- side view (b) cavity (female part) (c) Male part (d) All parts assembled together

3.2.3 Preparation of Fibers

The fibers are available in rolls. The roll contains a specific amount of fibers. One roll of Woven FG contains 30 kg of fibers and one roll of Matt FG contains 40 kg of fibers. This roll is placed over the Laser Beam Cutter Machine to cut the fibers into specific dimension. In this research each of the composite is made of 6” x 6” dimension. This dimension is chosen according to the minimum dimension of a target plate in a firing range. Once the composite is fabricated then it is cut into required specific dimension according to the test specimen dimension of tensile, bending, charpy tests etc.



(a)

(b)

Fig 3.3: (a) Cutting of FG by Laser Beam Cutting Machine (b) FG samples after cut

3.2.4 Preparation of Epoxy Resin

The epoxy resin is a high density liquid. It is measured in the measuring beaker. For each sample of 6” x 6” size, total 300 ml of epoxy resin was used. Resin is poured into the measuring cup and then hardener is added to it. The hardener is added upto 10% of the epoxy weight. In this case, 30 ml of hardener was added to the liquid epoxy for each of the composite sample. A curing agent named Cobalt 6% is added to this mixture to fasten the rate of curing. The weight of it is 1% of the liquid epoxy. Hence the epoxy hardener mix is ready for use.

Fig 3.4: Epoxy Resin-hardener mixture

3.2.5 Fabrication Process

The fabrication process in this research is hand ply layup process. The process is described below:

a) The base plate is cleaned with metal brush for removing any sort of metal or any other impurities. Then Isopropyl Alcohol is applied over the base plate to remove any sort of chemical residue.
b) The bolts on the thread of the base plate are placed.

c) The cavity or female part is placed over the base plate. Then wax is applied at the borders of the cavity to seal any exit route of the liquid resin.

d) A polythene paper was placed in the cavity. This will facilitate the removal process of the sample after the hardening is complete.

e) The first FG ply was placed inside the cavity. Then the liquid resin is applied with the help of a brush. Then another ply is placed over it and epoxy resin brushed over it.

f) Same process is repeated until the desired amount of ply is placed.

g) In case any liquid resin is left after brushing, the remaining liquid is poured inside the cavity.

h) The male part is placed over the prepared plies. With the help of nut the all three parts are tightened.

i) Then whole part is kept for curing for about 24 hours.

j) After 6 hours the bolts are loosened, the male part is removed and the composite is brought out of the cavity or dye.

(a)

(b)

(c) (d)

Fig 3.5: Fabrication process of composite (a) Placing of polythene paper inside the cavity (b) Brushing of epoxy over the first FG ply (c) Brushing of epoxy over the second ply FG (d) Composite after pouring of all the epoxy resin

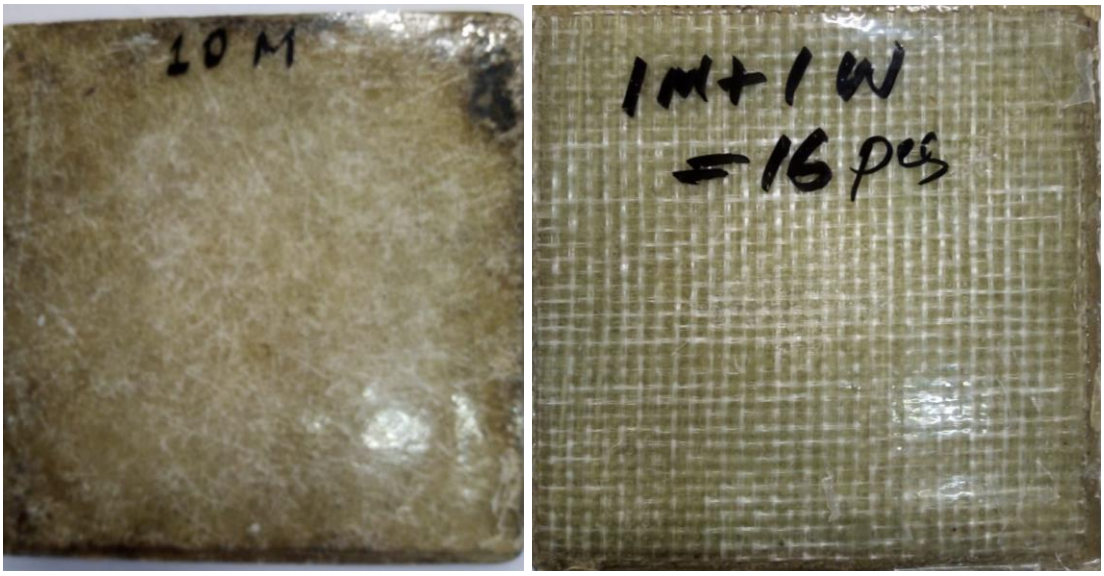
3.2.6 Combinations of FG composite

Different combinations of FG composites are made and tests are done to find the best combination. The combinations are shown in Table 3.1.

Table 3.1: Combinations of FG ply for composite fabrication

Ser	Combination	Curing period
1	10 ply woven FG	24 hours
2	10 ply matt FG	
3	16 ply woven FG	
4	16 ply matt FG	
5	5 ply woven/ 5 ply matt FG (10 layers)	
6	8 ply woven/ 8 ply matt FG (16 layers)	
7	(1 ply woven/1 ply matt FG) x 10 layers	
8	(1 ply woven/1 ply matt FG) x 16 layers	

The mixture of woven and matt type FG is done to investigate the change of the properties of the composite lamina for having different combination. Then another combination was made as per the weight of ply. 3 woven ply has the same weight of 5 matt ply. So one combination is made of those. Again it was found that, 5 woven plies have the equal weight of 11 matt plies. So another combination was made of that. The Fig 3.6 shows some fabricated composite.



(a) (b)

Fig 3.6: Fabricated composite (a) 10 matt ply FG (b) (1ply woven/1ply matt) x 16 layers

3.3 Mechanical and Physical Tests

The fabricated composites are tested for mechanical properties and physical properties. The tests were done according to the different testing standards. Table 3.2 shows the tests done and the standards followed in the research.

Table 3.2: List of property tests and standards

Ser	Name of the Test	Standard followed
1	Tensile Test	ASTM A 370
2	Bending Test	ASTM D 7264
3	Charpy Impact Test	ASTM E 23
4	Free fall Impact Test	No standard available
5	High velocity projectile Impact Test	

All fabricated composites went through these tests and their results are compared to find out the better performer against any high impact.

3.3.1 Tensile Test

The tensile test is destructive test process which gives the information about yield strength, tensile strength and ductility of a metallic material. It measures the force required to break a composite or plastic specimen and the extent to which the specimen stretches or elongates to that breaking point (Saba et al., 2018). For tensile test, ASTM Standard of A 370 has been followed to standardize the experiment. The experimental setup and specimen size was prepared following the ASTM standard.

The specimen was prepared of a dimension of total length 175 mm having 12.5 mm radius as testing radius. The grips of the specimen are 20 mm width while having 12.5 mm radius of corner radius. The Fig 3.1 shows the ideal measurement of a tensile test specimen.

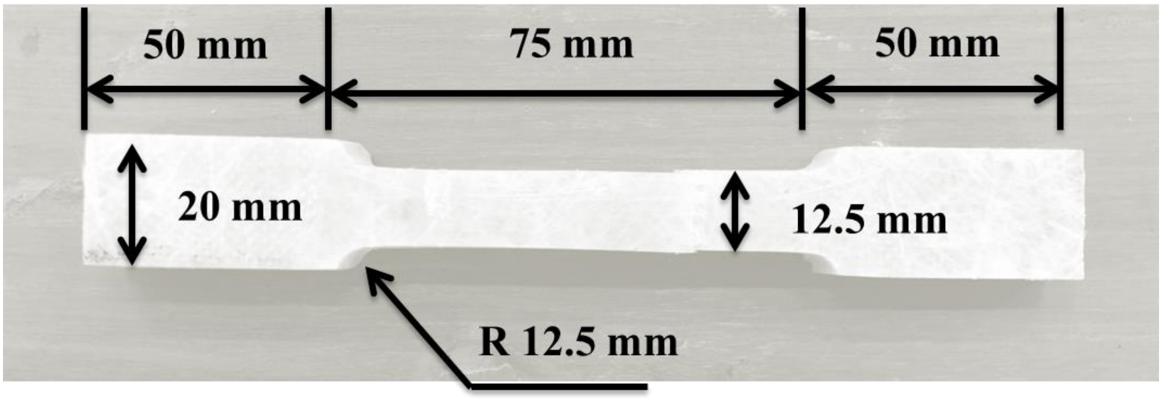


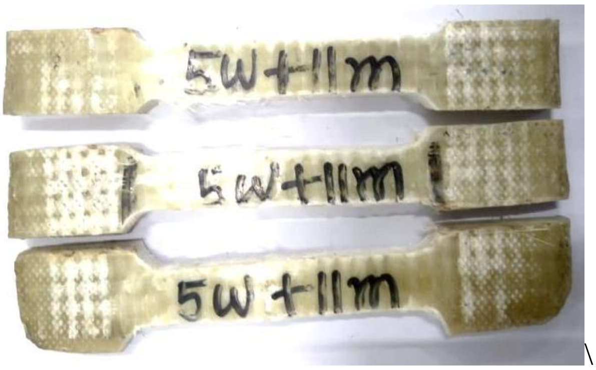
Fig 3.7: Specimen dimension for tensile test

The fabricated composites are cut into the specimen dimension for the tensile test with the help of CNC milling machine. The 20 mm grips are used to grip the specimen inside the Universal Testing Machine (UTM). The machine was calibrated before the use. According to the ASTM standard, the composite material used for testing falls under Type I semi rigid material which should be tested under the machine speed for type I material. In this case, speed of testing should 5 mm/min. After setting up the specimen and choosing the option of the machine speed the tensile test is done for 3 specimen of each composite combination. The average of the three results are taken and considered as the result of tensile test. Fig 3.2 shows the composite specimen for tensile test.

(a)

(b)

(c)



(d)

Fig 3.8: Specimen for tensile test of different composite combinations (a) 10 matt FG ply (b) 8 ply woven/ 8 ply matt FG (16 layers) (c) 5 ply woven/ 5 ply matt FG (10 layers) (d) 5 woven/ 11 matt ply FG

The mounted specimens were given load by the machine and the data acquisition panel recorded the data of each extension against the load. Hence a curve of load vs. extension could be produced by the machine. Later the strain vs. stress curve was produced to find the maximum yield strength, maximum stress and breaking point of the composite. Fig 3.3 shows the mounted specimen on the UTM.

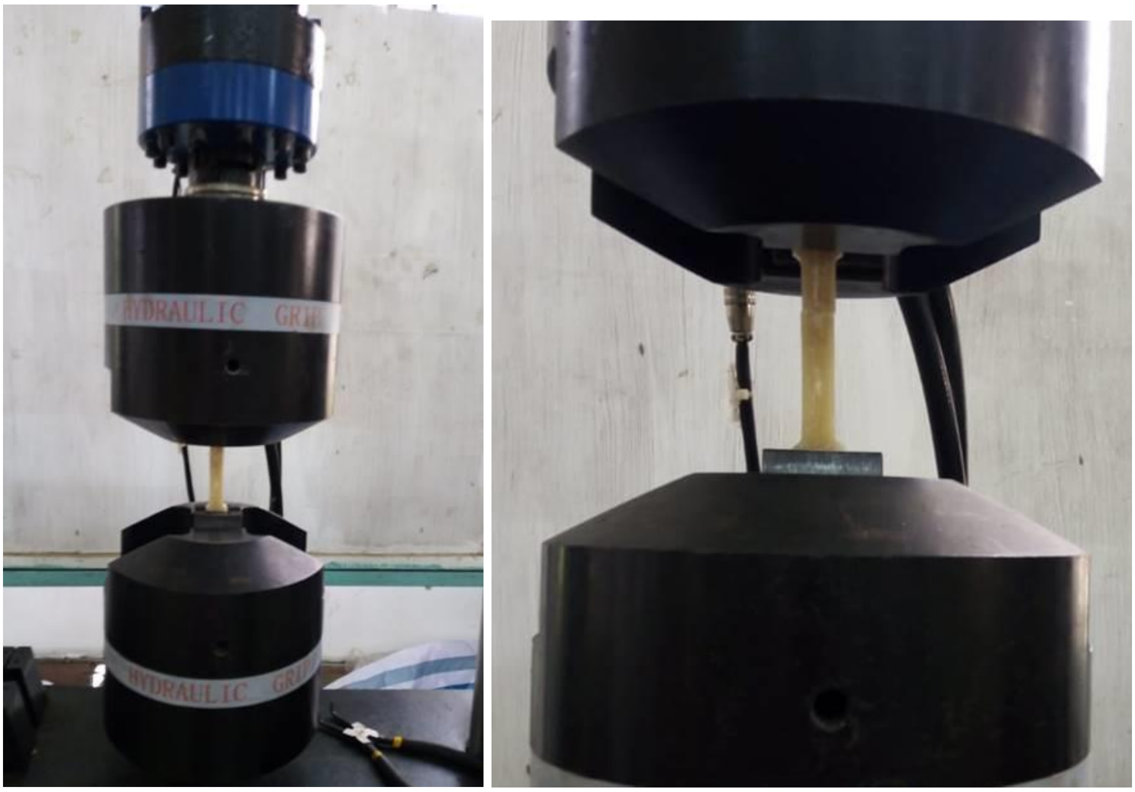


Fig 3.9: Mounted composite specimen on UTM

3.3.2 Bending Test

Bending test is done for the composites to find out the flexural strength of the specimen. The test is done under the regulations of ASTM standard D 7264. Three point bending is done in this research. In the bending test, there are two supports in two sides having the specimen mounted on those supports. A load is given at the middle of the specimen until it bends to some extent and stops taking the load. The data acquisition system records the load vs. extension which at the end produces a curve for stress vs. strain showing the ultimate stress point where the breakage happens. Fig 3.10 shows the schematic form of the three point bending test.

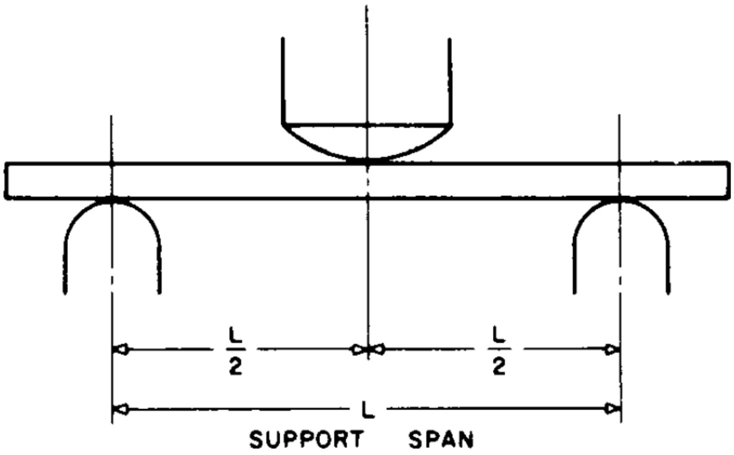
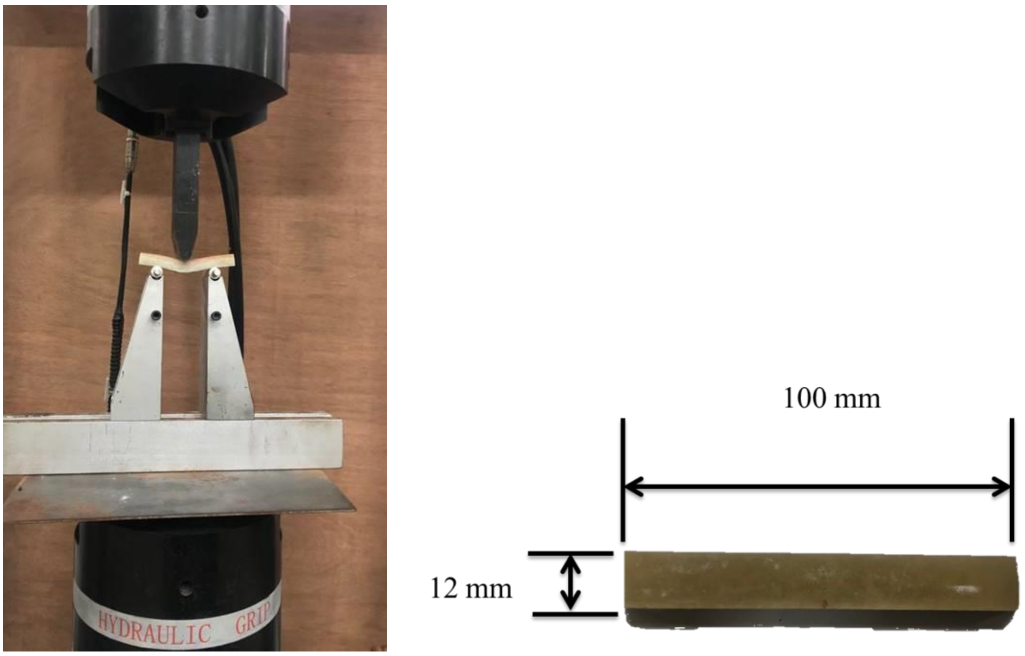


Fig 3.10: Three point bending test

The Fig 3.11 shows the specimen dimension used in this research and the mounted specimen on the machine.



(a) (b)

Fig 3.11: (a) Specimen mounted in UTM (b) specimen dimension

3.3.3 Charpy and Izod Impact Test

The Charpy impact test is the standard test to determine the fracture toughness of materials and the ductile materials absorb more energy at higher test temperatures while at lower test temperature this energy is found lower. The standard followed in this research ASTM E 23. The standard has both Simple Beam Impact machine and Compound Pendulum type machine details. In this research Simple Beam Impact Machine has been used. In Charpy test, the specimen contains a small notch to facilitate the breaking of the specimen. The notch dimension is 45 ± 1º with a radius of curvature at the apex of 0.25 ± 0.05 mm (ASTM E23, 2019). Fig 3.12 shows the specimen dimension of a charpy impact test.

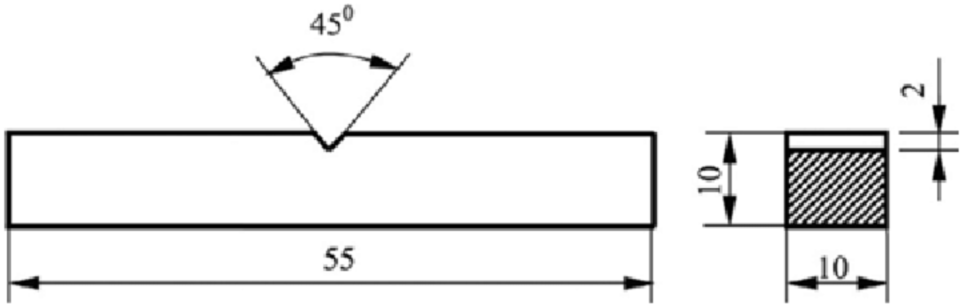


Fig 3.12: Specimen dimension of Charpy Impact test

At least three specimen of each composite were prepared for Charpy test and the average of all those values give the Impact result of that specific composite combination. Fig 3.13 shows some of the specimen prepared of the composites.

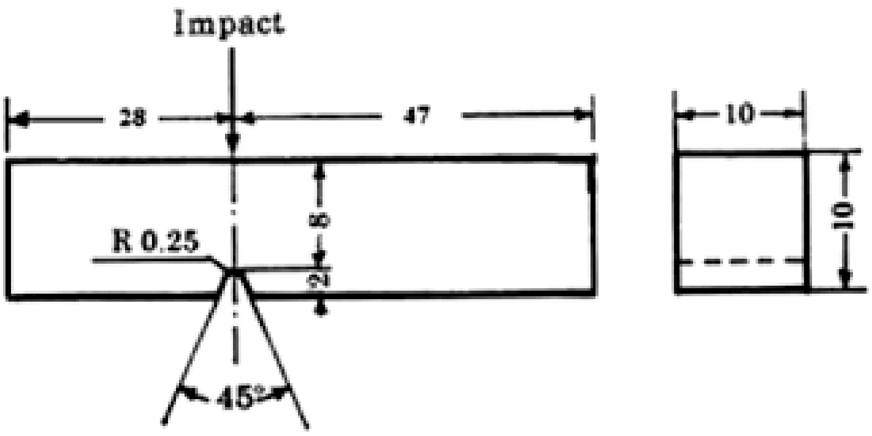


Fig 3.13: Specimen with notch dimension and position

The Fig 3.14 shows the Charpy Impact test setup used in this research.

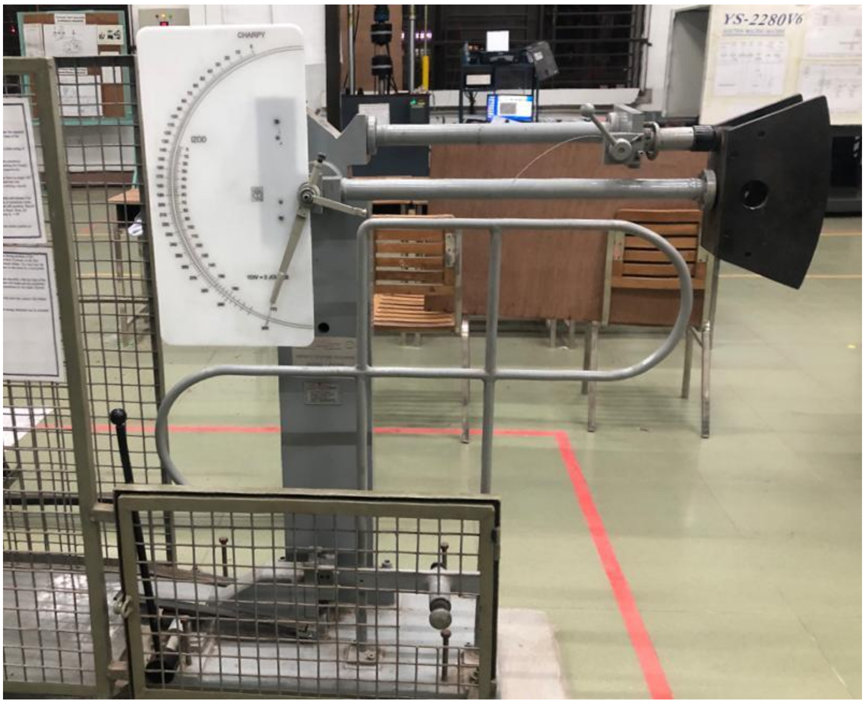
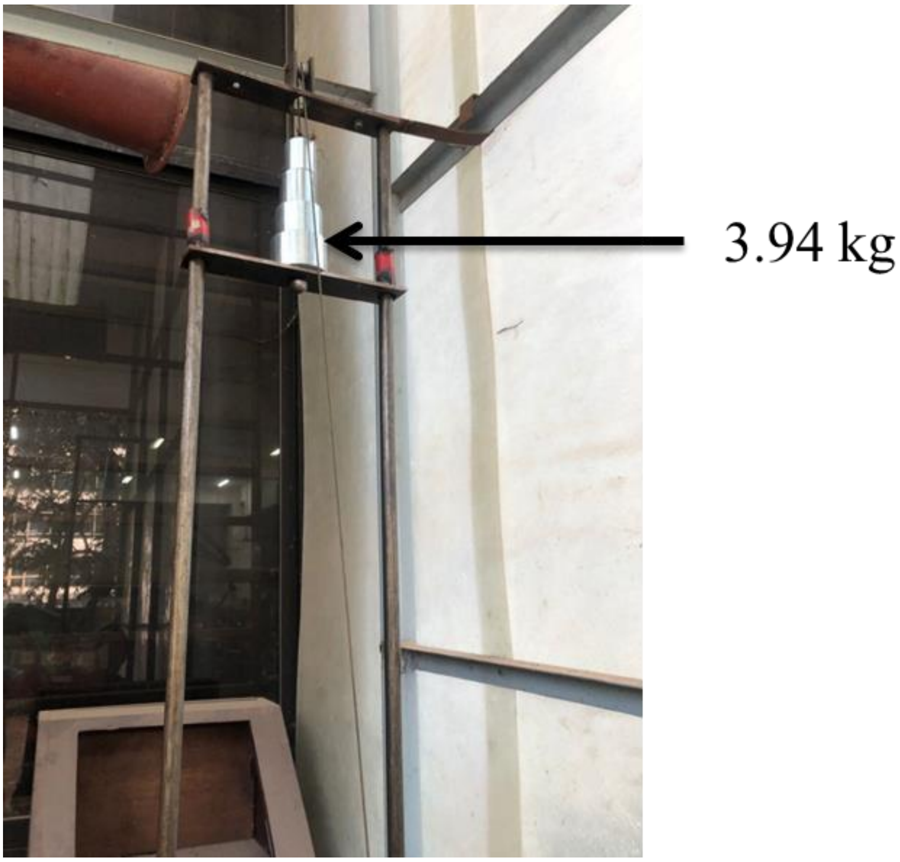


Fig 3.14: Charpy and Izod Impact Test setup

3.3.4 Free Fall Impact Test

The free fall impact test was done by an indigenous method developed in the lab. A sharp projectile with a load attached to it is released from a set of distance over the specimen. The radius of the projectile is 10 mm. The attached load can be increased upto 4 kg. In the research, total of 3.94 kg load was used and the distance of falling was set at 2 m. Fig 3.15 shows the Free fall impact test setup for the composite.

(a)



(b)

Fig 3.15: (a) Placement of composite for free fall impact (b) The projectile with load

The free fall impact test provides the composite breakage or damage after the impact. The impact energy is calculated and the end result of the energy absorption will show the composite's impact resistance of the composite.

3.3.5 High Velocity Impact Test

The high velocity impact test is done to find out the performance of the composites against the high velocity projectile. The steps are described briefly as below:

(i) Sample Preparation: The samples are fabricated at the same size and dimension of the target plate. For this research, the dimension of the target plate is 6" x 6".

(ii) Setting up the specimen in target plate: The specimen is set in the target plate with the help of hooks attached with the target plate.

(iii) The firing: A 9 mm diameter projectile is fired towards the target from a specified distance in this case 50 meter distance. Each specimen is fired at least for 3 times for ensuring the proper hitting of the projectile on the specimen.

(iv) Investigation: The physical investigation is done to measure the damage and penetration effect of the projectile. The measurement of the penetration is measured with the help of the ruler.

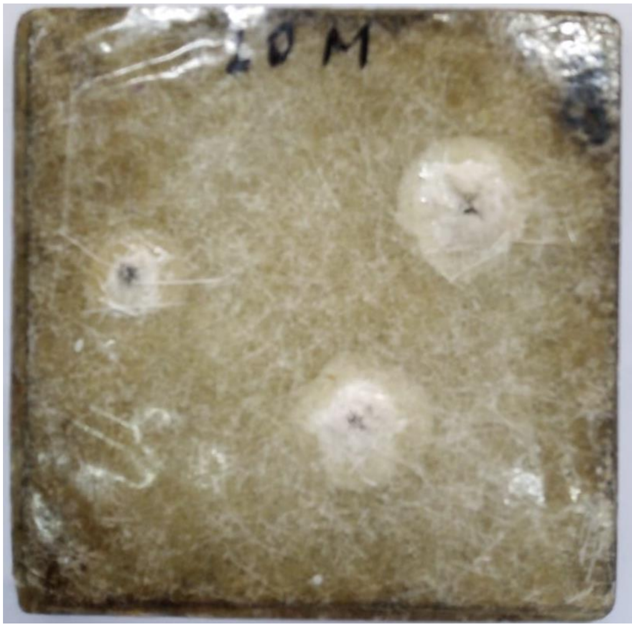


Fig 3.16: The specimen after projectile hit

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 General

The produced specimens of composites were put into different mechanical property tests to find out the performance. The composites' performance against loads, bending and impact determine the application of them into different arena. In this chapter, the results are compiled and compared to find the better suited composite for high impact resistance application.

4.2 Tensile Test

The tensile test produces the stress vs strain diagram and from there the yield strength is measured. The samples used in the tensile test are given below:

Table 4.1: Composite material combinations used for Tensile Test

Ser	Description of composite material combination
1	10 ply woven FG
2	10 ply matt FG
3	16 Ply woven FG
4	16 ply matt FG
5	5 ply woven FG + 5 ply Matt FG
6	8 ply woven FG + 8 ply Matt FG
7	(1 ply woven + 1 ply matt FG) = Total 5 set ply (10 Ply)
8	(1 ply woven + 1 ply matt FG) = Total 8 set ply (16 Ply)

The stress-strain diagram for different composite combination is given below:

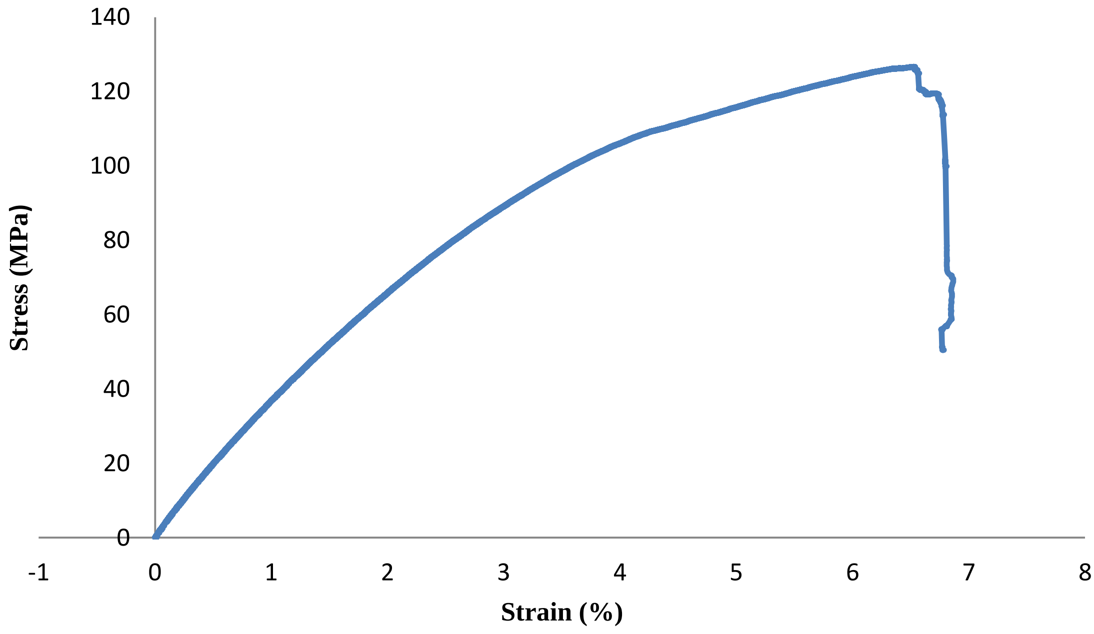


Fig 4.1: Stress – Strain graph for 10 ply woven FG

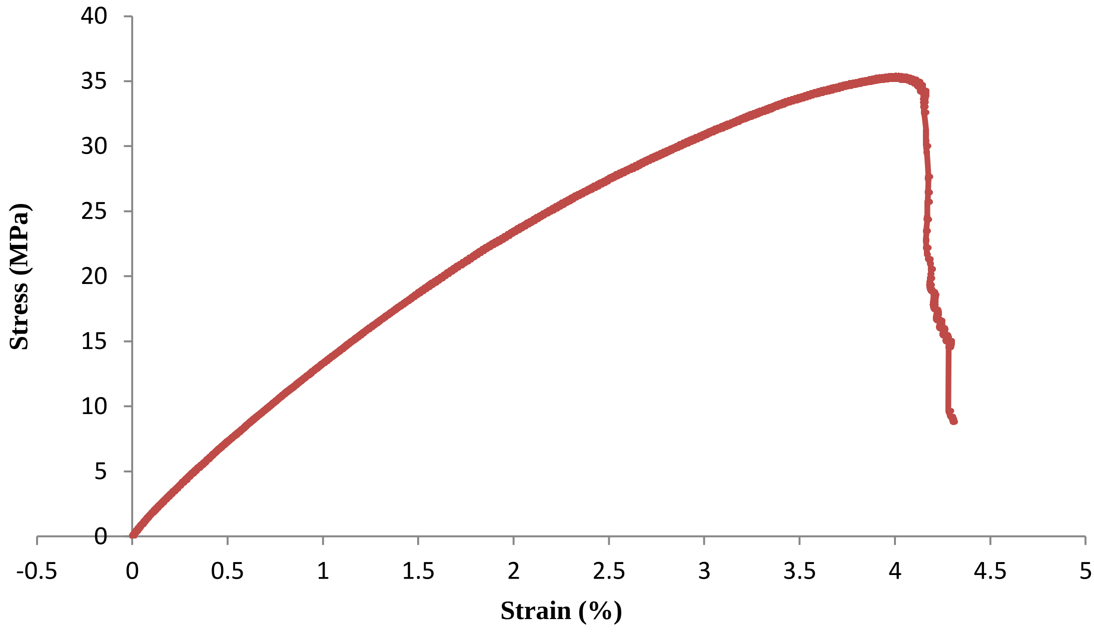


Fig 4.2: Stress – Strain graph for 10 ply matt FG

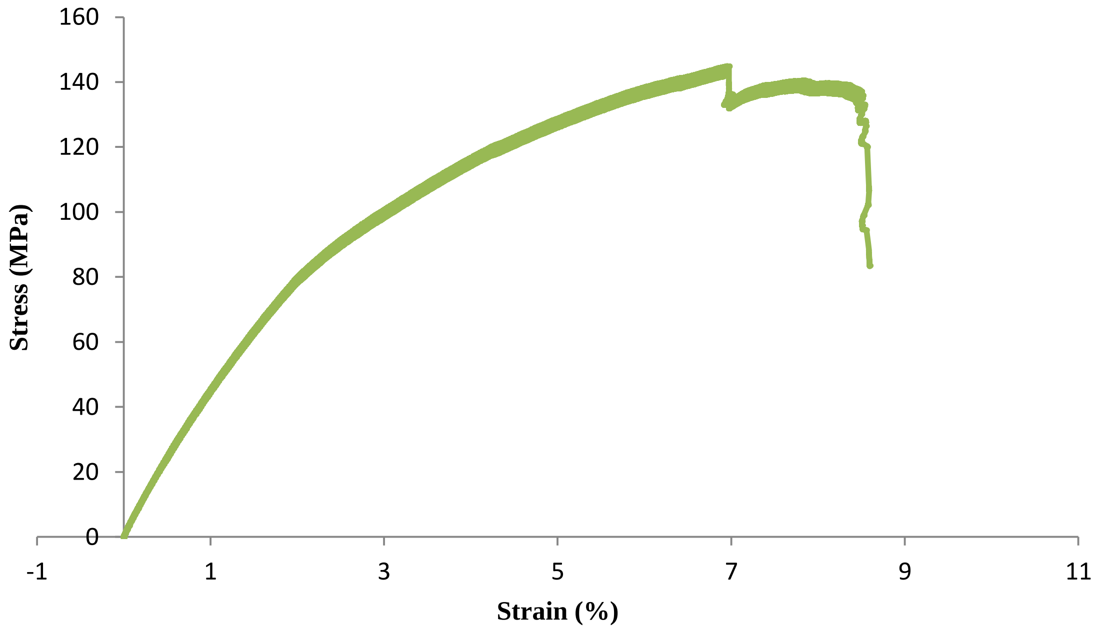


Fig 4.3: Stress – Strain graph for 16 ply woven FG

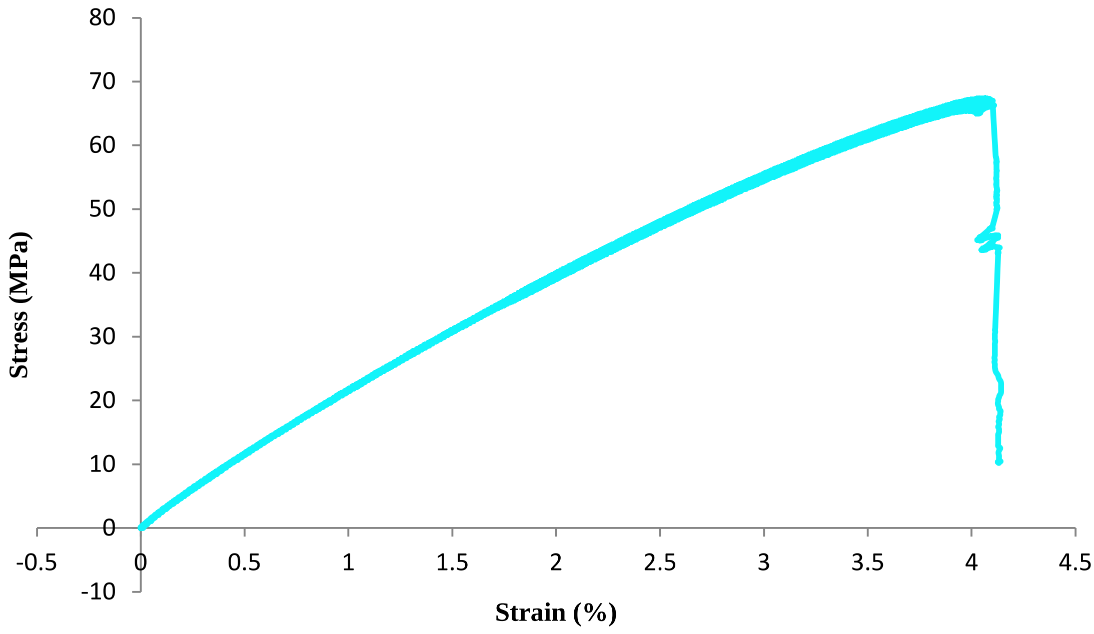


Fig 4.4: Stress – Strain graph for 16 ply matt FG

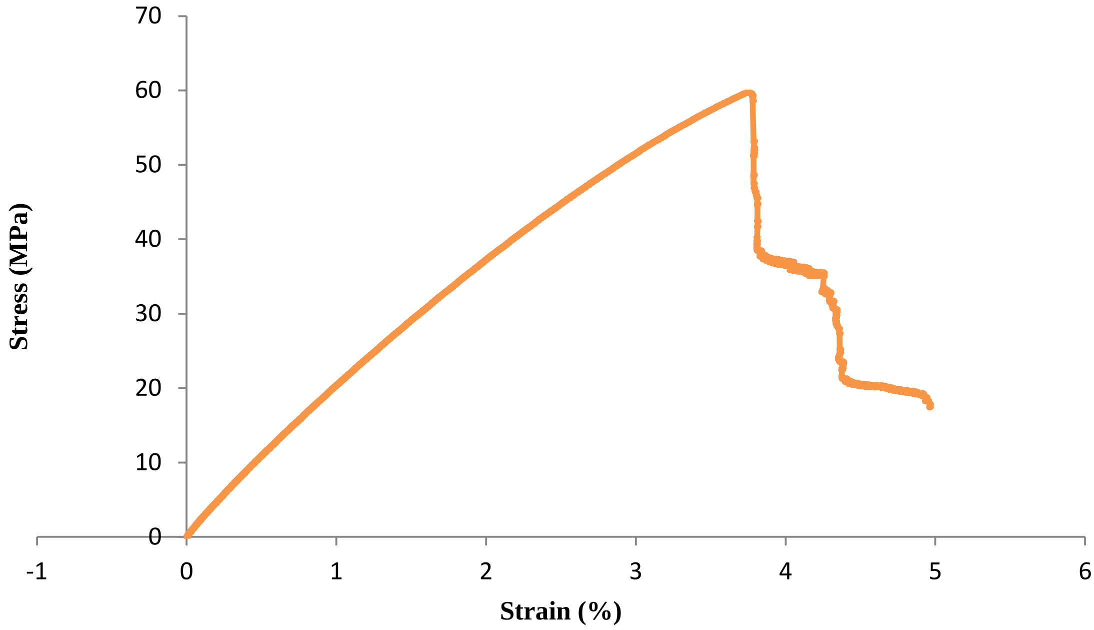


Fig 4.5: Stress – Strain graph for 5 ply woven + 5 ply matt FG

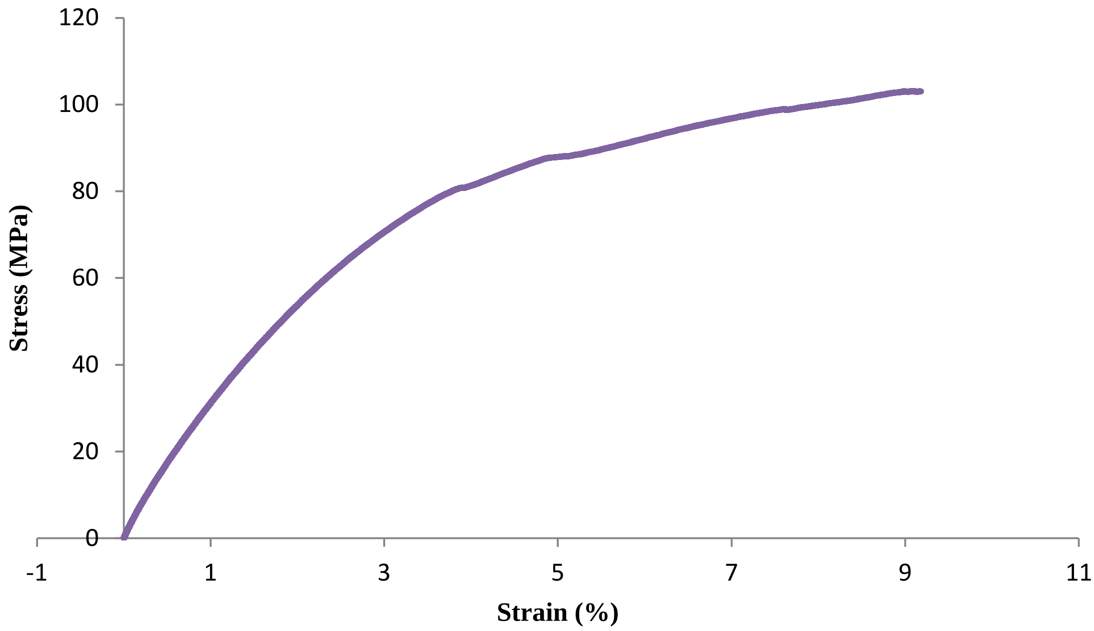


Fig 4.6: Stress – Strain graph for 8 ply woven + 8 ply matt FG

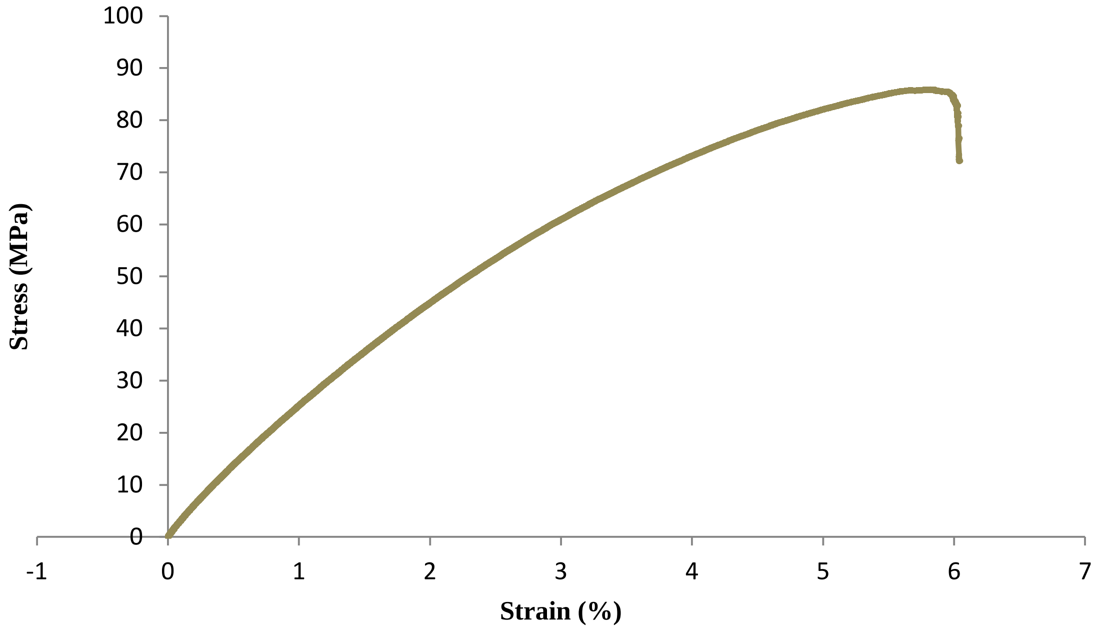


Fig 4.7: Stress – Strain graph for (1 ply woven + 1 ply mat)t FG x 5 set = 10 ply FG

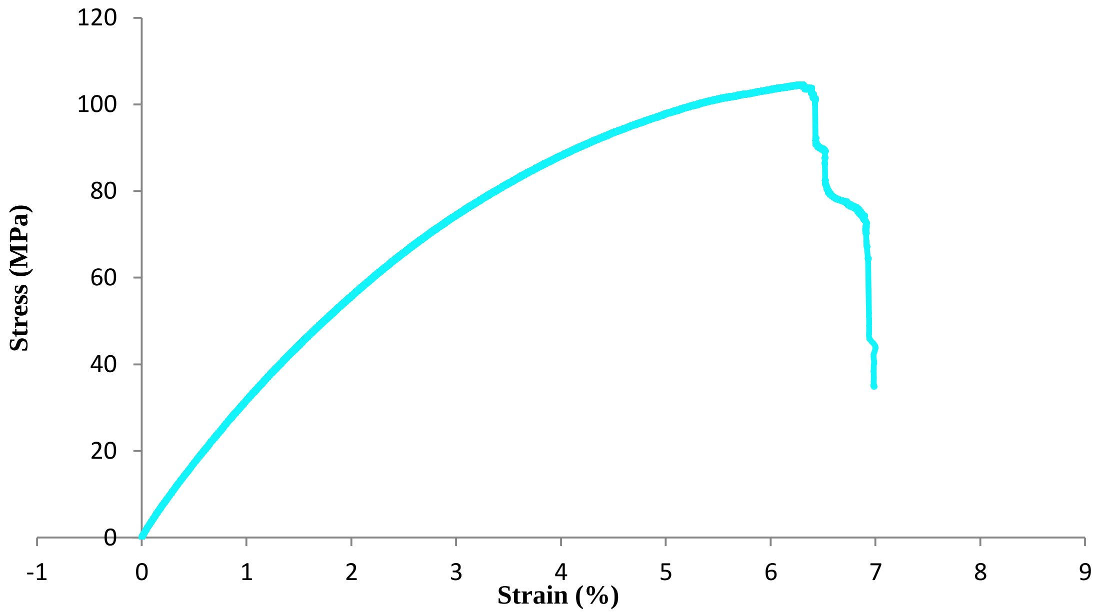


Fig 4.8: Stress – Strain graph for (1 ply woven + 1 ply mat)t FG x 8 set = 16 ply FG

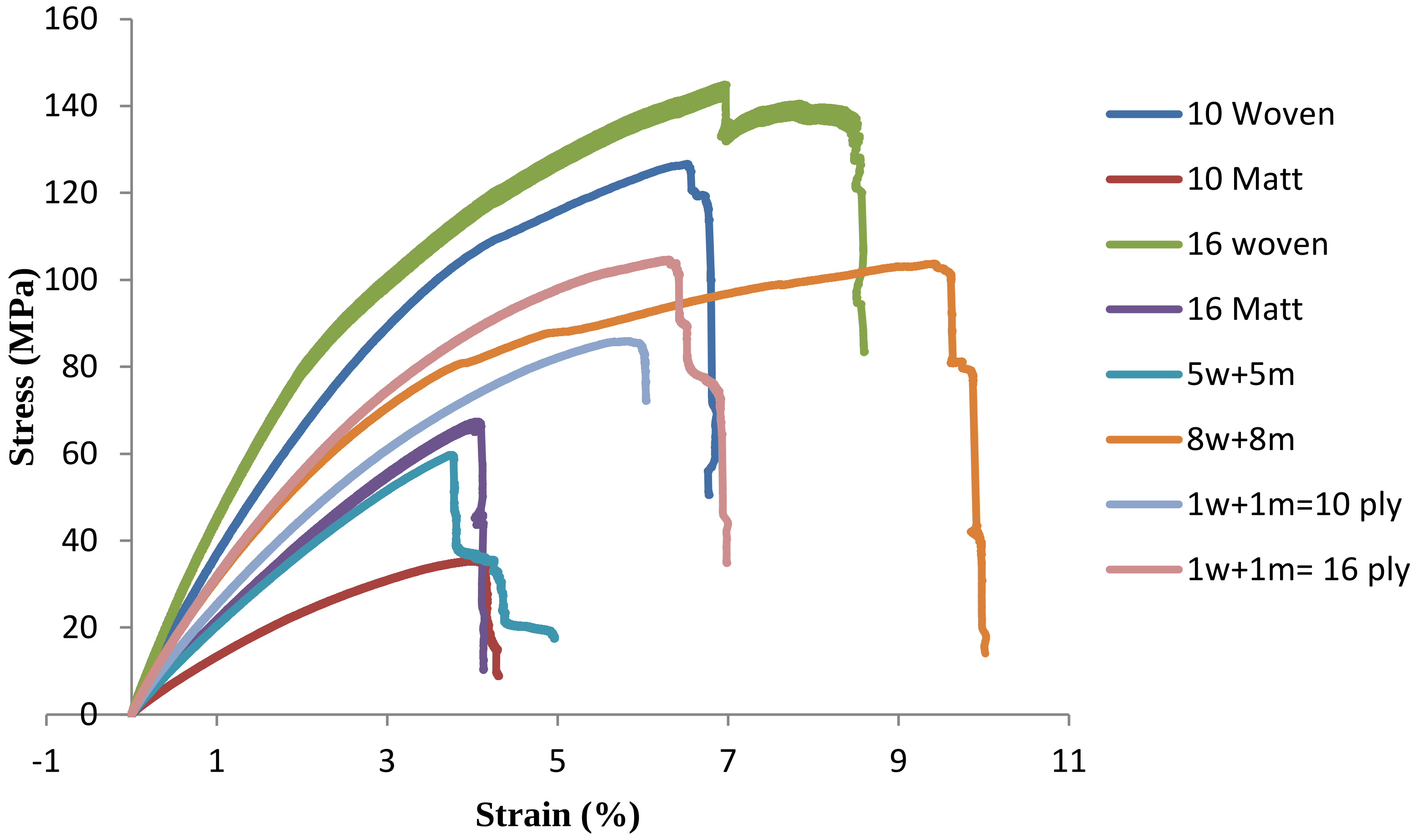


Fig 4.9: Stress strain diagram for all composite material combination

The curves on the all combinations shown in Figure (4.9) indicate that 16 ply woven FG will give better yield strength and better elastic limit. The important parameters for finding out the better performing composite are given below in the table.

Table 4.2: Tensile properties of composite combinations

Ser	Composite combination	Yield Strength (MPa)	Weight (gm)	Density (gm/cm^3)	Strength to weight ratio	Young Modulus (GPa)	Specific Modulus
1	10 ply woven FG	127	380	1.604	79.18	2.8	1.74
2	10 ply matt FG	35	310	1.308	26.76	1.08	0.82
3	16 Ply woven FG	145	413	1.741	83.29	3.38	1.94
4	16 ply matt FG	67	343	1.446	46.33	1.80	1.24
5	5 ply woven FG + 5 ply Matt FG	67	349	1.472	45.51	1.71	1.16
6	8 ply woven FG + 8 ply Matt FG	104	408	1.720	60.46	2.16	1.25
7	(1 ply woven + 1 ply matt FG) = Total 5 set ply (10 Ply)	86	351	1.480	58.11	1.91	1.29
8	(1 ply woven + 1 ply matt FG) = Total 8 set ply (16 Ply)	105	410	1.729	60.73	2.32	1.34

The table indicates that, 16 ply woven FG combination gives highest strength to weight ratio as well as highest specific modulus.

4.3 Bending Test

The bending test is also known as Flexural test. The test determines the maximum flexural load a composite can carry before it fails. This test also finds out the flexural modulus of the material which dictates the material's stiffness or resistance to bending. All the combination's graphs are given below:

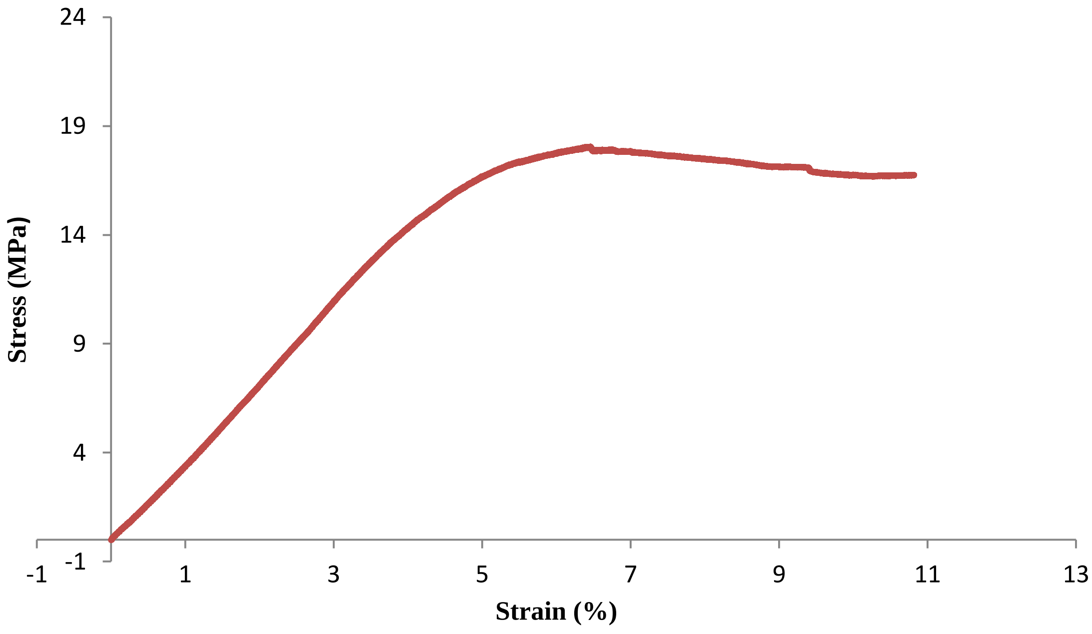


Fig 4.10: Bending stress strain diagram for 10 ply woven FG

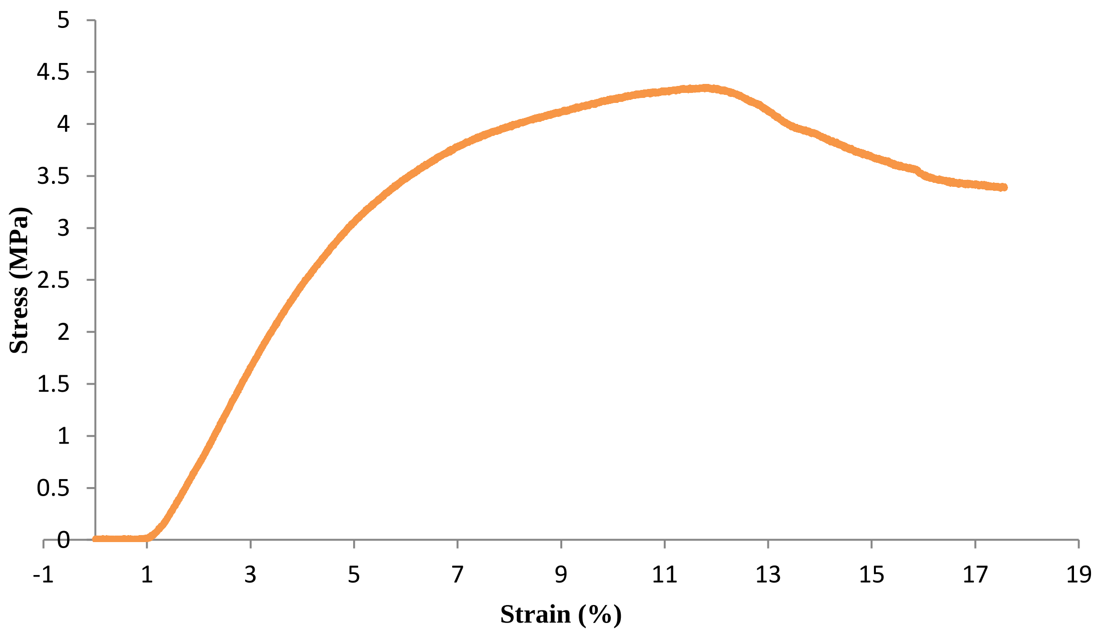


Fig 4.11: Bending stress strain diagram for 10 ply matt FG

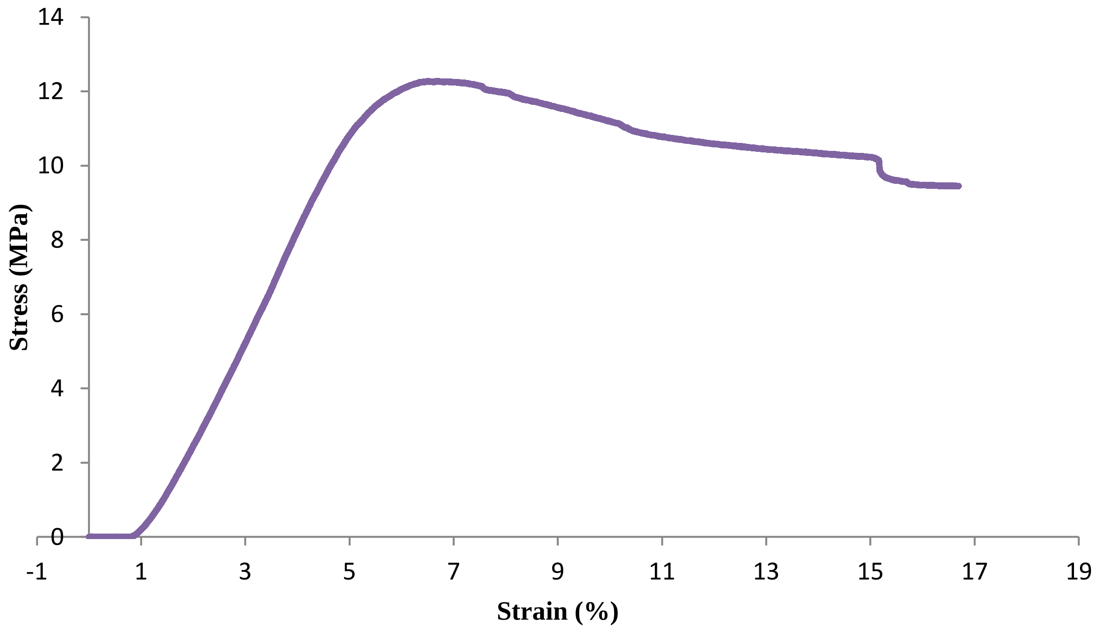


Fig 4.12: Bending stress strain diagram for 16 ply woven FG

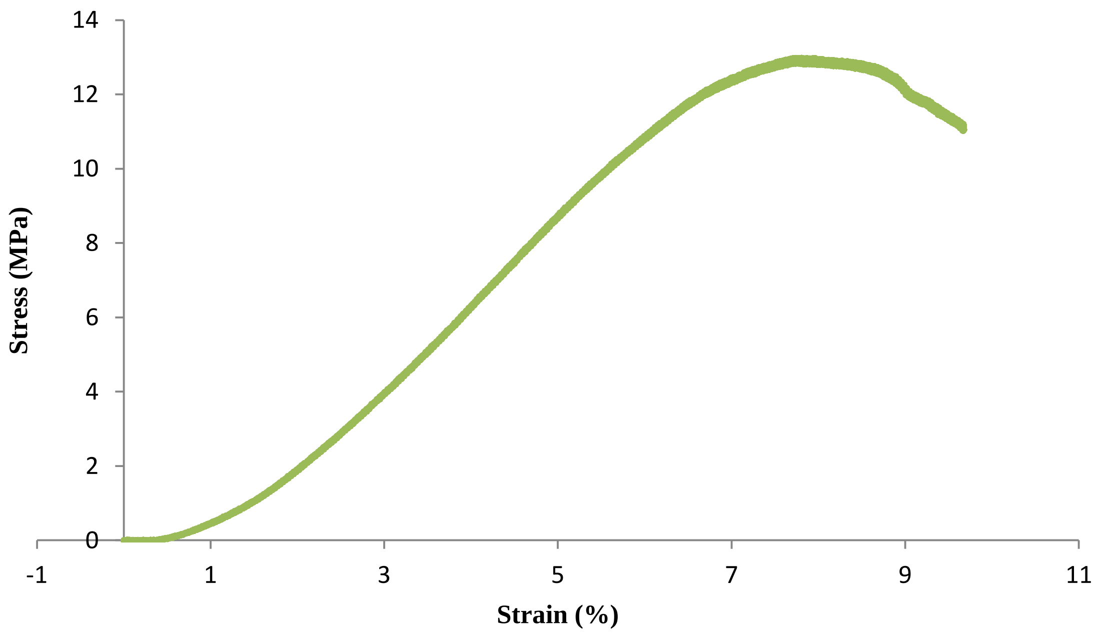


Fig 4.13: Bending stress strain diagram for 16 ply matt FG

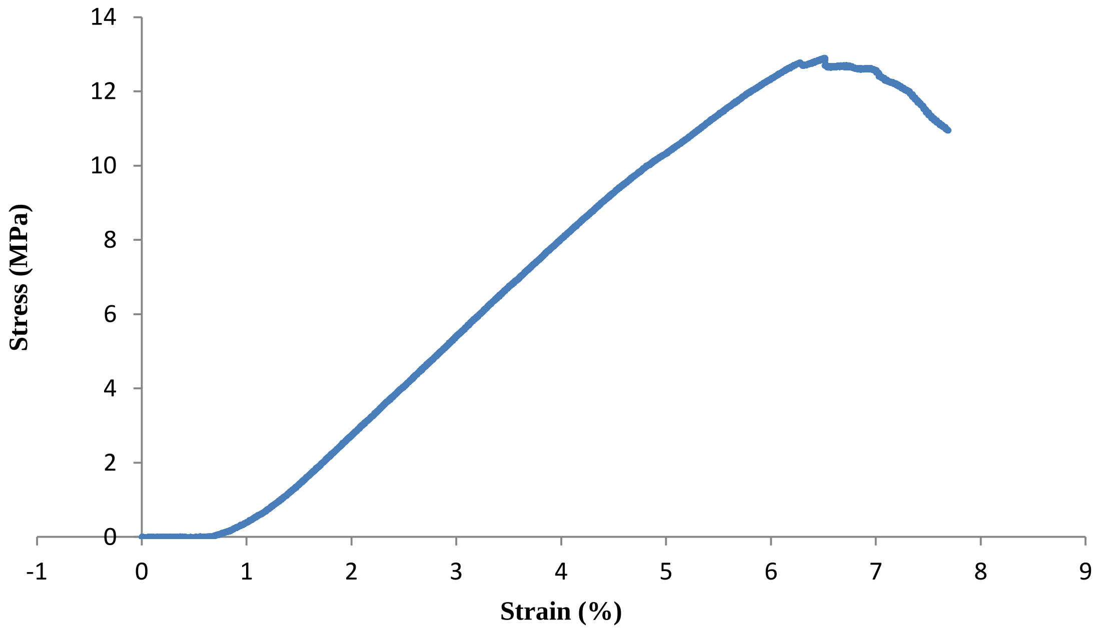


Fig 4.14: Bending stress strain diagram for 5 ply woven + 5 ply matt FG= 10 ply FG

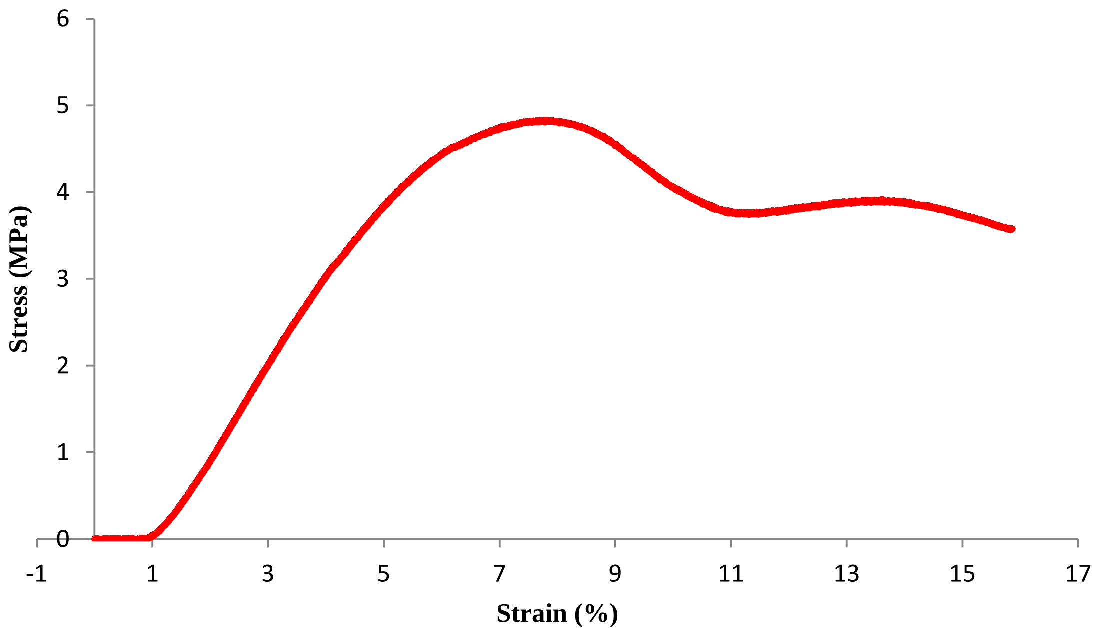


Fig 4.15: Bending stress strain diagram for 8 ply woven + 8 ply matt FG= 16 ply FG

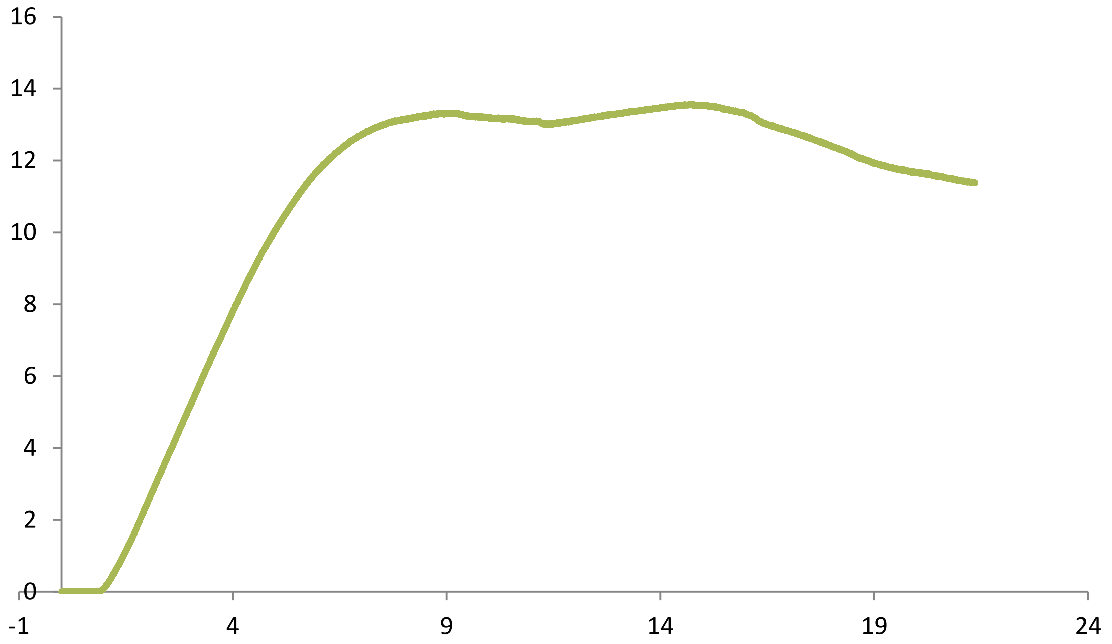


Fig 4.16: Bending stress strain diagram for (1 ply woven + 1 ply matt FG) x 5 sets= 10 ply FG

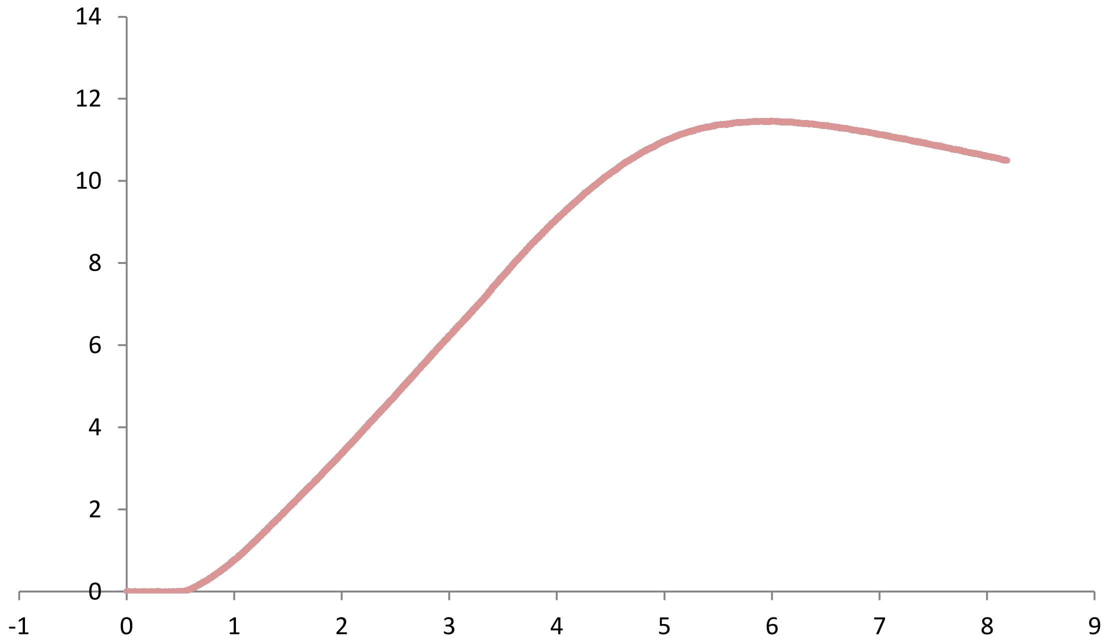


Fig 4.17: Bending stress strain diagram for (1 ply woven + 1 ply matt FG) x 8 sets= 16 ply FG

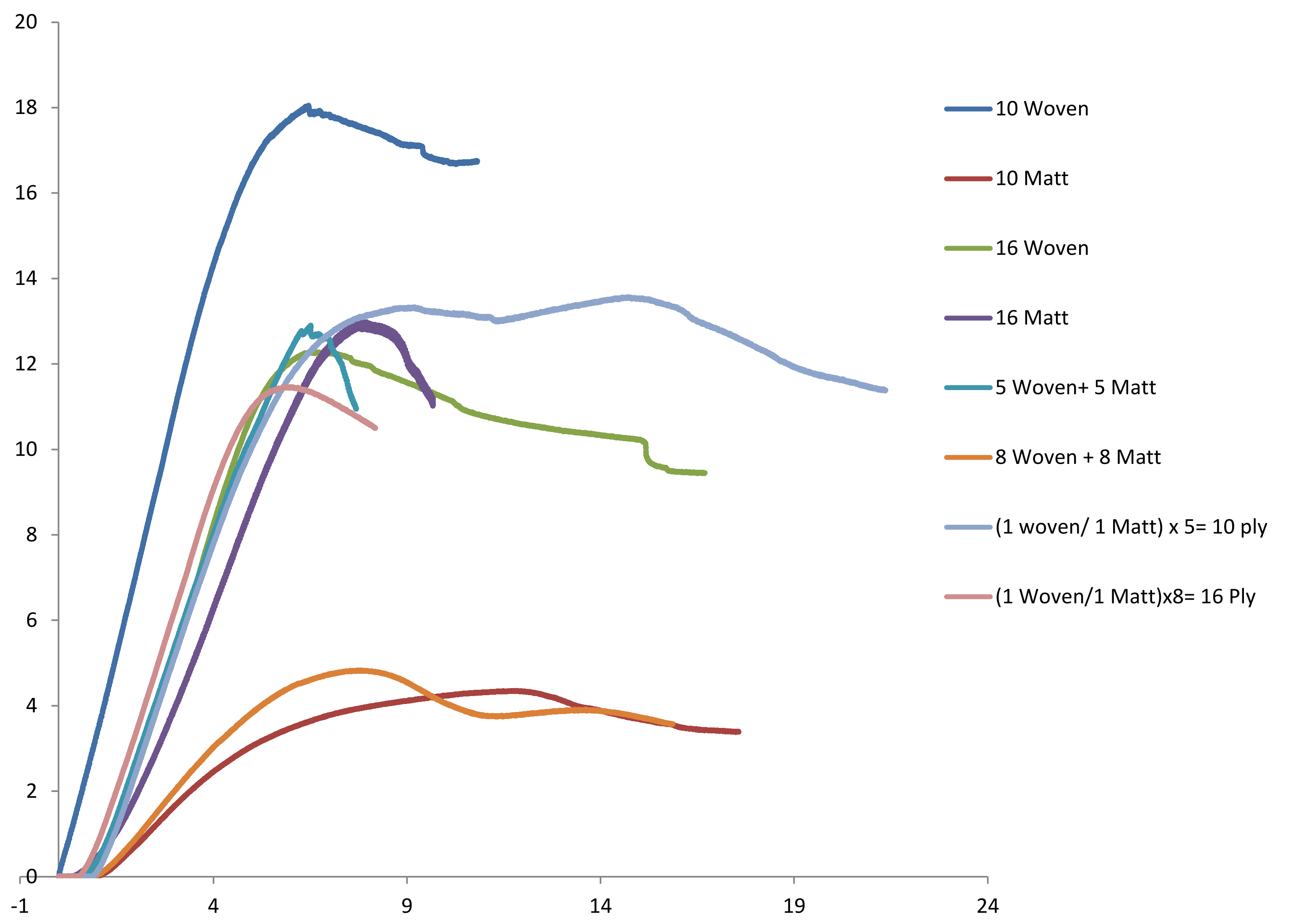


Fig 4.18: All composite combination’s stress strain diagram for Bending test

The bending test however helps to find out some important parameters of the composite materials to evaluate their performance. The table 4.3 contains the information.

Table 4.3: Bending properties of composite combinations

Ser	Composite combination	Elastic Modulus (MPa)	Maximum Bending Moment (N)	Flexural Strength (Pa)
1	10 ply woven FG	5303	1805.37	19.37
2	10 ply matt FG	2780.5	1127.87	15.02
3	16 Ply woven FG	5407	1880.80	25.02
4	16 ply matt FG	3496	1298.62	15.68
5	5 ply woven FG + 5 ply Matt FG	1929	1215.5	17.47
6	8 ply woven FG + 8 ply Matt FG	2311.5	752	9.29
7	(1 ply woven + 1 ply matt FG) = Total 5 set ply (10 Ply)	4741.5	1213.75	15.82
8	(1 ply woven + 1 ply matt FG) = Total 8 set ply (16 Ply)	5194.71	1791.63	16.89

4.4 Charpy Impact Test

The Impact test gives the total energy absorbed before the break down of sample. The energy absorbed by different combinations of the composite material is given below in Table 4.4.

Table 4.4: Impact properties of composite combinations

Ser	Composite combination	Impact Energy (J)	Energy Absorbed (J/mm^2)
1	10 ply woven FG	10	121.9
2	10 ply matt FG	4	53.8
3	16 Ply woven FG	12	153.8
4	16 ply matt FG	6.25	76.9
5	5 ply woven FG + 5 ply Matt FG	8.25	121.4
6	8 ply woven FG + 8 ply Matt FG	10.25	139.9
7	(1 ply woven + 1 ply matt FG) = Total 5 set ply (10 Ply)	7	81.6
8	(1 ply woven + 1 ply matt FG) = Total 8 set ply (16 Ply)	10.5	151.7

4.5 Sample Condition after Property Tests

The samples are physically investigated to find out the effect of impact over them. The conditions are given below:

4.5.1 Condition of sample after Charpy Impact Test

(a)

(b)


(c) (d)

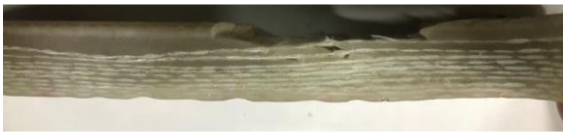

(e) (f)


(g) (h)

Fig 4.19: Physical condition of samples after Charpy Impact Test (a) 10 woven FG; (b) 10 matt FG; (c) 16 woven FG; (d) 16 matt FG; (e) 5 woven+ 5 matt = 10 ply FG; (f) 8 woven + 8 matt = 16 ply FG; (g) (1 woven/ 1 matt) x 5= 10 ply FG; (h) (1 woven/ 1 matt) x 8= 16 ply FG

4.5.2 Condition of sample after Free fall Impact Test

(a)



(b)

Fig 4.20: Physical condition of samples after Free fall Impact Test of 10 ply woven FG (a) Top view; (b) Side view

(a)

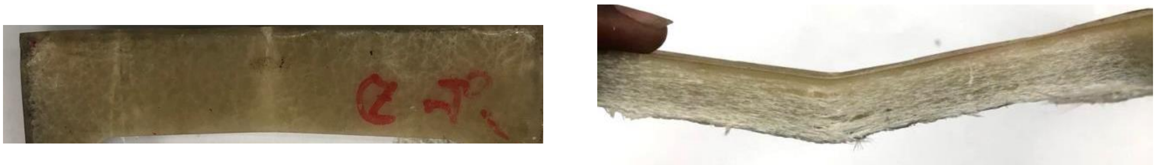
(b)

Fig 4.21: Physical condition of samples after Free fall Impact Test of 10 ply matt FG (a) Top view; (b) Side view

(a)

(b)

Fig 4.22: Physical condition of samples after Free fall Impact Test of 16 ply woven FG (a) Top view; (b) Side view

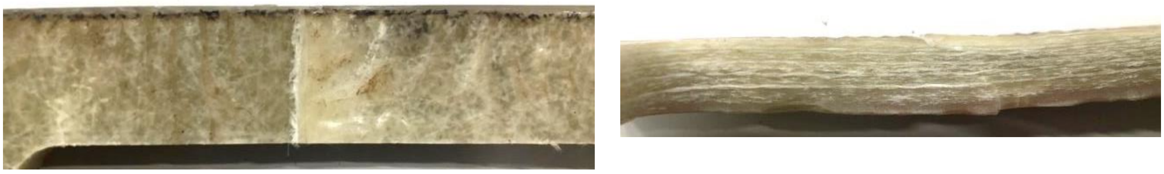


(a) (b)

Fig 4.23: Physical condition of samples after Free fall Impact Test of 16 ply matt FG (a) Top view; (b) Side view

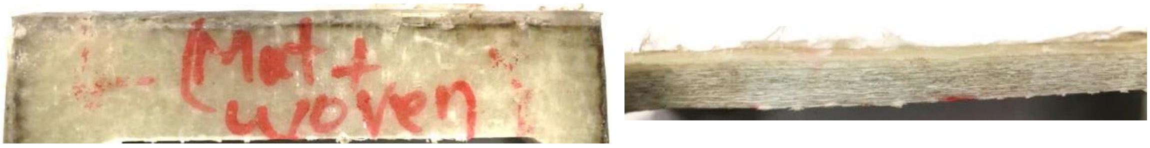
(a) (b)

Fig 4.24: Physical condition of samples after Free fall Impact Test of 5 ply woven + 5 ply matt FG (a) Top view; (b) Side view



(a) (b)

Fig 4.25: Physical condition of samples after Free fall Impact Test of 8 ply woven + 8 ply matt FG (a) Top view; (b) Side view



(a) (b)

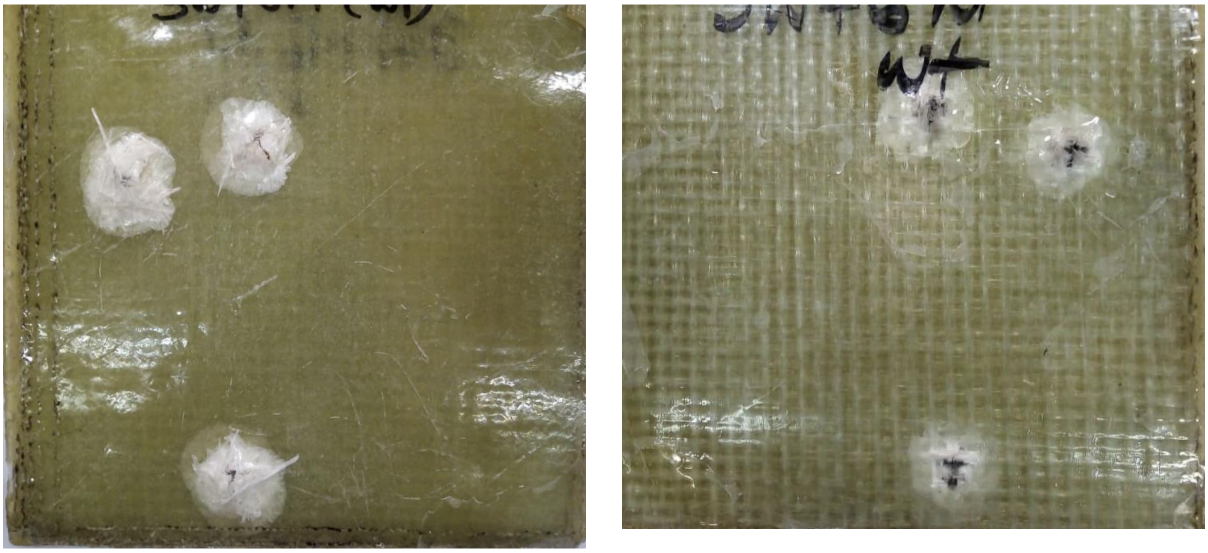
Fig 4.26: Physical condition of samples after Free fall Impact Test of (1 ply woven/ 1 ply matt) x 5 = 10 ply FG (a) Top view; (b) Side view

(a) (b)

Fig 4.27: Physical condition of samples after Free fall Impact Test of (1 ply woven/ 1 ply matt) x 8 = 16 ply FG (a) Top view; (b) Side view

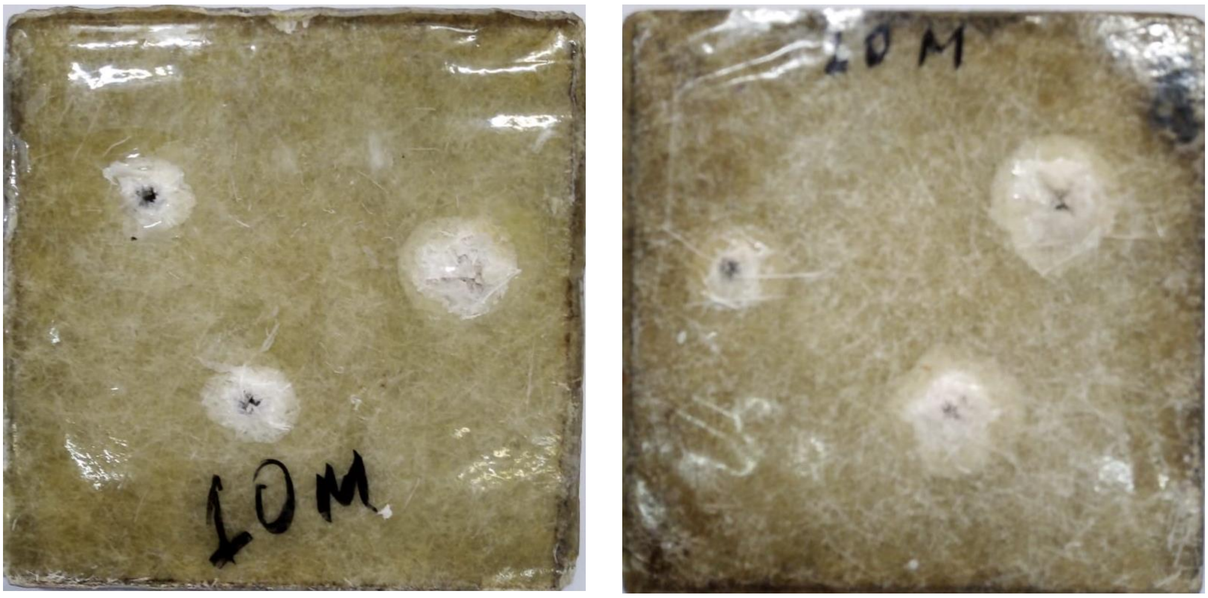
4.5.3 Condition of sample after High Velocity Impact Test

The samples are tested against the high velocity projectile. The target plate was prepared with the samples mounted on it. From 25 m distance a high velocity projectile is released and the penetration effect of the projectile on the specimens.



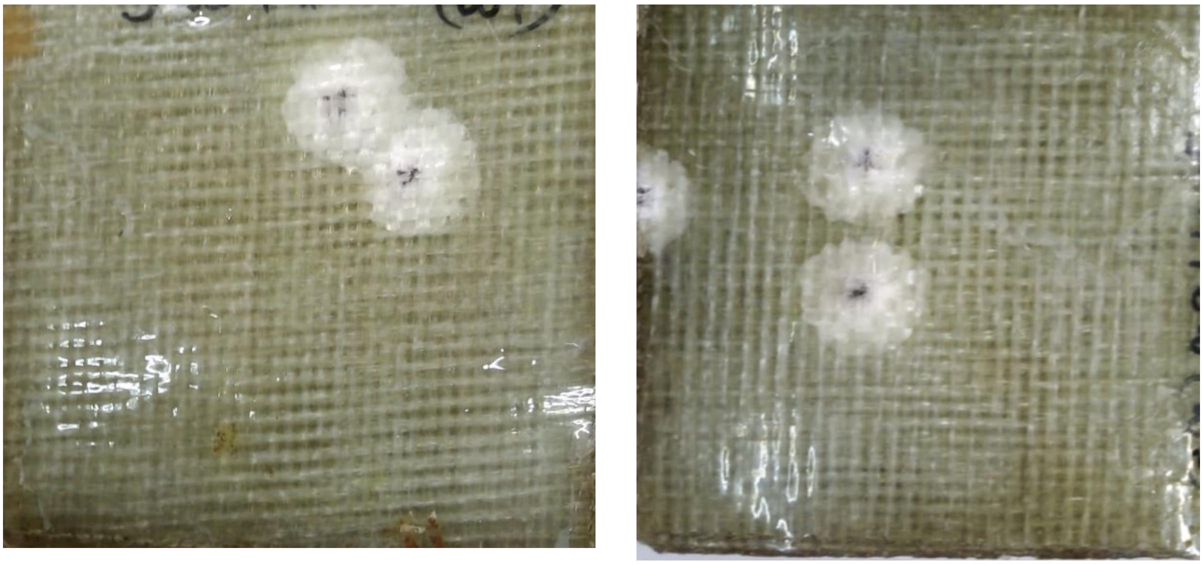
(a) (b)

Fig 4.28: 10 Ply Woven FG specimen after High velocity projectile hit (a) Front side; (b) Back side



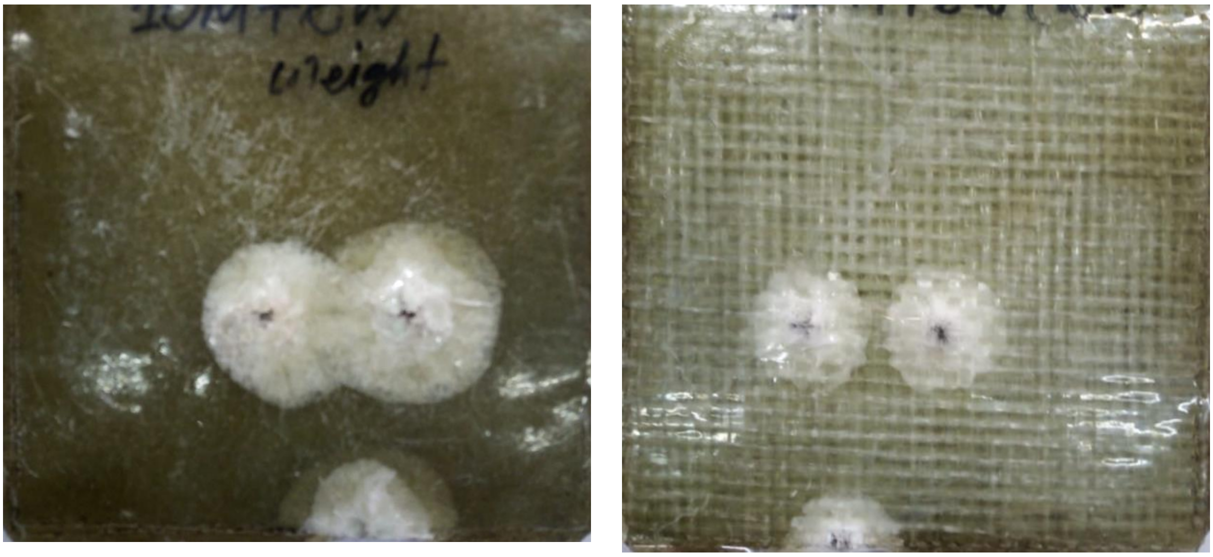
(a) (b)

Fig 4.29: 10 Ply Matt FG specimen after High velocity projectile hit (a) Front side; (b) Back side



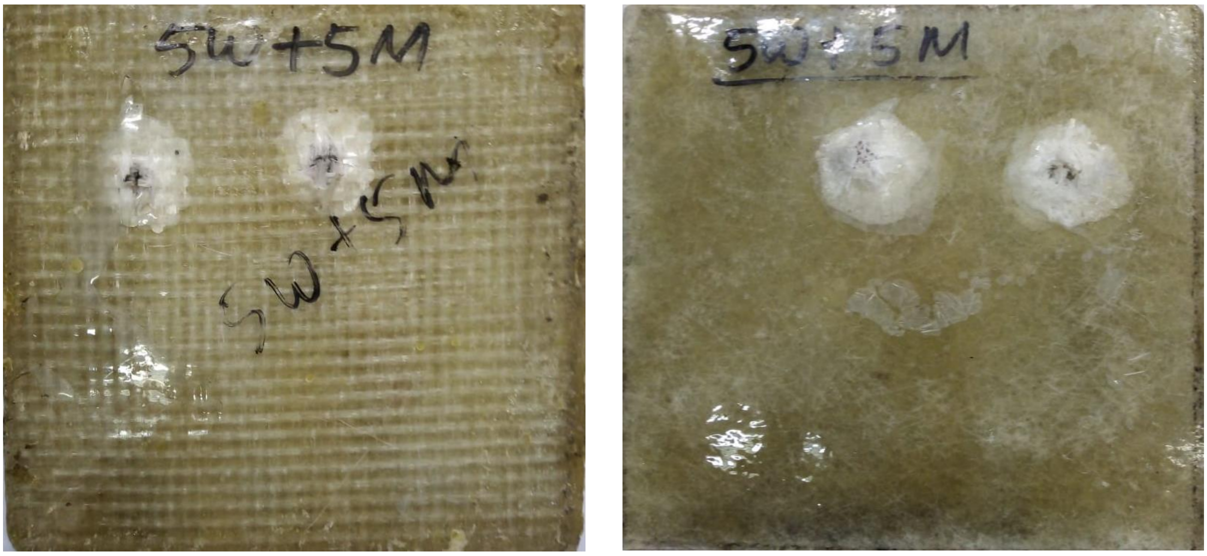
(a) (b)

Fig 4.30: 16 Ply Woven FG specimen after High velocity projectile hit (a) Front side; (b) Back side



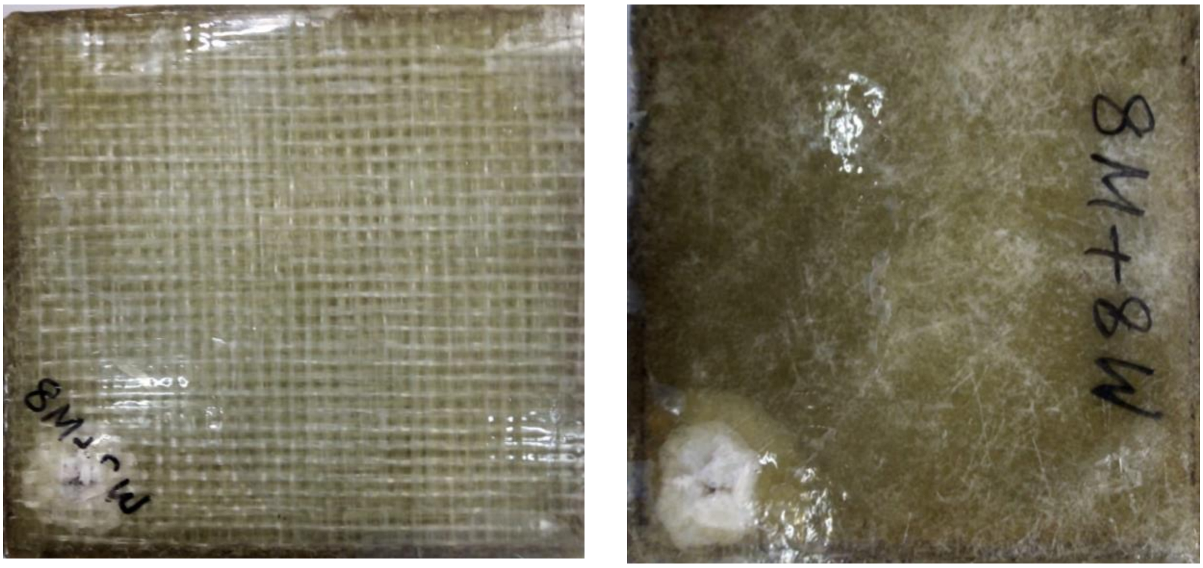
(a) (b)

Fig 4.31: 16 Ply Matt FG specimen after High velocity projectile hit (a) Front side; (b) Back side



(a) (b)

Fig 4.32: 5 Ply Woven + 5 Ply Matt FG specimen after High velocity projectile hit (a) Front side; (b) Back side



(a) (b)

Fig 4.33: 8 Ply Woven + 8 Ply Matt FG specimen after High velocity projectile hit (a) Front side; (b) Back side

(a) (b)

Fig 4.34: (1 Ply Woven / 1 Ply Matt) x 5= 10 ply FG specimen after High velocity projectile hit (a) Front side; (b) Back side

(a) (b)

Fig 4.35: (1 Ply Woven / 1 Ply Matt) x 8= 16 ply FG specimen after High velocity projectile hit (a) Front side; (b) Back side

4.6 Comparison of results

The composites were tested for different property tests. From the property tests different important parameters were derived and results were shown above. The important factors of different property tests are compared below to find the best suited composite.

Table 4.5: Comparison of different properties of produced composites

Ser	Combination	Yield Strength (MPa)	Strength to weight ratio	Specific Modulus	Flexural Strength (Pa)	Energy Absorbed (J/mm^2)
1	10 ply woven FG	127	79.18	1.74	19.37	121.9
2	10 ply matt FG	35	26.76	0.82	15.02	53.8
3	16 ply woven FG	145	83.29	1.94	25.02	153.8
4	16 ply matt FG	67	46.33	1.24	15.68	76.9
5	5 ply woven/ 5 ply matt FG (10 layers)	67	45.51	1.16	17.47	121.4
6	8 ply woven/ 8 ply matt FG (16 layers)	104	60.46	1.25	9.29	139.9
7	(1 ply woven/1 ply matt FG) x 10 layers	86	58.11	1.29	15.82	81.6
8	(1 ply woven/1 ply matt FG) x 16 layers	105	60.73	1.34	16.89	151.7

The property comparison table shows that the 16 pky woven FG combination gives the highest value for all tests. The graph for all the comparison shows clearly the scenario.

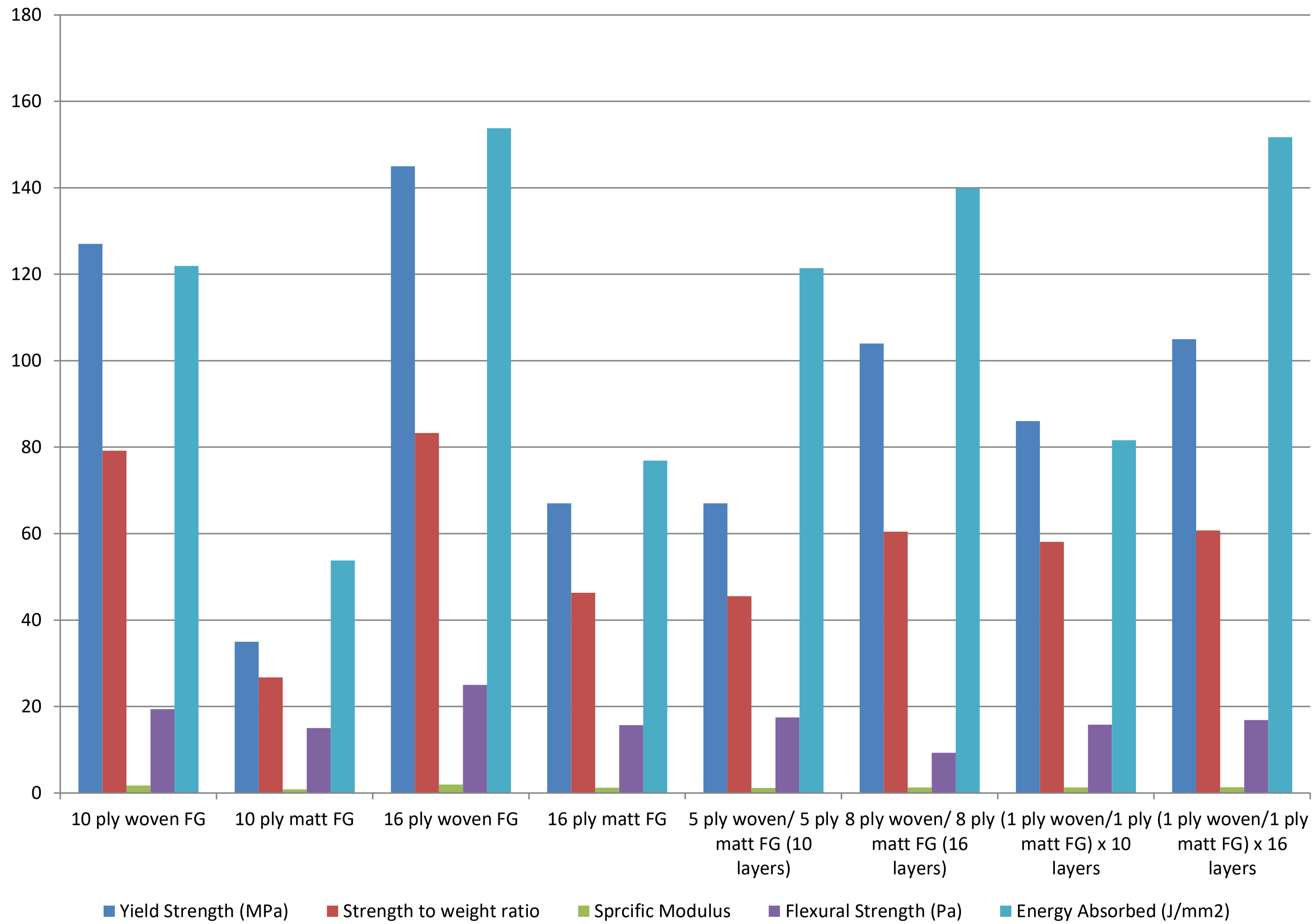


Fig 4.36: Property Comparison for all composite combination

4.7 Cost Analysis

The cost analysis is required to compare the cost of produced specimen with the high end products used for producing impact resistant composites. The composites can be made with the same matrix binder used in this thesis. So the only differentiating factor of the composite is the type of fibers used here. Most cases, the fiber used for higher impact property are Kevlar fiber and Carbon fiber. Both these fibers are not locally found or easily procured item rather these needs to be imported for specific purpose. The Glass fibers on the other hand are easily available in the market as well as cheaper than the other two alternatives. The cost of per sample production is compared in the table given below:

Table 4.6: Comparison of cost for 1 m^2 fibers

Ser	Name of Fiber	Minimum Order Quantity	Unit Price (BDT)	Total Price (BDT)	Total m^2 fiber in minimum order	Per m^2 cost of Fiber (BDT)
1	Woven Type Glass Fiber	1roll	6000	6000	58	103.4
2	Matt Type Glass Fiber	1 roll	4500	4500	95	47.3
3	Kevlar 29 (Kevlar-29-Fabric-120g-M2-1000mm-x-1000mm.Html, n.d.)	1m^2	3040	3040	1m^2	3040
4	Carbon Fiber (808IEI04M-6-5ft-x-12-Carbon-Fiber-Fabric-Roll-Vinyl-Wrap-Fabric-Carbon-Fiber-Sheet, n.d.)	0.4 m^2	6180	6180	0.4 m^2	15,450

The comparison of the per m^2 fiber shows that the cost of different fibers. Now to calculate the total cost of producing same specimen with different fibers but same matrix binder and other fixed costs, the table below shows the comparison among all the fiber components.

Table 4.7: Production cost of composites using different fibers

Ser	Material required		Quantity required	Unit Cost (BDT)	Total Cost of materials for per piece of specimen (BDT)	Total cost of specimen (BDT) [Fiber cost + 2+3+4]
1	Fiber Cost	Woven Type Glass Fiber	0.37 m^2	103.4	38.25	179.75
		Matt Type Glass Fiber	0.37 m^2	47.3	17.5	159
		Kevlar 29	0.37 m^2	3040	1124.8	1266.3
		Carbon Fiber	0.37 m^2	15450	5716.5	5858
2	Matrix (Epoxy Resin) Cost		300 ml	325 per ltr	97.5	-
3	Hardener Cost		30 ml	1200 per ltr	36	-
4	Cobalt 6% Cost		5 ml	1600 per ltr	08	-

The costing of the materials give the idea that, the produced composite with glass fiber has much less costing than that of high performing fibers like Kevlar and Carbon fiber. All the calculations were done keeping 16 ply of fibers in the composite.

4.8 Impact Effect Analysis

The Charpy impact test and Izod impact tests were carried out to all the specimens. The effects of these tests show various lamina failure. The following section discusses the effects.

4.8.1 De-lamination

The failure mode of delamination occurs when the layers of a laminated composite entirely or partially separate from one another. The strength and stiffness of the composite are decreased by this separation, which happens parallel to the layers. In laminated composites, delamination is a significant failure mechanism because it can spread quickly and cause the structure to fail catastrophically. Delamination can happen for a number of reasons, including impact, fatigue, high loading, or production flaws. Using non-destructive evaluation methods including ultrasonic scanning, X-ray radiography, and thermography, the degree of delamination can be measured. Laminated composites can avoid delamination with the use of proper design, production, and maintenance procedures. (Kaw, 2006).

Fig 4.37: De-lamination of composite laminate

4.8.2 Crack Propagation

Crack propagation in composite materials is the process through which a pre-existing fracture or crack inside the material widens and progresses under a load or stress. The qualities of the material, the type of loading, and the environment are some of the variables that might affect the complexity of the crack propagation process. Assessing a composite material's overall strength and durability as well as its failure mechanisms under various loading circumstances depends heavily on how cracks behave. The dependability and performance of composite structures can be increased with the help of proper crack propagation modeling and analysis. (Kaw, 2006)

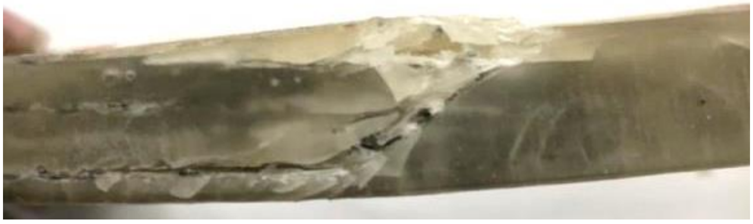


Fig 4.38: Crack Propagation of composite laminate

4.8.3 Distortion

When referring to composite materials, the term "distortion" describes how the material's shape or dimensions vary as a result of external loads or temperature fluctuations. Due to their orientation and material characteristics, the individual layers or plies of a composite material experience varying degrees of deformation when it is subjected to external loads, changing the overall shape of the composite structure. Particularly in high-precision applications like aerospace or medical equipment, where dimensional accuracy is crucial, distortion can be an essential design factor for composite materials. To reduce distortion and guarantee that the composite structure retains its intended shape and dimensions despite external loads and temperature changes, techniques like fiber steering or customized layup can be used. (Gibson, 2012)

Fig 4.39: Distortion of composite material

4.9 Penetration Effect Analysis

The composites produced were exposed to high velocity projectile hitting. The fibers were damaged and penetrated through and through. The fiber deformation criteria and lamina distortion criteria can be observed with a closer look of the specimens. As per the property tests, the best performing composite was the 16 ply woven type composite combination. The penetration effect of this combination was checked with magnification and closer look. The figure below shows the penetration of the high velocity projectile.

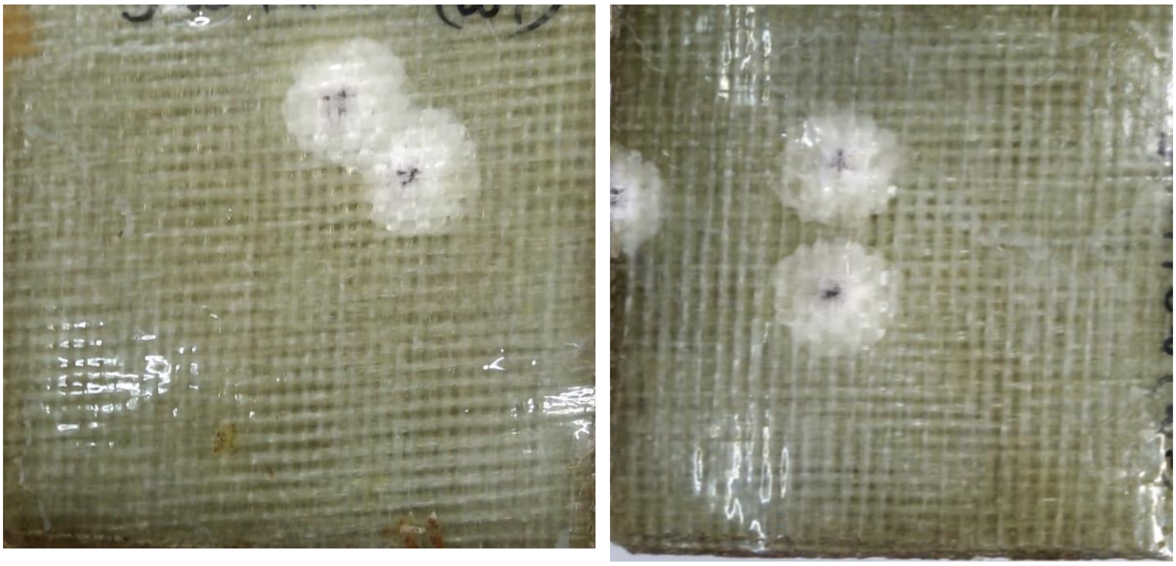


Fig 4.40: 16 Ply woven FG combination composite after high velocity projectile hit

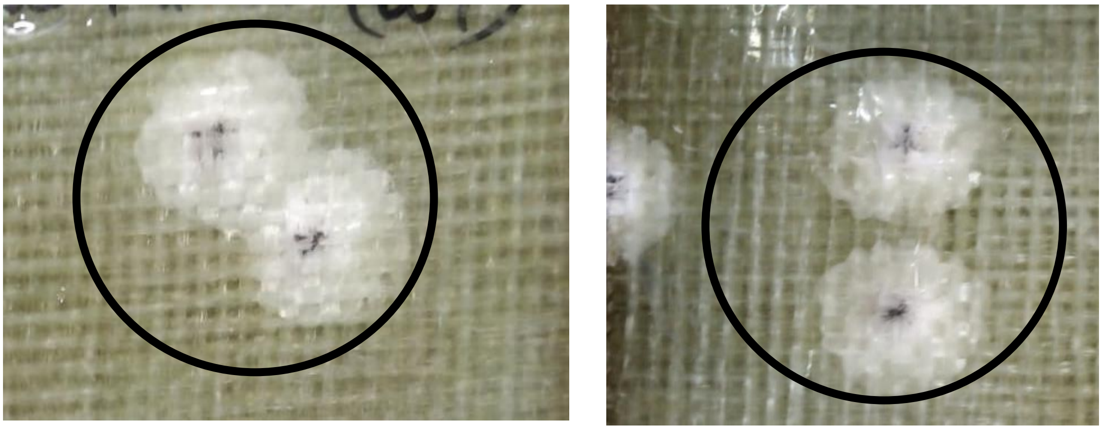


Fig 4.41: Magnified projectile hit area of 16 ply woven composite combination

The magnified area of projectile hit suggests the projectile went through the composite. Despite the full penetration the affected fibers around the projectile hit shows that the fibers were compact and resisted the projectile penetration. Addition of few more layers of lamina may stop the projectile motion.

CHAPTER 5

CONCLUSION

5.1 General

The results and the graphs are analyzed and best suited composite is found out. The cost analysis also finds out the better economically feasible option of making composite. The analysis suggests that 16 ply woven type fiber glass constitute a better performance in terms of property test results and projectile hit surface. The effects are further analyzed for an overall achievement of thesis objective.

5.2 Choice of Raw Material

Despite being a brittle material, glass fiber was ultimately chosen to find out the performance against high impact. As per the objective of making a composite of lower cost, this material was chosen. The material is readily available in the market at a cheap rate. The diverse application of this material has made it easier to procure and use. With the proper mixture of epoxy, hardener and cobalt 6 the material shows behaves steadily against all property tests and high value of impact though the brittleness was suggesting to behave otherwise.

5.3 Costing

The costing was very less as the raw materials used are very common in local markets. Also the widely used materials like Kevlar and carbon fibers need to be imported from abroad and have a high price rates. So the produced composites are of less cost.

5.4 Epoxy Hardener Mixture Ratio

The mixture ratio is kept constant for all the combination to avoid any sort of alteration associated with this factor. Keeping this constant ensures that the fibers are exposed to same amount of binder mixture and their behavior change with the fiber fraction only not for the binder mixture.

5.5 Impact resistant

The impact property tests and high velocity projectile test and free fall impact test categorically suggest the FG ply composites are capable of resisting the impacts. So the objective of thesis is met.

5.6 Conclusion

The thesis aimed to establish a simple method to fabricate composites with the readily available materials and a better suited impact resistant composite. The simple steps of production and easier raw materials requirement has enabled to composite to be low cost and simply fabricated. Though the high velocity projectile penetrated the composites yet it suggests that addition of few more layers would enable composite to stop projectile. At the end, this research has successfully produced a low cost high impact resistant composite with the help of Glass fiber and epoxy.

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