MECHANICAL CHARACTERIZATION OF CRYOGENICALLY TREATED COMPOSITE MATERIAL FOR SPACE APPLICATIONS

Dissertation-II

Submitted in partial fulfillment of the requirement for the award of degree

Of

Master of Technology

IN

MECHANICAL ENGINEERING

By

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Under the guidance of

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CERTIFICATE

I hereby certify that the work being presented in the dissertation entitled "MECHANICAL CHARACTERIZATION OF CRYOGENICALLY TREATED COMPOSITE MATERIAL FOR SPACE APPLICATIONS" in partial fulfillment of the requirement of the award of the Degree of master of technology and submitted to the Department of Mechanical Engineering of Lovely Professional University, Phagwara, is an authentic record of my own work carried out under the supervision of (Name Of Supervisor, Designation) Department of Mechanical Engineering, Lovely Professional University. The matter embodied in this dissertation has not been submitted in part or full to any other University or Institute for the award of any degree.

5th June 2017

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This is to certify that the above statement made by the candidate is correct to the best of my knowledge.

5th June 2017

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The external viva-voce examination of the student was held on successfully _______________

Signature of Examiner

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INDEX

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DECLARATION

I, Nitin Khosla, student of Master of Technology (Mechanical Engineering) under school of Mechanical Engineering of Lovely Professional University, Punjab, hereby declare that all the information furnished in this dissertation report is based on my own intensive research and is genuine. This dissertation does to the best of my knowledge, contain part of my work which has been submitted for the award of my degree either of this university without proper citation.

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Date:

CONTENTS

List of Figures

List of Tables

Chapter 1

1 Introduction

There a many research centers which are working on the space organization whole over the world. Around 70 different government agency of space are in existence over the world. Only six government agencies of space have got full launch capabilities. The major applications of Space Organizations are like Earth observation, Satellite communication, Disaster Management, Navigation and Climate & Environment.

Table 1 Top Research Organizations for Space Application in World.

Name	Acronym	Country	Founded
National Aeronautics and Space Administration	NASA	United States	1958
Russian Federal Space Agency	ROSCOSMOS	Russia	1992
European Space Agency	ESA	European states	1975
Japan Aerospace Exploration Agency	JAXA	Japan	2003
Indian Space Research Organization	ISRO	India	1969
China National Space Administration	CNSA	China	1983
Space Studies Institute	SSI	California	1977
Space Science and Engineering Center	SSEC	USA	1960
International Space University	ISU	France	1987
International Space Science Institute	ISSI	Switzerland	1995

SAC (Space Applications Centre) is one of the major centers of the ISRO (Indian Space Research Organization). The main aim of the centre is to deal with a wide variety of disciplines comprising design and development of payloads, societal applications, capacity building and space sciences, thereby creating relations of technology, science and applications.

1.1 Properties of the materials for space applications

To build up with the composite material for space application we should analyze the different kind of properties which are desirable for the material under various boundary conditions such as:

- Firstly the material should be dimensional stabile as we know that the space object will be direct contact with solar heat so it would get expand and contract.
- Material should be environment stabile as it has to withstand with harsh environment so that material can stay stable even after the presence of radiation and the vacuum in space.
- When the object will face the incredible forces in the orbit around the earth the weaker part will get tear out, to overcome it the material should have strength and stiffness.
- At the time of launching the material under goes three times the force of gravity which means each component will weigh up to three times of its earth weight. Due to immense forces the material should not break or bend and maintain its integrity.

So in order to build a material for space applications we have to keep all the above points and the material should be incredibly light in weight as a single kilogram of extra mass increases the cost of launching by thousands of dollar. [2]

One of the materials that are often appropriate for a particular purpose is Kevlar. Kevlar is a material used in bulletproof vests and covering a military vehicle or ship to defend it from attack. It is ideal for space applications due to its property of extremely light in weight and strength. It has also high resistant to temperature changes making it ideal for the orbiting structures. Its toughness and durability also makes it perfect for protecting space applications

1.2 Cryogenic Treatment

In the terms physics, to make a material at very low temperatures (mostly below -150°C) and afterwards to study about the behavior of material is known as cryogenic. Cryogenic is a word taken from two Greek words.

"Kryos" means cold or freezing
"Genes" means born or generated

A cryogenic treatment is the process of treating work pieces to cryogenic temperatures in order improves its physical as well as chemical properties of material. Cryogenic treatment also known as cold or subzero treatment. It is a very old process and is widely used for high precision parts.

SCT: - Shallow cryogenic treatment ranging from - 60°C to - 80°C
DCT: - Deep cryogenic treatment ranging from -125°C to -196°C

1.2.1 Nomenclature

Cryogenics: - In the terms physics science, cryogenic is the study of the behavior of materials at very low temperatures.

Cryobiology: - It is the branch of medicinal in which we study about the effects on organisms at temperature under normal. It includes studies of cells, organs, tissues, proteins.

Cryosurgery: - Cryosurgery is also known as cryotherapy. It is a surgery used to treat external tumors mostly those on the skin by using extreme cold to tear down tissues e.g. cancer cells. Most often we use liquid nitrogen, although carbon dioxide and argon may also be used.

Cryoelectronics: - It is a branch of electronics dealing with the study of superconductivity under cryogenic conditions and its applications.

Cryotronics: -The practical applications to utilize superconductivity are known as cryotronics.

Cryonics: - it is the science of using ultra-cold temperature to preserve human and animal life with the intention of future revival.

1.2.2 Advantages

Various advantages that we can achieve to material after Cryogenic Treatment are as blow:-

- Increase in hardness,
- Increase in wear resistance,
- Reduce residual stresses,
- Increase Fatigue resistance,
- Increase dimensional stability
- Increase thermal conductivity
- Increase Toughness

1.2.3 Applications

Cryogenic is widely used in all the applications for example it is used in space, biology, medical field, mechanical engineering, refrigerators, food industry, superconductivity etc.

1.2.3.1 Use of cryogenics in Space Applications

Space simulation: Testing on the space craft under duplicate conditions same as of the a given mission and to achieve the level of vacuum required in space simulation chamber is very high and it is achieved by using cryopumps.

Nuclear rocket propulsion: - Liquid Hydrogen is used as a fuel to propel the nuclear rocket. Cryogenic propellants give powered to cryogenic engines.

1.2.3.2 Use of cryogenics in Bio-medical Applications

The use of low temperature in medical has given a new birth to sub science named "Cryobiology"

Treatment of skin diseases: - Warts, swelling, blister and scarring can be treated by liquid nitrogen. When a region in an organ or tissue which has suffered damage through injury or disease is touched by a cotton swab of liquid nitrogen, freezing occurs instantly and helps in recovery.

Tissue preservation: - At cryogenic temperature it has been possible to preserve the tissue and cell. Transplantation has been achieved of corneal tissues from cadavers to individual whose corneas have been damaged.

Blood preservation: - Mainly two types of cryogenic blood storage techniques are followed. In first one the technique the red cells are separated from the blood and then mixed with protective agent (glycerol) and stored at – 80 ° C. In second technique whole blood in storage in a bath of liquid nitrogen (cryogenic temperature).

1.2.3.3 Use of cryogenics in food preservation

Preserving and transporting large masses of frozen food is well known technique. Freezing of sea foods, meat, milk products are achieved by using liquid nitrogen. This frozen food is used in war areas, earthquake hit regions etc.

1.2.3.4 Use of cryogenics in superconductivity

Nuclear Magnetic Resonance (NMR): - To determine the chemical and physical properties of atoms by the ratio frequency absorbed and subsequent relaxation of nuclei in a magnetic field, one of the best and common ways is NMR. To super conduct, high- temperature superconducting compounds are made with the help of liquid nitrogen.

Magnetic resonance imaging (MRI): -The Magnetic resonance imaging machines are used for body scanning by detecting the relaxation of protons that have been perturbed by a radio-frequency pulse in the strong magnetic field. Superconducting magnets for MRI machines are cooled by liquid helium. Fig shows the MRI system containing nitrogen chamber, helium chamber and cryogen transfer port.

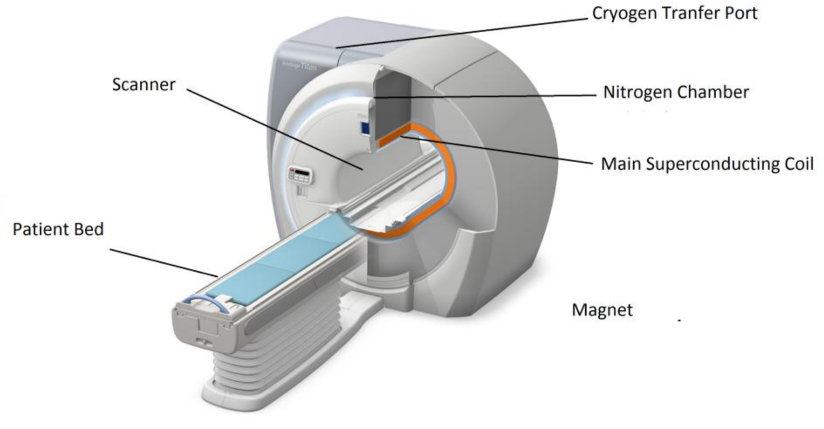

Figure 1 MRI

1.3 Composite Material

Basically the composite materials are the materials formed by the combination of two or more materials on macroscopic level to form a new useful material. The result of new material formed by combination is far better than those of the individual components if used alone. In comparison to metallic alloys with composite material, in composite each material retains its separate mechanical, chemical, and physical property. The composites material needs to withstand very large temperature variations and extremely low temperatures when served at various extreme conditions.

Properties that can be improved by forming a composite material are as such:-

- Strength
- Fatigue life
- Stiffness
- Temperature- dependent behavior
- Wear resistance
- Thermal insulation
- Thermal conductivity
- Weight

1.3.1 Classification and Characteristics of Composite Materials

- Particulate composite material that consist of particles in a matrix
- Fibrous composite materials that consist of fiber in matrix
- Laminated composite material that consist of layers of various materials
- Combinations of any two or three types from above

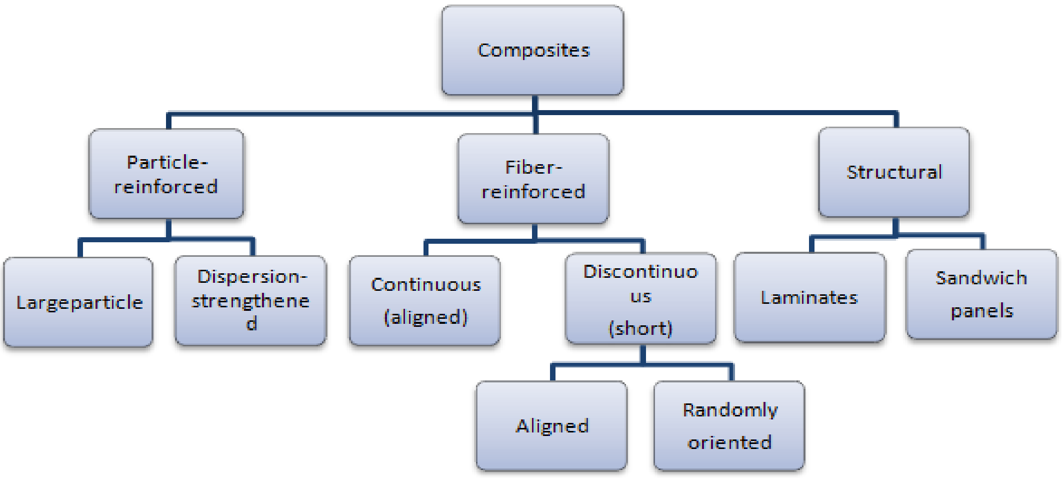

Figure 2 Classification of composite

1.3.1.1 Particle-reinforced composites

Particle-reinforced composites are broadly available and are cheaper than others ones so they are most commonly used composite. Some of the examples of Particle-reinforced composites are: automobile tires, concrete, spheroidite steel etc. They are further divided into two parts: particulate-reinforced composite (large particle) and dispersion-strengthened.

In particulate-reinforced composite, particles are comparatively larger then compare to dispersion-strengthened. The composite is designed in such a way to improve its mechanical properties (elastic modulus) rather than advancing its strength.

Dispersion-strengthened composite particles are smaller in size varies from 10-100 nm. The composite is designed to improve its yield and tensile strength. Major portion of the load is bearded by matrix.

1.3.1.2 Fiber- reinforced composite

Fiber reinforced composite materials provides enhanced strength and strength to weight ratio. Matrix material bears most of the applied load and it transfer the load to fibers. It also provide security from atmosphere and external loads. They are further dived into two types: continuous or discontinuous. Continuous reinforcement matrix provides higher strength and stiffness as compare to discontinuous fibers. Discontinuous reinforcement matrix are economically better than others ones.

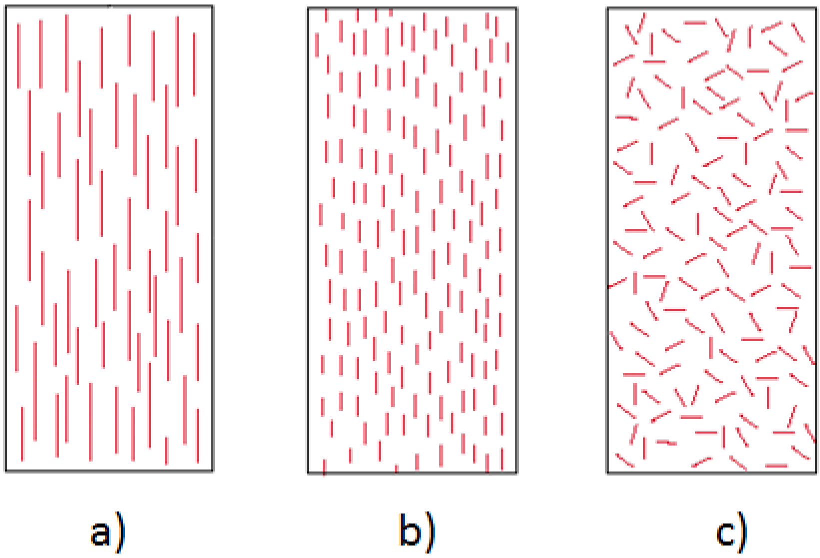

Figure 3 a) Aligned continuous, b) Aligned discontinuous, c) Random discontinuous

1.3.1.3 Structural composites

This is a particular composite consisting of both homogeneous and composite materials. There are two types of structural composites: laminar composites and sandwich structures.

Laminar composites: Laminar composite are composted of 2-dimensional sheets. They are designed to increase corrosion resistance at the same time retaining its high strength and light weight. Resources used in their manufacture comprise: cotton, paper, metal sheets, woven glass fibers etc.

Sandwich structures: Sandwich composite are composed of thin layers of material joined to filler material. Composite is designed to tend strong and rigid. Resources used for materials are: rubber, synthetics, polymer, balsa wood. They are mostly found in applications like: aircraft wings, floor, roof, walls etc.

Chapter 2

2 Terminology

2.1 Cryocan

Cryocan is a double walled vacuum insulated refrigerator for storing Liquid Nitrogen (-196°C). The cryogenic container is manufactured with advance vacuum technology and multi layered super insulation. Inner vessel and outer vessel of container is fabricated out of prime quality aluminum.

Figure 4Cryocan

2.2 Carbon Fabric

A carbon fiber is a long, thin fiber of material about 0.005mm to -0.010mm in diameter and composed generally of carbon atoms.

Figure 5 Carbon Fabric

2.3 Kevlar Fabric

Kevlar has a unique combination of high strength, modulus, toughness and thermal stability developed at DuPont in 1965. It was first commercially used in the early 1970s as a replacement for steel in racing tires.

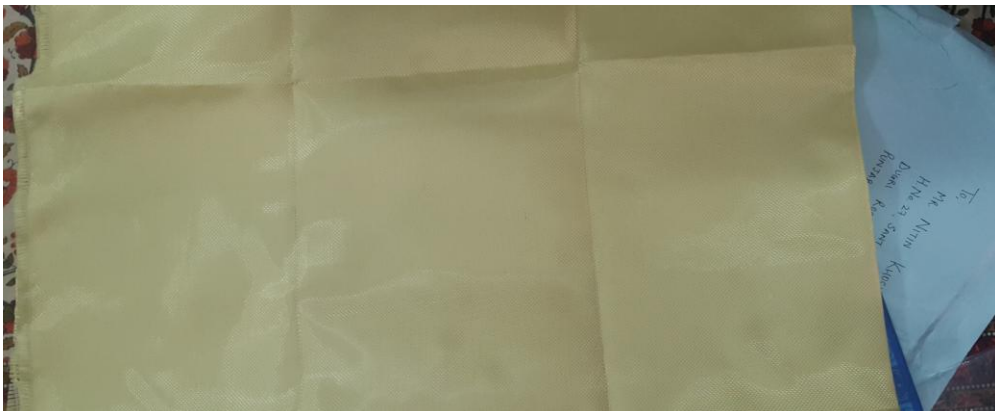

Figure 6 Kevlar Fabric

2.4 Epoxy

An epoxy adhesive is combination of resin and hardener in ration of 30:10.Depending upon the required thickness of layer and the temperature of work area it will take several hours to days accordingly to dry and cure.

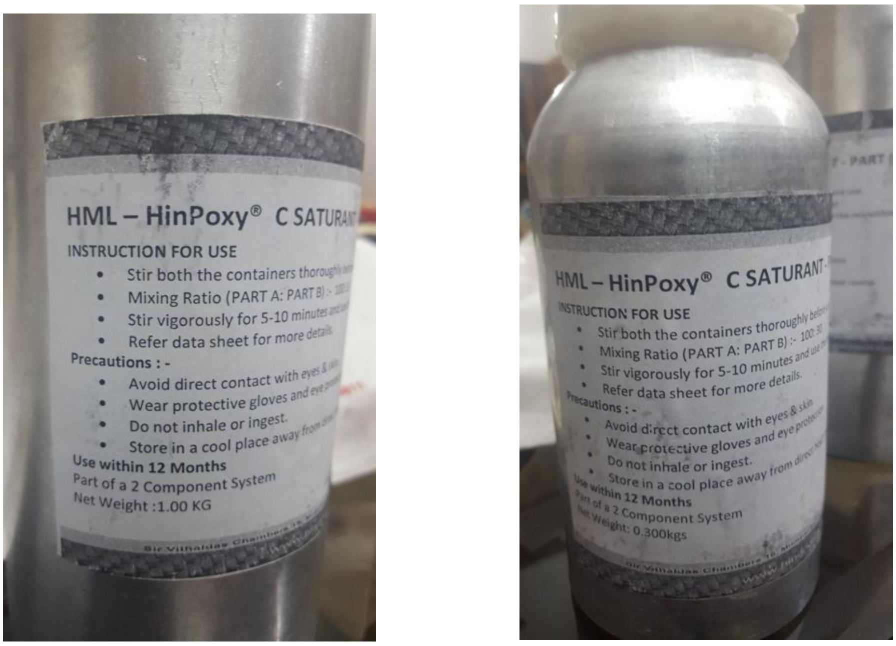

Figure 7Resin and Hardener

2.5 Liquid Nitrogen

It is nitrogen in a liquid state at an tremendously low temperature. Properties of liquid nitrogen are colorless clear liquid with a density of 0.807 g/ml at its boiling point (−195.79 °C (77 K; −320 °F)). Liquid nitrogen is a cryogenic fluid that can cause rapid freezing on contact with living tissue.

2.6 Polycarbonate sheet

Polycarbonate sheet is generally replacing glass, toughened glass and polyethylene membrane in many fields. It is a perfect combination of lightweight, high impact strength, light transmission. It was used for the sample preparation as the slots were made in polycarbonate sheet with the help of laser cutting

Figure 8 Polycarbonate sheet

2.7 Electronic Digital Scale Weighing

Electronic Digital Scale Weighing with a High Precision Strain Gauge Sensor System has option to weigh different ingredients in the same container. Used when you have to measure some liquid or powder which you can put a bowl on the machine & press tare the machine will show zero & then shall take the weight of the liquid or powder separately.

Figure 9Electronic Digital Scale

Chapter 3

3 Review of Literature

3.1 Present Research

This chapter is basically the review of the studies related to cryogenically treatment and composite materials in the present time. This includes the study of various scientist and scholar. As my thesis work is on Mechanical characterization of cryogenically treated Composite Material for Space Application so all the paper related to my topic are covered and the review points are noted down.

3.2 Studies by Researchers and Co-Workers

- **CHI Hong-xiao et ol. (2010);** studied about "Effect of Cryogenic Treatment on Properties of CrS-Type Cold Work Die Steel", four treatment cycles were carried out. Micro structure surveillance was passed out by transmission electron microscope (TEM). For the consequences XRD patterns of retained austenite for different treatment cycles were in use. Finally increasing the hardness by decreasing retained austenite. Deep cryogenic treatment improves the wear resistance[1]

- **Gang Wang et ol .(2016):** studied about "Improving the wear resistance of as-sprayed WC coating by Deep Cryogenic Treatment", important changes in the microstructure & wear resistance were experiential after 48hr of DCT. For the microstructure and phase analysis Scanning electron microscopy (SEM) and X-ray diffraction (XRD) were used. The transformation of α-Co to ε-Co and an increase in the number of η phase particles after the cryogenic treatment have given superior wear resistance[2]

- **Mahdi Koneshlou et ol.(2010):** studies about "Effect of cryogenic treatment on micro-structure, mechanical and wear behaviors of AISI H13 hot work tool steel" . Before CT, the samples used were held at 1040 °C for 30 min for austenitizing followed by air quenching by which austenite was transformed to martensite which help out to achieve more durable tool steel parts.[3]

- **S. Zhirafar et ol. (2006):** studies about “Effect of cryogenic treatment on the mechanical properties of 4340 steel” by the method of neutron diffraction there was a small reduction in the quantity of retained austenite, which was transformed to marten site by applying the cryogenic treatment which led to an boost in hardness. The fatigue limit of the steel was enhanced which attributed to the higher hardness and strength of the material due to this cure.[4]

- **A. Bensely et ol.(2009):** studied about “Fatigue behavior and fracture mechanism of cryogenically treated En 353 steel” using rotating bending fatigue machine apparatus. S–N curves were generated for CHT, SCT and DCT specimens. On the whole fatigue life improvement of SCT over CHT is 71.42% whereas there is a reduction of 26% fatigue life in DCT over CHT. SCT specimens experience high fatigue strength and can be attributed to the low core hardness value and too much case rubbing[5]

- **Fla´vio J. da Silva et ol. (2006):** studied about “Performance of cryogenically treated HSS tools” based on their consequences obtained conclusions can be drawn practically the 25% volume of the retained austenite observed in the untreated sample were transformed into marten site by the cryogenic treatment which enlarged the performance. Overall the cryogenic treatment had positive influences on the performance of the tools tested. [6]

- **Joel Hemanth (2005):** studied about “Tribological behavior of cryogenically treated B4Cp/Al–12% Si composites” Strength, hardness and wear resistance of the chilled MMCs are superior to those of the matrix alloy. It was found that there properties increases with an increase in the spreading content up to 9% vol.[7]

- **Nursel Altan at ol.(2015):** studied about “Effect of cutting conditions on wear performance of cryogenically treated tungsten carbide inserts in dry turning of stainless “as a result of image processing analysis, it was originate that the quantity of fine carbides in the deep cryogenically treated inserts had increased by 5.4% in comparison to that of the untreated ones. Cryogenic treatment led to an addition of 9% in the grain size of the treated inserts with respect to that of the untreated.[8]

- **Hadi at ol.(2015):** studies about "Alternative phase transformation path in cryogenically treated AISID2 tool steel" by dilatometry results joined with micro structural examine showed an alternative phase transformation path during conventional heat treatment of AISID2 tool steel. The obtained micro structure was composed of higher volume fraction of carbides with area below 1 μm [9]

- **S. Harish at ol(2018):** studied about "Micro structural study of cryogenically treated En 31 bearing steel" the SEM analysis reveals the presence of extensive micro voids due to the pull off of coarse carbide particles during the impact test. [10]

- **N.B. Dhokey at ol (2011)**: studied about "Metallurgical investigation of cryogenically cracked M35 tool steel" concluded that As-hardened specimen when cryotreated increases hardness due to austenite to marten site transformation and increase in residual stresses as a result of cryoprocessing[11]

- **A.Akhbarizadeh at ol. (2008**): studied about "Effects of cryogenic treatment on wear behavior of D6 tool steel" the CT improves the wear resistance and the hardness of the steel. When specimens kept for longer periods at SCT higher wear resistance and higher hardness were observed.[12]

- **D. Das at ol(2008):** studied about "Correlation of microstructure with wear behavior of deep cryogenically treated AISI D2 steel" The Wear resistance CHT specimen is significantly higher than that of DCT specimen. The degree of development in WR by CT and DCT in contrast to Conjugate Heat transfer varies from 39 to 12% and from 88 to 34%, respectively.[13]

- **Joel Hemanth (2005):** studied about "Tribological behavior of cryogenically treated B4Cp/Al–12% Si composites" resulting in microstructures of the chilled composites are finer than that of the un-chilled matrix. Strength, hardness and wear resistance of the chilled matrix were increased. [14]

- **Guo Jia at ol.(2014):** studied about "A cryogenic treatment system for treating large rolls" results showed that most of the residual austenite would be changed into marten site after cryogenic treatment, which contributed to the improved hardness and dimensional stability.[15]

- **Chen-hui XIE at ol.(2015)**: studies about "Effects of deep cryogenic treatment on microstructure and properties of WC−11Co cemented carbides with various carbon contents" resulting in hardness and bending strength after deep cryogenic treatment are higher than those of untreated ones and the cobalt magnetic slightly decreases.[16]

- **Yinnan Zhang at ol.(2016):** studied about "Tensile and interfacial properties of polyacrylonitrile-based carbon fiber after different cryogenic treated condition" concluding a small increase in crystallinity and a decrease in crystallite size were observed, increased inter-planar distance along fiber axial direction and a slightly decreased inter-planar distance along fiber radial direction were observed.[17]

- **Fujun Xu at ol.(2016):** studied about "Modification of tensile, wear and interfacial properties of Kevlar fibers under cryogenic treatment" concluded after conditioning in sharp cooling rate, the fiber tensile strength increased by 24.9% and after conditioning in slow cooling rate, the fiber surface morphology became rougher, rendering the 18.9% increase of the interfacial shear strength [18]

- **Yiqin Shao at ol(2017):** studied about "Influence of cryogenic treatment on mechanical and interfacial properties of carbon nanotube fiber /bisphenol-F epoxy composite" accomplished that the interfacial shearing strength was found to be 31% higher than the pristine carbon nanotube fiber composite. The tensile strength of the epoxy was increased by 27% after cryogenic treatment.[19]

- **M. Araghchi at ol.(2017):** studies about "A novel cryogenic treatment for reduction of residual stresses in 2024 aluminum alloy" and concluded that this method not only resulted in reduction of residual stresses, but also improved the mechanical properties. [20]

- **B. Podgornik at ol(2015):** studied about "Deep cryogenic treatment of tool steels" concluding that in case of low carbon cold-work tool steel resulting greatly improved fracture toughness while maintaining high hardness. On the other hand, for high C cold-work tool has negative effect, while for high-speed steel has practically no effect on its properties.[21]

- **Sirui Fu at ol(2015):** studied about "Combined effect of interfacial strength and fiber orientation on mechanical performance of short Kevlar fiber reinforced olefin block copolymer" concluded that that kevlar fiber can be used to reinforce significantly improved tensile yield strength and modulus can only be obtained by introducing hydrolyzed or polydopamine-coated Kevlar fiber using a small amount of 3 wt.%. Composites with randomly orientated fibers, injection molded composites with highly oriented fibers display a significantly enhanced tensile strength at the same composition.[22]

- **Rongxian Ou at ol(2010):-** studied about "Reinforcing effects of Kevlar fiber on the mechanical properties of wood-flour/high-density-polyethylene composites" concluded that addition of a small amount (2–3%) of Kevlar fiber caused an improvement in the tensile, flexural, and impact properties of wood-flour/high-density-polyethylene composites.[23]

Chapter 4

4 Rationale and Scope of the Study

The aim of the study is to find the mechanical characterization of cryogenically treated composite material. For this we have to conduct a tensile and flexural test on the composite material.

- Samples will be treated in cryogen solution for different time intervals.
- First sample of composite will be treated cryogenically for one hour, same material sample for two hours, same three hours. Will do this process till we get four samples of each material of different composites.
- We can make out numbers of samples by increasing the time interval gap and the layers of fiber.
- After treating cryogenically these samples will be tested on universal testing machine for flexural and tensile load.
- From universal testing machine we will find the ultimate tensile strength & compressive strength.
- From torsional testing machine will find the torsional properties of the material.
- After this all we will compare the mechanical properties of both treated sample and untreated sample for comparison.

We are going to split both test by different parameters such as Composite fiber, No. of layers, Cryogenically Treatment at different time intervals and arrangement of layers. Fibers used in experiment work are Carbon Fiber and Kevlar Fiber. For 3 point bending we are using ASTM 7264 32:1 length-to-thickness. For tensile testing we are using ASTM D3039.

Fiber Used	According to material layer	Cryogenically Treatment at different time intervals	Samples	Layers
Carbon Fiber	Single layer of fiber	0 hour, 1 hour , 2 hours, 3 hours	4	ECE
	Double layer of fiber	0 hour, 1 hour , 2 hours, 3 hours	4	ECECE
	Triple layer of fiber	0 hour, 1 hour , 2 hours, 3 hours	4	ECECECE
Kevlar Fiber	Single layer of fiber	0 hour, 1 hour , 2 hours, 3 hours	4	EKE
	Double layer of fiber	0 hour, 1 hour , 2 hours, 3 hours	4	EKEKE
	Triple layer of fiber	0 hour, 1 hour , 2 hours, 3 hours	4	EKEKEKE
Carbon & Kevlar Fiber	Hybrid layer	0 hour, 1 hour , 2 hours, 3 hours	4	ECEKE
	Hybrid layer	0 hour, 1 hour , 2 hours, 3 hours	4	ECEKECE
	Hybrid layer	0 hour, 1 hour , 2 hours, 3 hours	4	EKECEKE

Table 2 Flexural Testing Expected Outcomes

For Flexural testing total expected experiments outcomes are 36. E is Epoxy, C is Carbon Fiber & K is Kevlar Fiber in layers lay out

Fiber Used	According to material layer	Cryogenically Treatment at different time intervals	Samples	Layers
Carbon Fiber	Single layer of fiber	0 hour, 1 hour , 2 hours, 3 hours	4	ECE
	Double layer of fiber	0 hour, 1 hour , 2 hours, 3 hours	4	ECECE
Kevlar Fiber	Single layer of fiber	0 hour, 1 hour , 2 hours, 3 hours	4	EKE
	Double layer of fiber	0 hour, 1 hour , 2 hours, 3 hours	4	EKEKE
Carbon & Kevlar Fiber	Hybrid layer	0 hour, 1 hour , 2 hours, 3 hours	4	ECEKE
	Hybrid layer	0 hour, 1 hour , 2 hours, 3 hours	4	ECEKECE
	Hybrid layer	0 hour, 1 hour , 2 hours, 3 hours	4	EKECEKE

Table 3 Tensile Testing Expected Outcomes

For Tensile testing total expected experiments outcomes are36. E is Epoxy, C is Carbon Fiber & K is Kevlar Fiber in layers lay out

Chapter 5

5 Objectives of the Study

The main objective of study is to develop and achieve a composite material that we will be treating it with cryogenically to enhance its properties to get use in space application with best suitable conditions. To meet up with the expectations we have to know the mechanical characteristic properties of materials. For this investigation we have to go through treatments and testing.

- To estimate the Load Vs Displacement characteristics of Carbon fiber composite using Flexural load testing with and without cryogenically treatment
- To estimate the Stress Vs Strain characteristics of Carbon fiber composite using Flexural load testing with and without cryogenically treatment
- To estimate the Load Vs Displacement characteristics of Kevlar fiber composite using Flexural load testing with and without cryogenically treatment
- To estimate the Stress Vs Strain characteristics of Kevlar fiber composite using Flexural load testing with and without cryogenically treatment

- To estimate the Load Vs Displacement characteristics of Carbon fiber composite using Tensile load testing with and without cryogenically treatment
- To estimate the Stress Vs Strain characteristics of Carbon fiber composite using Tensile load testing with and without cryogenically treatment
- To estimate the Load Vs Displacement characteristics of Kevlar fiber composite using Tensile load testing with and without cryogenically treatment
- To estimate the Stress Vs Strain characteristics of Kevlar fiber composite using Tensile load testing with and without cryogenically treatment

Chapter 6

6 Materials and Research Methodology

6.1 Materials:

6.1.1 Carbon Woven Reinforcement Fabric

200 GSM – Plain Woven Carbon Fabric

Characteristic	Specification	Tolerance
Area Weight (g/m^2)	200	±3%
Width (mm)	1000	-0/ +10 mm
Dry Fabric Thickness (mm)	0.2	±0.03mm

Fiber Properties	
Density(g/cm^3)	1.8
Filament Diameter (µm)	7
Tensile Strength (MPa)	4000
Tensile Modulus (GPa)	240
Elongation (%)	1.7
Sizing	Epoxy Compatible

<table>
<tr><td rowspan="3">WARP</td><td>Carbon Fiber</td><td rowspan="3">50% by weight</td><td rowspan="6"></td></tr>
<tr><td>Standard modulus 3k</td></tr>
<tr><td>12.70 ends/inch</td></tr>
<tr><td rowspan="3">WEFT</td><td>Carbon Fiber</td><td rowspan="3">50% by weight</td></tr>
<tr><td>Standard modulus 3k</td></tr>
<tr><td>12.70 picks/inch</td></tr>
</table>

6.1.2 Kevlar Fabric

Part No. KP1000163 1000D Kevlar 163g/Sq. m plain fabric

Type of yarns	
Warp Yarn	Kevlar 1000D (K29
Fill Yarn	Kevlar 1000D (K29)

Fabric Weight	
4.8	(oz/yd2)
163	(g/m2)

CONSTRUCTION

Nominal Construction	Warp Count/CM	7
Yarns	Fill Count/CM	7

Fabric Thickness	
0.16	(mm)
0.06	(Inch)

Avg. Break Strength	231
Avg. Modulus	5300
Avg. Elongation at Break	3.40%

6.1.3 Hinpoxy C

PRODUCT

HINPOXY C RESIN is a Bisphenol-A based liquid epoxy resin. HINPOXY C HARDENER is a colorless, low viscosity, modified amine hardener.

APPLICATION

HINPOXY C RESIN/ HINPOXY C HARDENER system is recommended for room temperature or low bake curing. An ideal application is for crack filling and carbon wrapping.

SPECIAL FEATURES

The following advantages make it ideal for industrial use.

• Simple mixing ratio (Resin: Hardener = 100: 30).

• Tolerant mixing ratio.

• Low viscosity resin/hardener mix, ensures proper flow.

• Excellent water resistance.

• Very Good chemical resistance and electrical insulation.

PROPERTIES- HINPOXY C RESIN

Characteristic	Test Method	Unit	Specification
Viscosity at 25°C	ASTM-D 445	mPas	9,000 – 12,000
Epoxy Content	ASTM-D 1652	g/eq	185 - 192
Density at 25oC	ASTM-D 4052	g/cc	1.15 - 1.20
Flash Point	ASTM-D 93	°X	> 200
Storage life		Years	3

HINPOXY C HARDENER

Characteristic	Test Method	Unit	Specification
Consistency	Visual		Colorless to pale yellow liquid
Viscosity at 25oC	ASTM-D 445	mPas	< 50
Flash Point	ISO 2719	°C	>123
Density at 25oC	ASTM-D 4052	g/cc	0.94 – 0.95
Storage life (2–40oC)		Years	1

PROPERTIES OF THE SYSTEM

Mix Ratio HINPOXY C RESIN : HINPOXY C HARDENER 100 : 30 (w/w)

Gel time at 30oC (100g) : 120 minutes

Full cure time at 30oC : 24 hours

Impact Strength @30oC, Kg cm (ISO6272) : 60 - 70

SURFACE PREPARATION

The surfaces should be free of moisture and oil.

STORAGE, HANDLING AND DISPOSAL

Storage: Store in a cool, dry place.

Shelf life: As given in the product specifications.

Handling: Use hand gloves and protective glasses.

Disposal: Dispose by incineration or as per local regulations.

6.2 Research Methodology

After studying the above sections and collected data and have analyzed research methodology technique that we are going to adopt in work. We will do test on composites of Carbon fiber and Kevlar fiber.

- Samples will be treated in cryogen solution for different time intervals.
- First sample of composite will be treated cryogenically for one hour and other for three hours. Will do this process till we get required number samples of each material of different composites.
- After treating cryogenically these samples will be tested on universal testing machine for flexural and tensile load.
- One set of samples will be test immediately after cryogenic treatment and other set will be tested after 24hours.
- From universal testing machine we will find the graph between stress vs. strain and load vs. displacement.
- After this all we will compare the mechanical properties of both treated sample and untreated sample for comparison.

Fiber Used	According to material layer	Testing after 24 hours of Cryogenically Treatment with different time intervals	Testing immediately after Cryogenically Treatment with different time intervals	Sam ples	Layers
Carbon Fiber	Single layer of fiber	0 hour, 1 hour , 3 hours	1 hour, 3 hour	5	ECE
	Double layer of fiber	0 hour, 1 hour , 3 hours	1 hour, 3 hour	5	ECECE
Kevlar Fiber	Single layer of fiber	0 hour, 1 hour , 3 hours	1 hour, 3 hour	5	EKE
	Double layer of fiber	0 hour, 1 hour , 3 hours	1 hour, 3 hour	5	EKEK E
Carbon & Kevlar Fiber	Hybrid layer	0 hour, 1 hour , 3 hours	1 hour, 3 hour	5	ECEKE

Table 4 Tensile & Flexural Testing

Chapter 7

7 Results and Discussion

In this section we calculate the mechanical properties the samples which were made of Carbon fiber and Kevlar fiber. The results were compared for both the conditions, cryogenically treated and untreated. With the help of Universal Testing Machine the mechanical properties such as tensile load and flexural load were calculated.

Number of samples for both the test tensile and flexural are 50.For each sample we have developed two graphs of stress Vs strain and load Vs displacement. So there would be total 100 graphs of all the samples.

Treatment Time	Sample	Operating Temperature (K)	Peak Load (kg)	Deflection at peak load (mm)
0 hr	Single Layer Carbon Fiber	300	21.26	7.27
	Double Layer Carbon Fiber	300	25.38	3.66
	Single Layer Kevlar Fabric	300	29.42	6.2
	Double Layer Kevlar Fabric	300	21.9	11.06
	Carbon & Kevlar Fibric	300	24.14	9.11
1 hr	Single Layer Carbon Fiber	300	13.71	9.4
	Double Layer Carbon Fiber	300	26.15	9.84
	Single Layer Kevlar Fabric	300	17.47	6.98
	Double Layer Kevlar Fabric	300	8.51	12.94
	Carbon & Kevlar Fibric	300	15.81	4.02
3hr	Single Layer Carbon Fiber	300	34.06	5.59
	Double Layer Carbon Fiber	300	34.01	8.7
	Single Layer Kevlar Fabric	300	6.48	7.5
	Double Layer Kevlar Fabric	300	15.28	6.61
	Carbon & Kevlar Fibric	300	23.74	7.61

Table 5 Flexural results immediate after cryogenic treatment

Treatment Time	Sample	Operating Temperature (K)	Peak Load (kg)	Elongation at Peak Load(mm)
0 hr	Single Layer Carbon Fiber	300	311.3	6.89
	Double Layer Carbon Fiber	300	292	7.41
	Single Layer Kevlar Fabric	300	198	4.45
	Double Layer Kevlar Fabric	300	297.9	7.68
	Carbon & Kevlar Fibric	300	300.3	6.12
1 hr	Single Layer Carbon Fiber	300	292.3	8.54
	Double Layer Carbon Fiber	300	211.8	7.03
	Single Layer Kevlar Fabric	300	233.5	7.56
	Double Layer Kevlar Fabric	300	337.5	7.57
	Single Carbon & Kevlar Fibric	300	353.7	5.48
3hr	Single Layer Kevlar Fabric	300	152.2	4.07

Table 6 Tensile results immediate after cryogenic treatment

Treatment Time	Sample	Operating Temperature (K)	Peak Load (kg)	Deflection at peak load (mm)
0hr	Single Layer Carbon Fiber	300	21.26	7.27
	Double Layer Carbon Fiber	300	25.38	3.66
	Single Layer Kevlar Fabric	300	29.42	6.2
	Double Layer Kevlar Fabric	300	21.9	11.06
	Carbon & Kevlar Fibric	300	24.14	9.11
1 hr	Single Layer Carbon Fiber	300	26.29	7.24
	Double Layer Carbon Fiber	300	16.76	7.15
	Single Layer Kevlar Fabric	300	20.93	6.08
	Double Layer Kevlar Fabric	300	14.74	7.88
	Carbon & Kevlar Fibric	300	25.67	10.89
3hr	Single Layer Carbon Fiber	300	19.58	9.06
	Double Layer Carbon Fiber	300	20.98	6.25
	Single Layer Kevlar Fabric	300	24	6.87
	Double Layer Kevlar Fabric	300	16.47	7.33
	Carbon & Kevlar Fibric	300	22.4	8.05

Table 7 Flexural results after 24hour of cryogenic treatment

Treatment Time	Sample	Operating Temperature (K)	Peak Load (kg)	Elongation at Peak Load(mm)
0hr	Single Layer Carbon Fiber	300	311.3	6.89
	Double Layer Carbon Fiber	300	292	7.41
	Single Layer Kevlar Fabric	300	198	4.45
	Double Layer Kevlar Fabric	300	297.9	7.68
	Carbon & Kevlar Fibric	300	300.3	6.12
1 hr	Single Layer Carbon Fiber	300	356.5	4.93
	Double Layer Carbon Fiber	300	193.3	13.11
	Single Layer Kevlar Fabric	300	188.2	5
	Double Layer Kevlar Fabric	300	287.8	8.59
	Single Carbon & Kevlar Fabric	300	327.8	7.18
3hr	Single Layer Carbon Fiber	300	246.9	6.11
	Double Layer Carbon Fiber	300	235.7	7.56
	Single Layer Kevlar Fabric	300	181.4	3.81
	Double Layer Kevlar Fabric	300	231.1	6.01
	Single Carbon & Kevlar Fabric	300	323	9.08

Table 8Tensile results after 24hour of cryogenic treatment

7.1 Flexural testing of untreated composite fiber

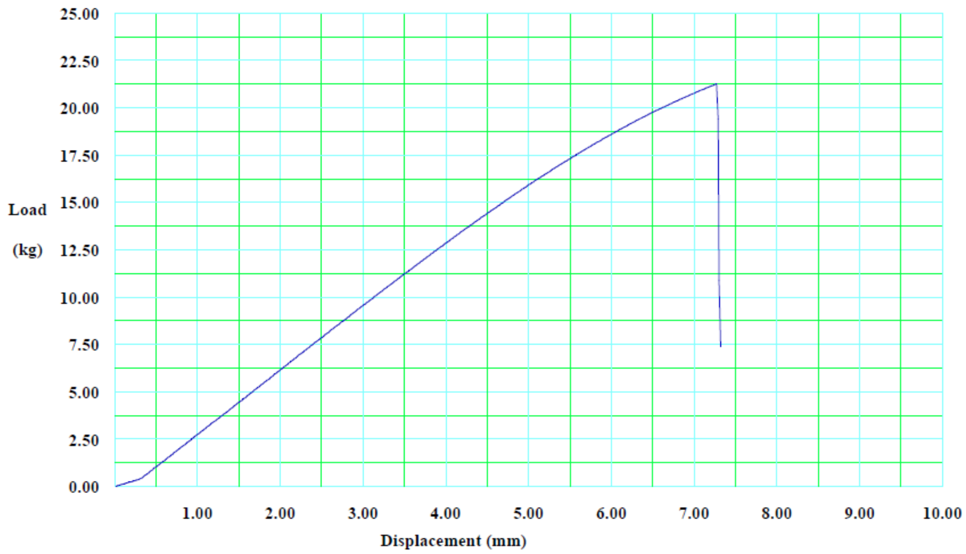

Figure 10 Load Vs Displacement Single Carbon Untreated

Figure 100 shows the variation of load with respect to displacement under flexural testing. It can be observed that as the load increases displacement increases. It can be noticed that a load of 21.26 Kg, untreated single layer carbon fiber was failed.

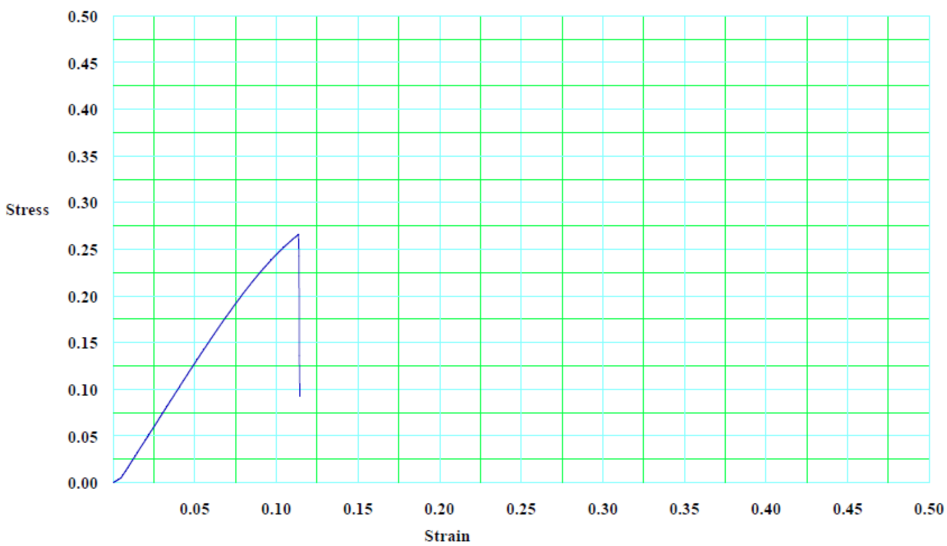

Figure 11 Stress Vs Strain Single Carbon Untreated

Figure 11 shows the variation of stress with respect to strain under flexural testing. It can be observed that as the stress increases strain is found to increase. It can be noticed that at a stress of 0.265 Kg/mm^2, untreated single layer carbon fiber was failed.

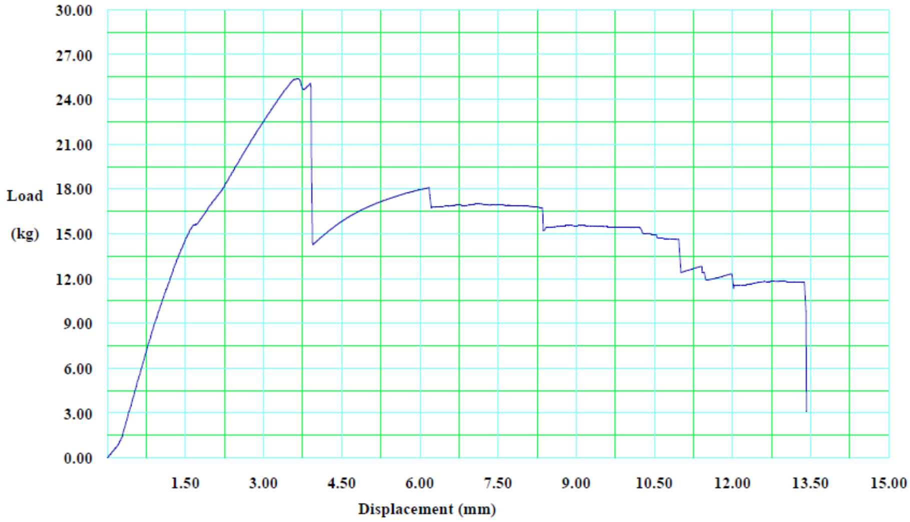

Figure 12 Load Vs Displacement Double Carbon Untreated

Figure 12 shows the variation of load with respect to displacement under flexural testing. It can be observed that as the load increases displacement increases. It can be noticed that a load of 25.38 Kg, untreated double layer carbon fiber was failed.

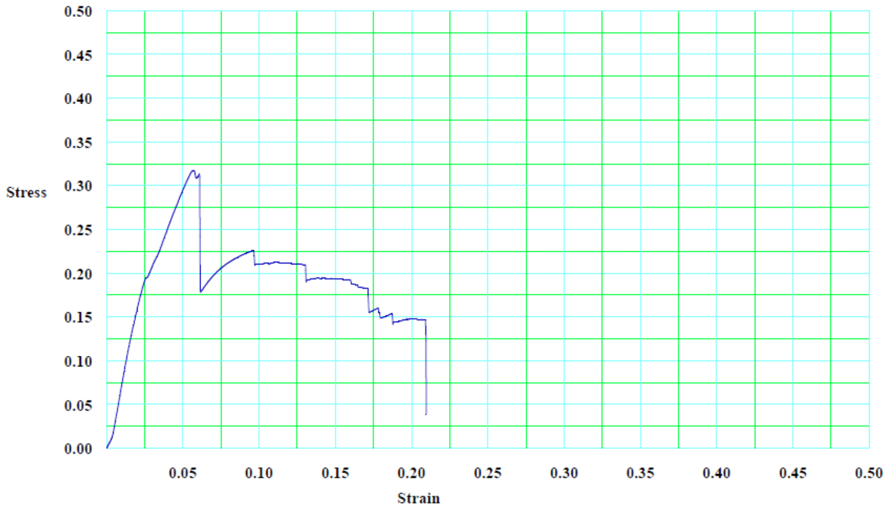

Figure 13 Stress Vs Strain Double Carbon Untreated

Figure 13 shows the variation of stress with respect to strain under flexural testing. It can be observed that as the stress increases strain is found to increase. It can be noticed that at a stress of 0.317 Kg/mm^2, untreated double layer carbon fiber was failed.

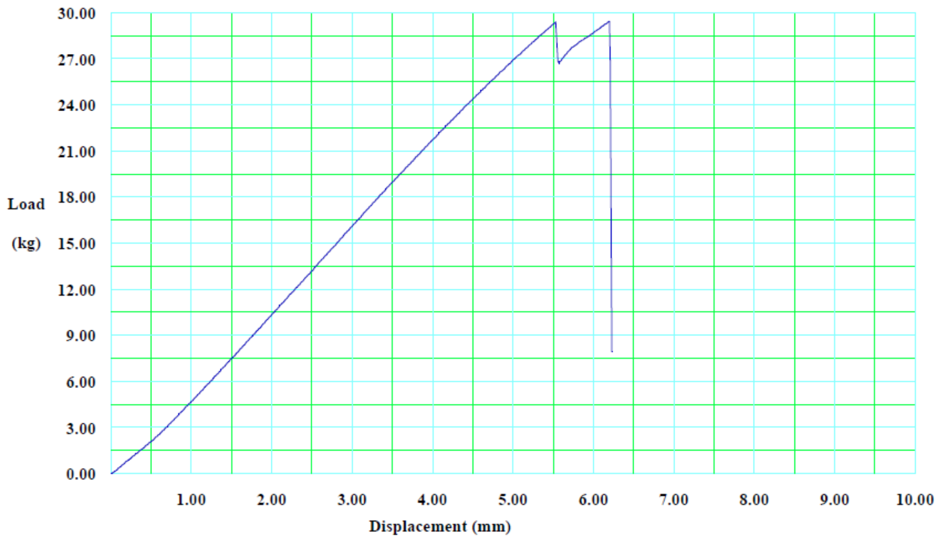

Figure 14 Load Vs Displacement Single Kevlar Untreated

Figure 14 shows the variation of load with respect to displacement under flexural testing. It can be observed that as the load increases displacement increases. It can be noticed that a load of 29.42 Kg, untreated single layer Kevlar fiber was failed.

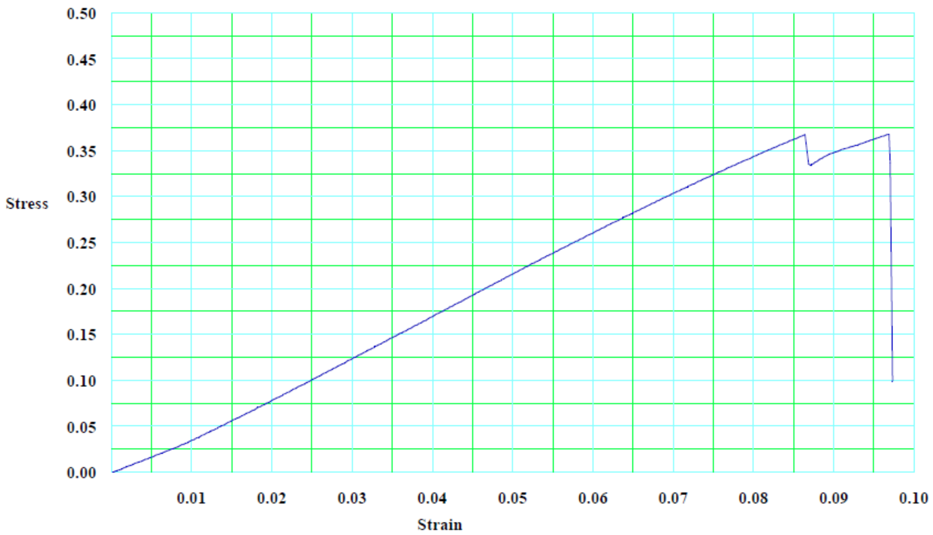

Figure 15 Stress Vs Strain Single Kevlar Untreated

Figure 15 shows the variation of stress with respect to strain under flexural testing. It can be observed that as the stress increases strain is found to increase. It can be noticed that at a stress of 0.367 Kg/mm^2, untreated single layer Kevlar fiber was failed.

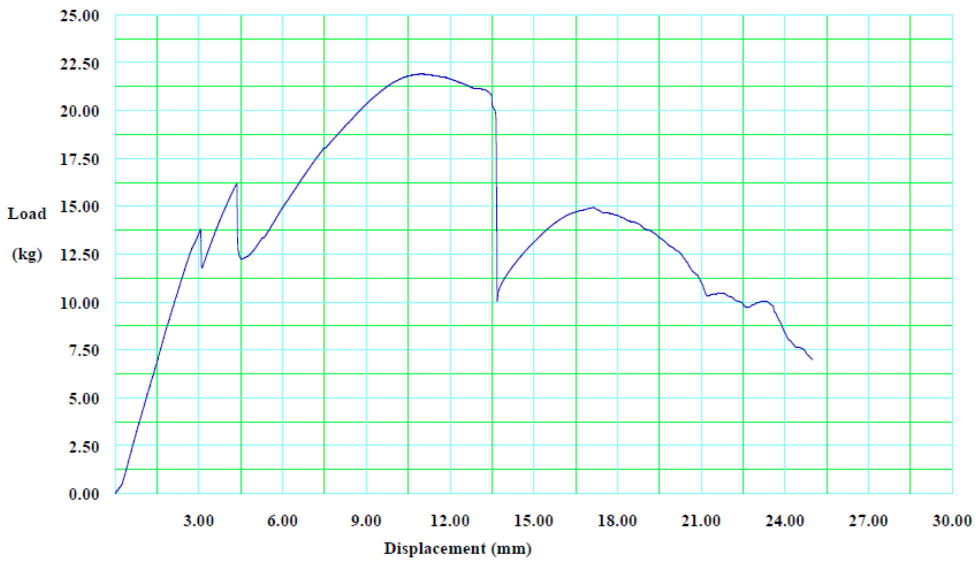

Figure 16 Load Vs Displacement Double Kevlar Untreated

Figure 16 shows the variation of load with respect to displacement under flexural testing. It can be observed that as the load increases displacement increases. It can be noticed that a load of 21.9 Kg, untreated double layer Kevlar fiber was failed.

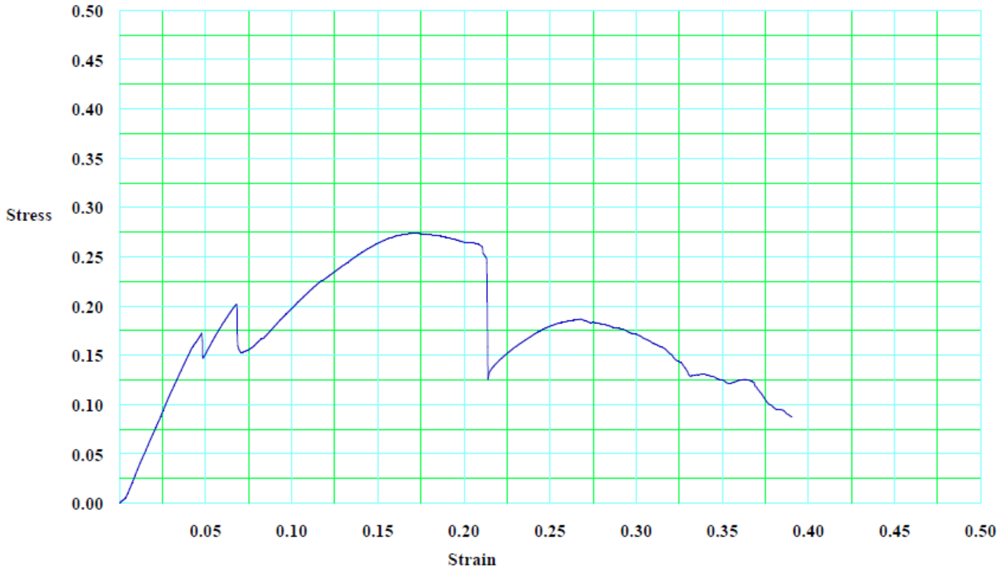

Figure 17 Load Vs Strain Double Kevlar Untreated

Figure 17 shows the variation of stress with respect to strain under flexural testing. It can be observed that as the stress increases strain is found to increase. It can be noticed that at a stress of 0.273 Kg/mm^2, untreated double layer Kevlar fiber was failed.

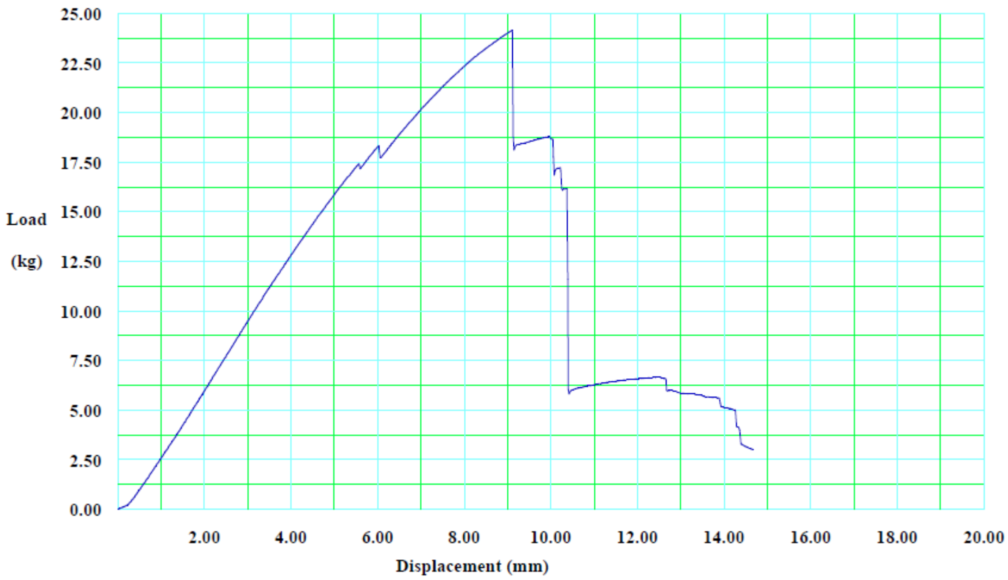

Figure 18 Load Vs Displacement Carbon Kevlar Untreated

Figure 18 shows the variation of load with respect to displacement under flexural testing. It can be observed that as the load increases displacement increases. It can be noticed that a load of 24.14 Kg, untreated Carbon Kevlar fiber was failed.

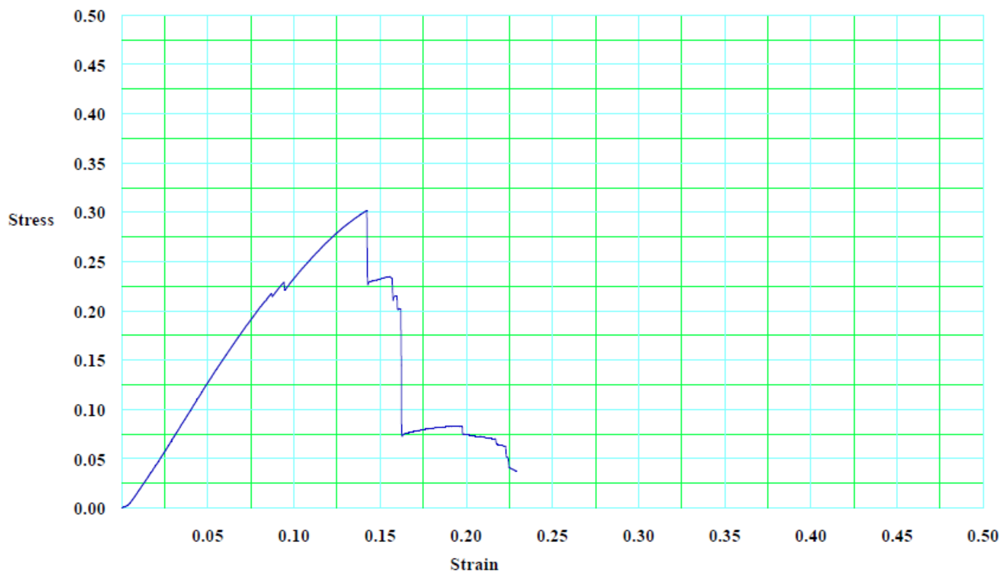

Figure 19 Stress Vs Strain Carbon Kevlar Untreated

Figure 19 shows the variation of stress with respect to strain under flexural testing. It can be observed that as the stress increases strain is found to increase. It can be noticed that at a stress of 0.3017 Kg/mm^2, untreated Carbon Kevlar fiber was failed.

7.2 Tensile testing of untreated composite fiber

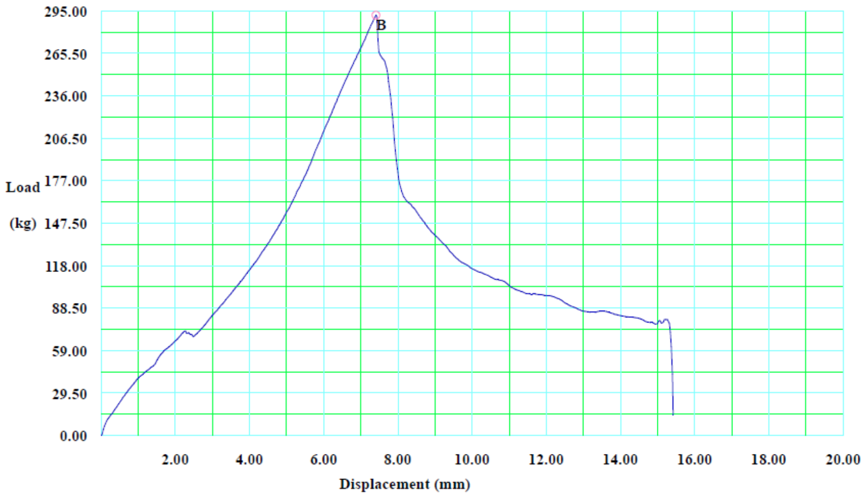

Figure 20Loav Vs Displacement Double Carbon Untreated

Figure 20 shows the variation of load with respect to displacement under tensile testing. It can be observed that as the load increases displacement increases. It can be noticed that a load of 292Kg, untreated double layer carbon fiber was failed.

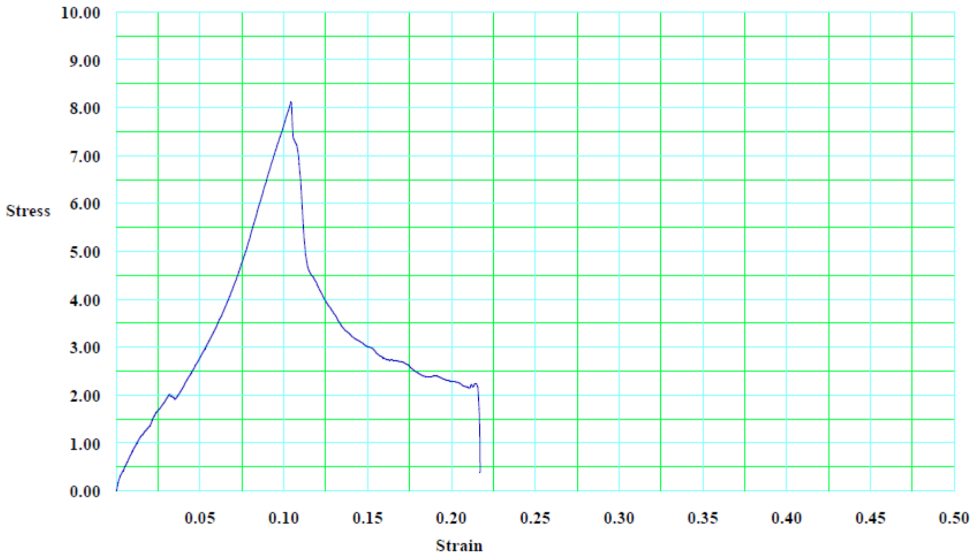

Figure 21 Stress Vs Strain Double Carbon Untreated

Figure 21 shows the variation of stress with respect to strain under tensile testing. It can be observed that as the stress increases strain is found to increase. It can be noticed that at a stress of 8.111 Kg/mm^2, untreated double layer carbon fiber was failed.

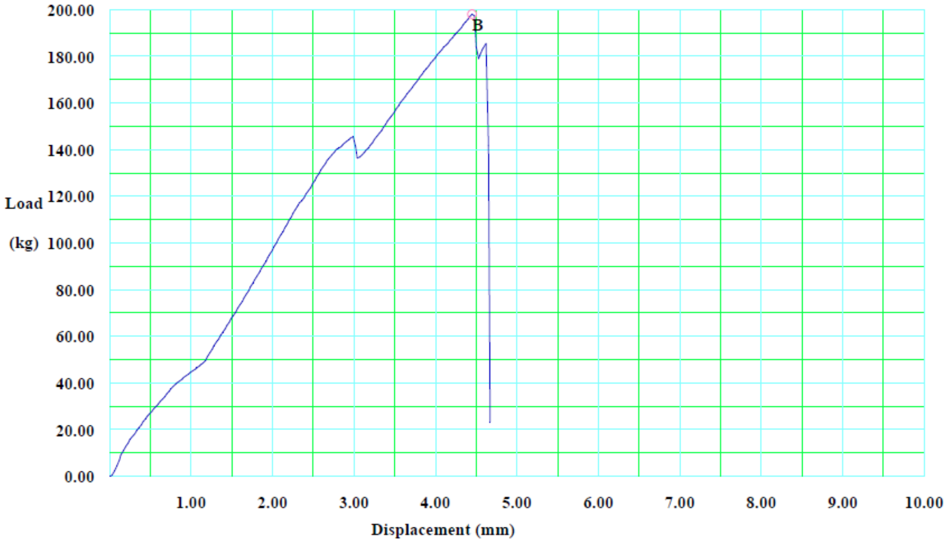

Figure 22 Load Vs Displacement Kevlar Untreated

Figure 22 shows the variation of load with respect to displacement under tensile testing. It can be observed that as the load increases displacement increases. It can be noticed that a load of 198Kg, untreated single layer kevlar fiber was failed.

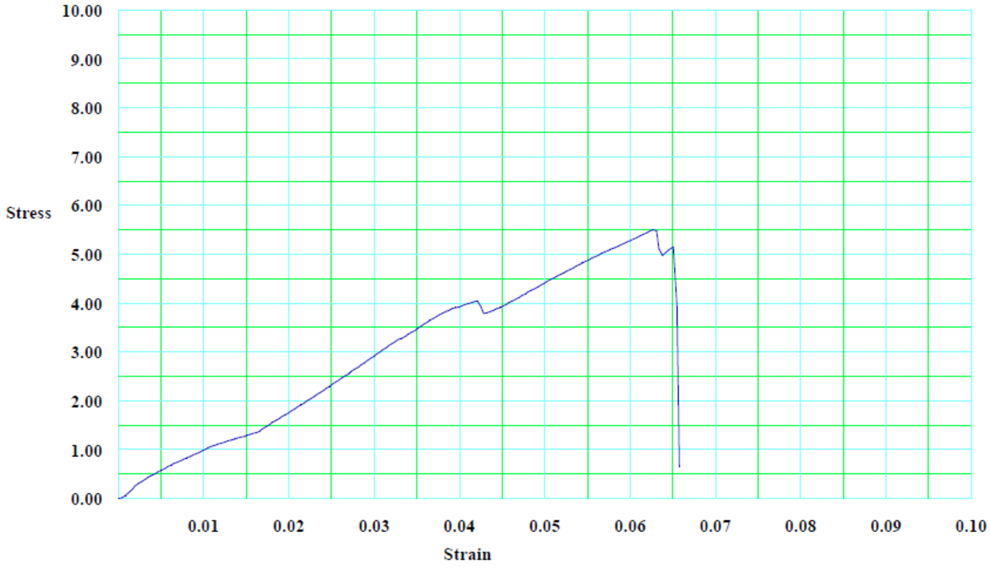

Figure 23 Stress Vs Strain Kevlar Untreated

Figure 23 shows the variation of stress with respect to strain under tensile testing. It can be observed that as the stress increases strain is found to increase. It can be noticed that at a stress of 5.5 Kg/mm^2, untreated single layer kevlar fiber was failed.

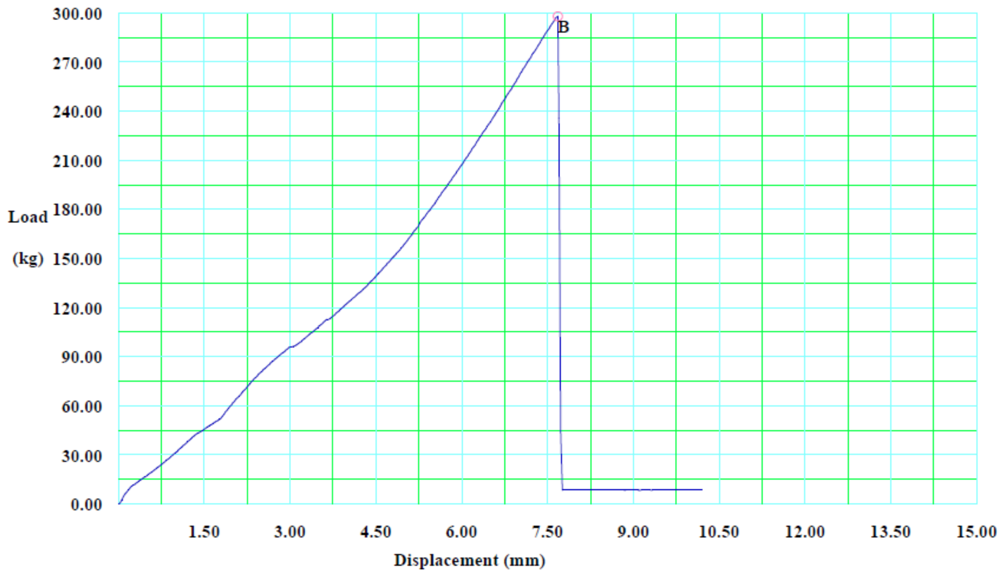

Figure 24 Load Vs Displacement Double Kevlar Untreated

Figure 24 shows the variation of load with respect to displacement under tensile testing. It can be observed that as the load increases displacement increases. It can be noticed that a load of 297.9Kg, untreated double layer kevlar fiber was failed.

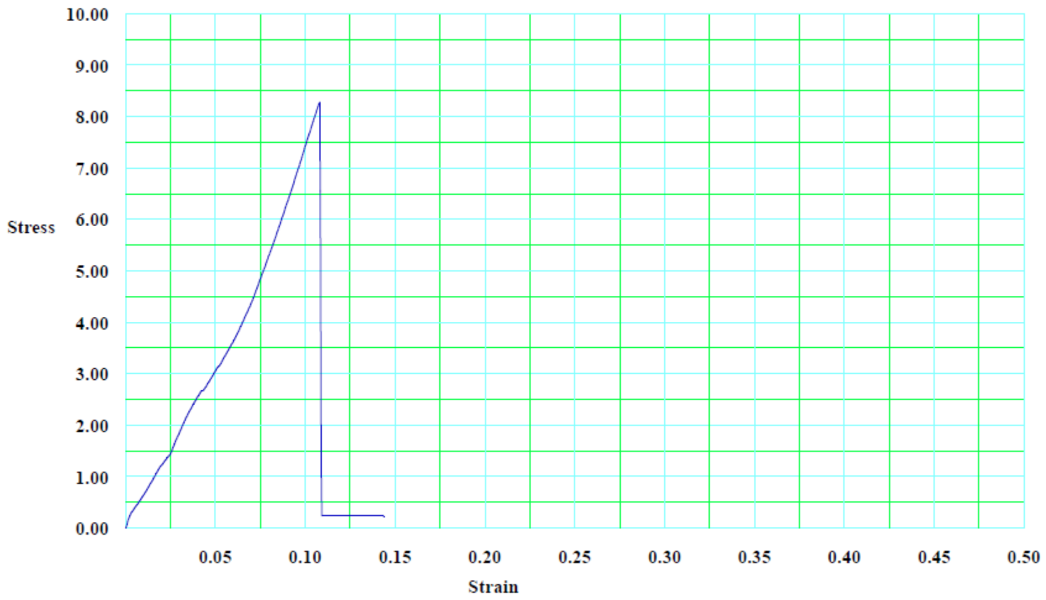

Figure 25 Stress Vs Strain Double Kevlar Untreated

Figure 25 shows the variation of stress with respect to strain under tensile testing. It can be observed that as the stress increases strain is found to increase. It can be noticed that at a stress of 8.275 Kg/mm^2, untreated double layer kevlar fiber was failed.

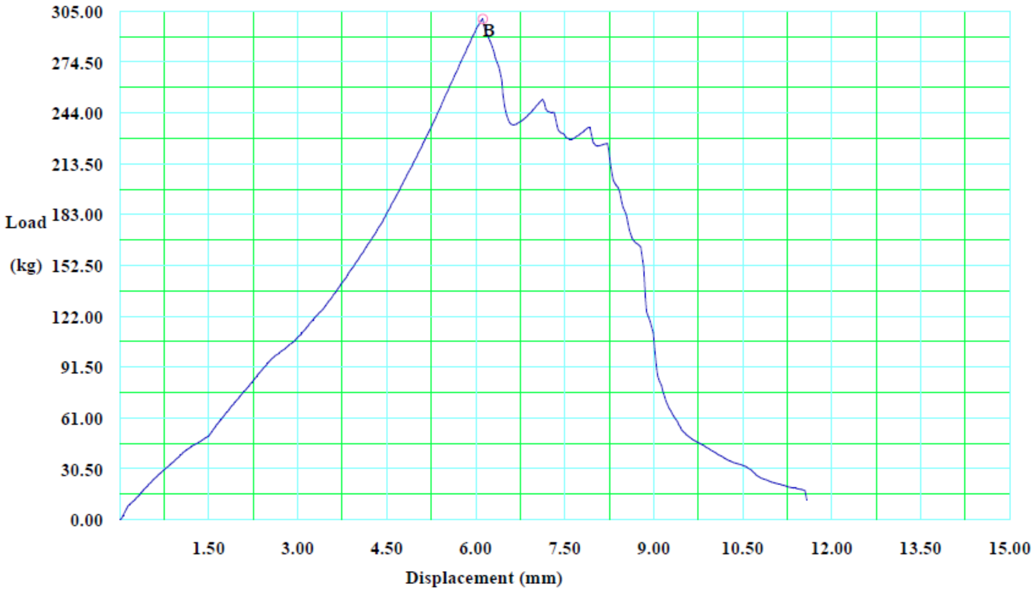

Figure 26 Load Vs Displacement Carbon Kevlar Untreated

Figure 26 shows the variation of load with respect to displacement under tensile testing. It can be observed that as the load increases displacement increases. It can be noticed that a load of 300.3Kg, untreated carbon kevlar fiber was failed.

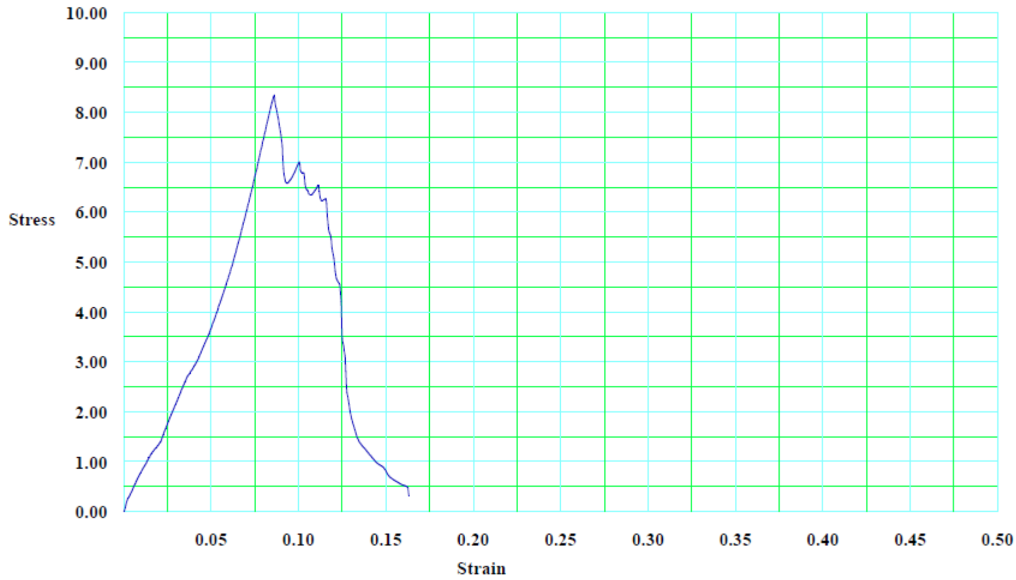

Figure 27 Stress Vs Strain Carbon Kevlar Untreated

Figure 27 shows the variation of stress with respect to strain under tensile testing. It can be observed that as the stress increases strain is found to increase. It can be noticed that at a stress of 8.341 Kg/mm^2, untreated carbon kevlar fiber was failed.

7.3 Flexural testing of 1 hour cryogenically treated composite fiber

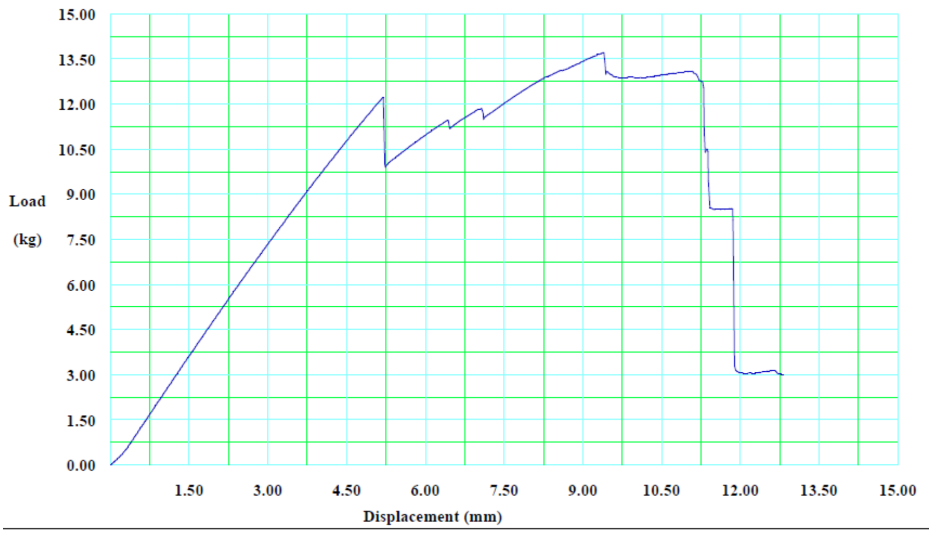

Figure 28 Load Vs Displacement Single Carbon 1 hour Treated

Figure 28 shows the variation of load with respect to displacement under flexural testing. It can be observed that as the load increases displacement increases. It can be noticed that a load of 13.71Kg, 1 hour cryogenically treated single layer carbon fiber was failed.

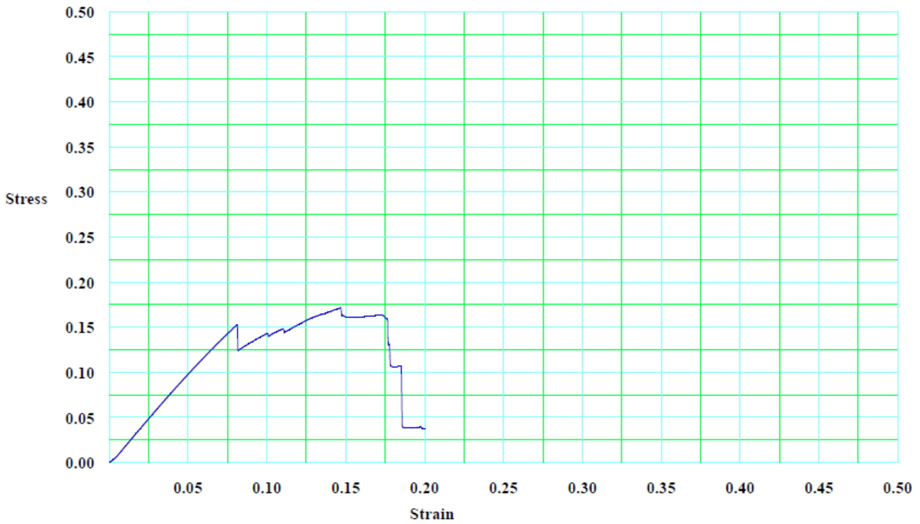

Figure 29 Stress Vs Strain Single Carbon 1 hour Treated

Figure 29 shows the variation of stress with respect to strain under flexural testing. It can be observed that as the stress increases strain is found to increase. It can be noticed that at a stress of 0.171 Kg/mm^2, 1 hour cryogenically treated single layer carbon fiber was failed.

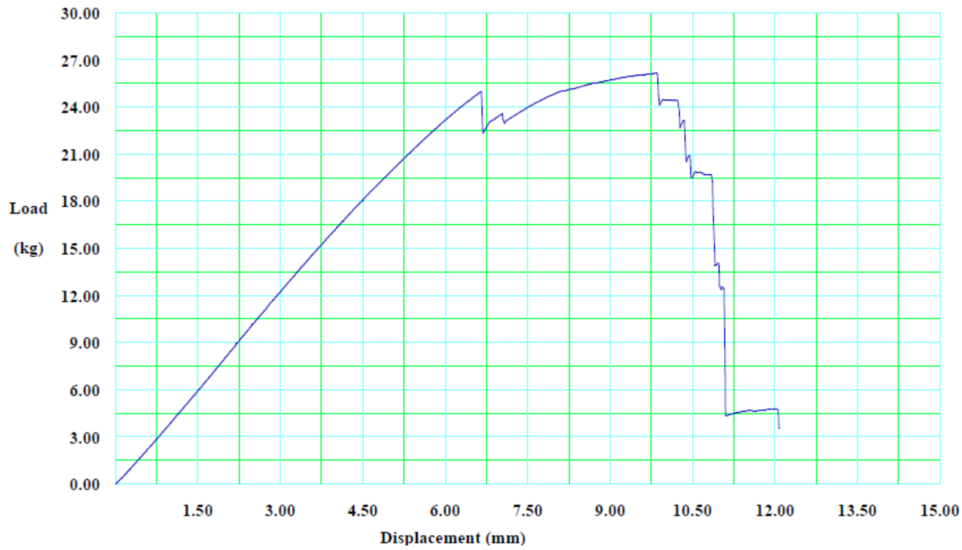

Figure 30 Load Vs Displacement Double Carbon 1 hour Treated

Figure 30 shows the variation of load with respect to displacement under flexural testing. It can be observed that as the load increases displacement increases. It can be noticed that a load of 26.15Kg, 1 hour cryogenically treated double layer carbon fiber was failed.

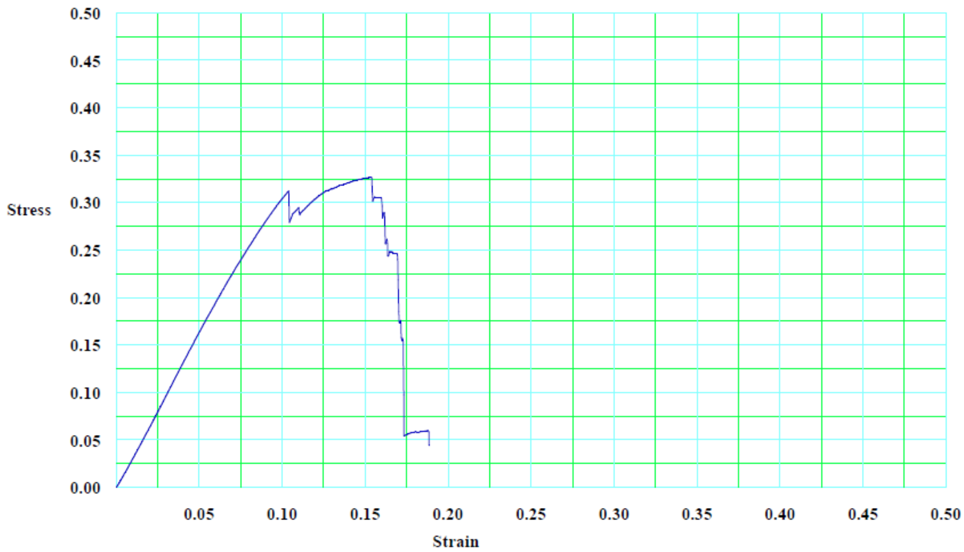

Figure 31 Stress Vs Strain Double Carbon 1 hour Treated

Figure 31 shows the variation of stress with respect to strain under flexural testing. It can be observed that as the stress increases strain is found to increase. It can be noticed that at a stress of 0.326 Kg/mm^2, 1 hour cryogenically treated double layer carbon fiber was failed.

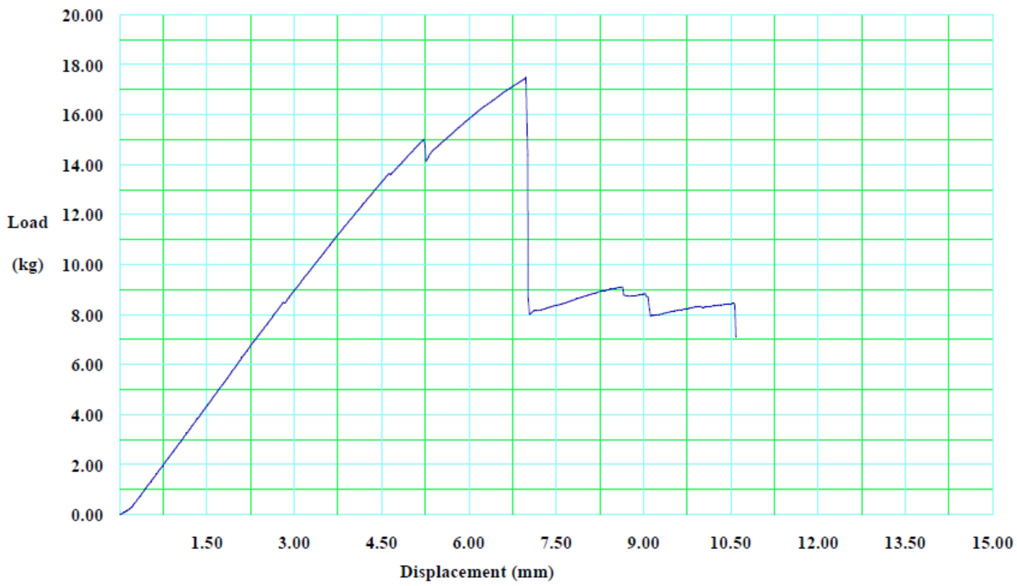

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Figure 32 Load Vs Displacement Kevlar 1 hour Treated

Figure 32 shows the variation of load with respect to displacement under flexural testing. It can be observed that as the load increases displacement increases. It can be noticed that a load of 17.47 Kg, 1 hour cryogenically treated single layer kevlar fiber was failed.

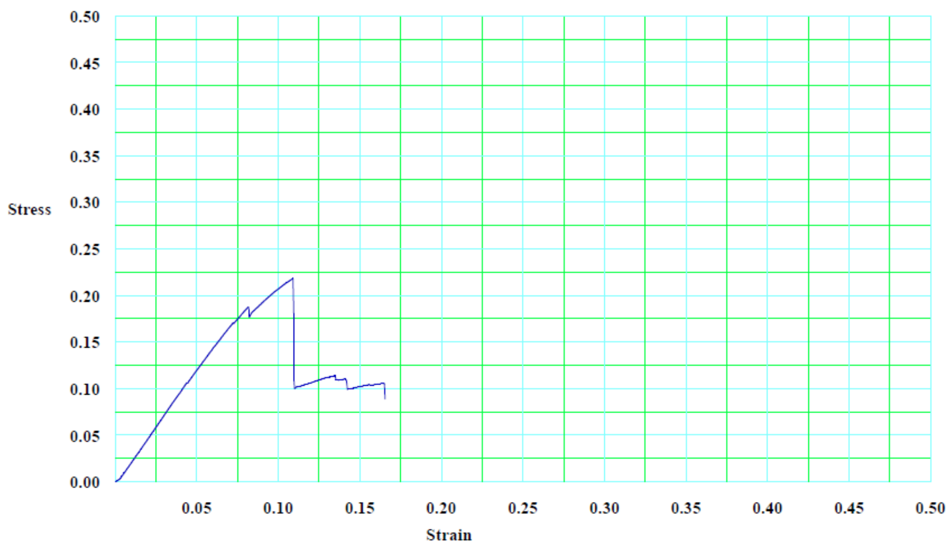

Figure 33 Stress Vs Strain Kevlar 1 hour Treated

Figure 33 shows the variation of stress with respect to strain under flexural testing. It can be observed that as the stress increases strain is found to increase. It can be noticed that at a stress of 0.218 Kg/mm^2, 1 hour cryogenically treated single layer kevlar fiber was failed.

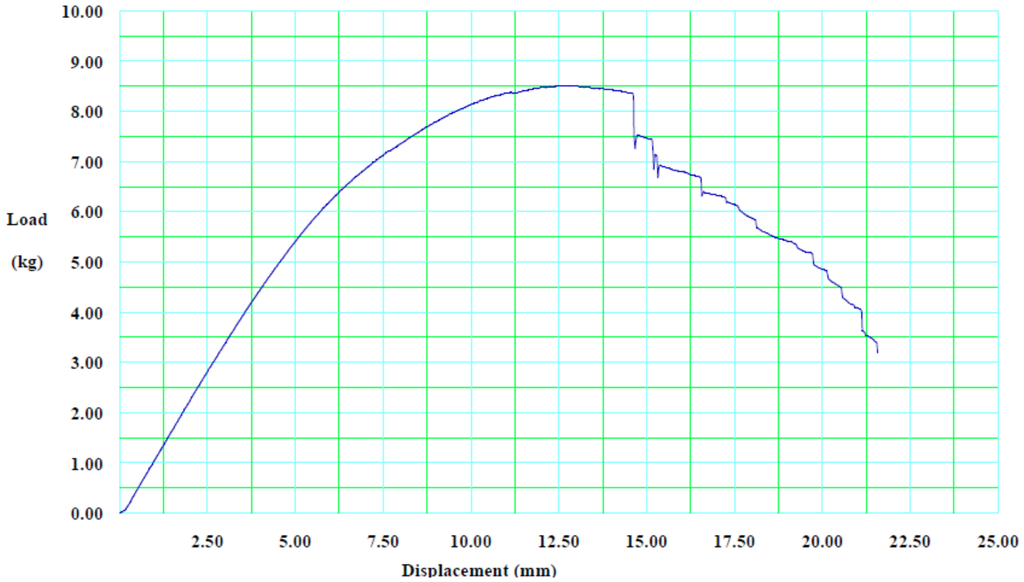

Figure 34 Load Vs Displacement Double Kevlar 1 hour Treated

Figure 34 shows the variation of load with respect to displacement under flexural testing. It can be observed that as the load increases displacement increases. It can be noticed that a load of 8.51 Kg, 1 hour cryogenically treated double layer kevlar fiber was failed.

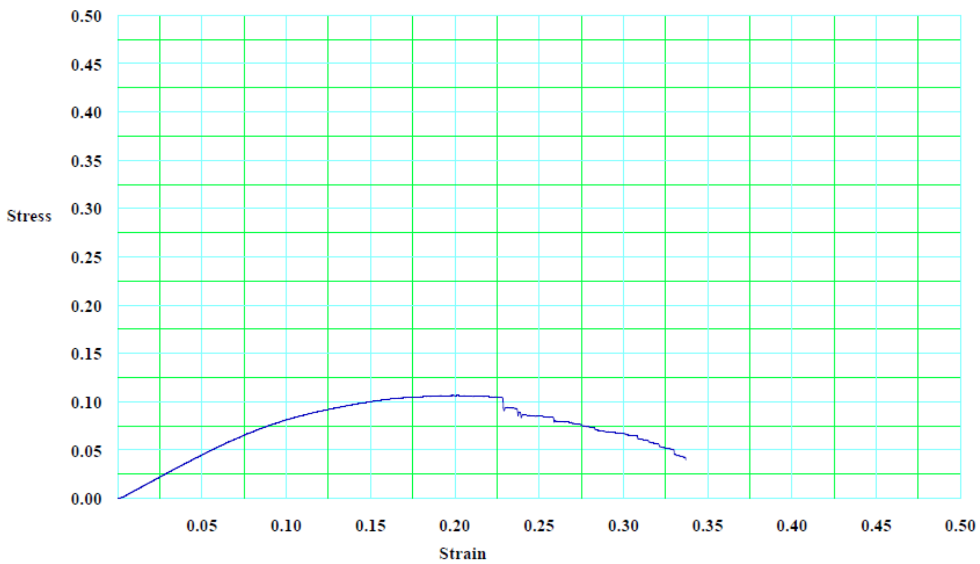

Figure 35 Stress Vs Strain Double Kevlar 1 hour Treated

Figure 35 shows the variation of stress with respect to strain under flexural testing. It can be observed that as the stress increases strain is found to increase. It can be noticed that at a stress of 0.106 Kg/mm^2, 1 hour cryogenically treated double layer kevlar fiber was failed.

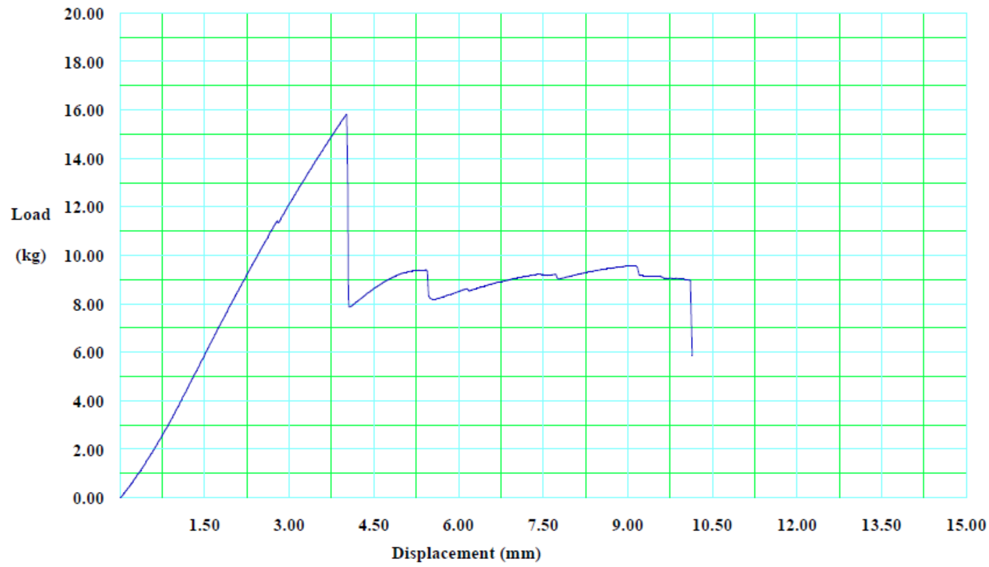

Figure 36Load Vs Displacement Carbon Kevlar 1 hour Treated

Figure 36 shows the variation of load with respect to displacement under flexural testing. It can be observed that as the load increases displacement increases. It can be noticed that a load of 15.81 Kg, 1 hour cryogenically treated carbon kevlar fiber was failed.

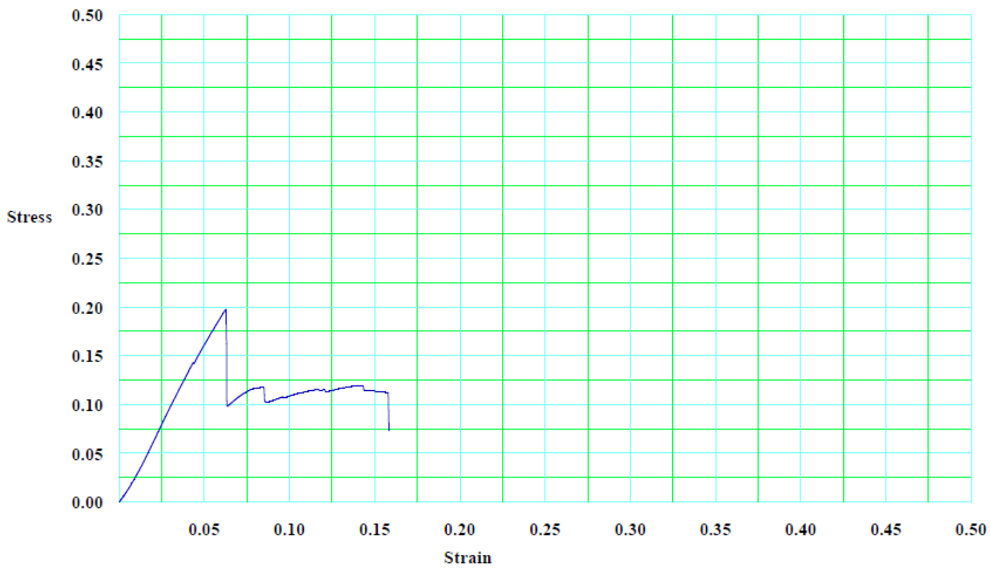

Figure 37 Stress Vs Stain Carbon Kevlar 1 hour Treated

Figure 37 shows the variation of stress with respect to strain under flexural testing. It can be observed that as the stress increases strain is found to increase. It can be noticed that at a stress of 0.197 Kg/mm^2, 1 hour cryogenically treated carbon kevlar fiber was failed.

7.4 Tensile testing of 1 hour cryogenically treated composite fiber

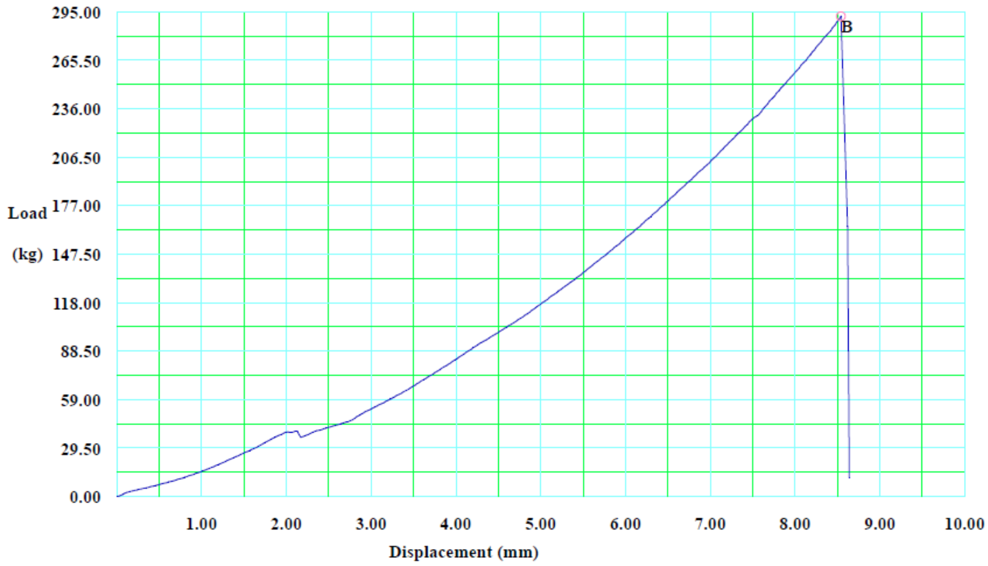

Figure 38 Load Vs Displacement Carbon 1 hour Treated

Figure 38 shows the variation of load with respect to displacement under tensile testing. It can be observed that as the load increases displacement increases. It can be noticed that a load of 292.3 Kg, 1 hour cryogenically treated single layer carbon fiber was failed.

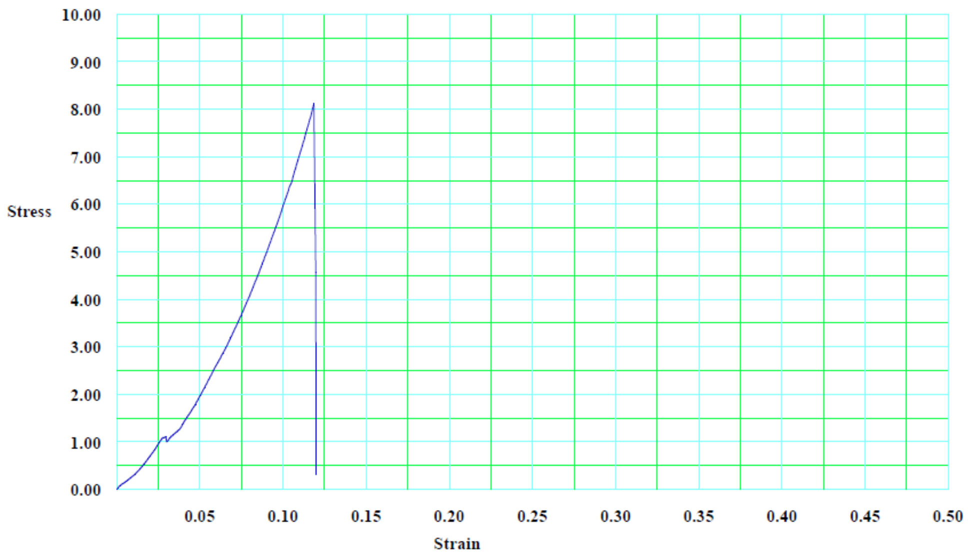

Figure 39 Stress Vs Strain Carbon 1 hour Treated

Figure 39 shows the variation of stress with respect to strain under tensile testing. It can be observed that as the stress increases strain is found to increase. It can be noticed that at a stress of 8.119 Kg/mm^2, 1 hour cryogenically treated single layer carbon fiber was failed.

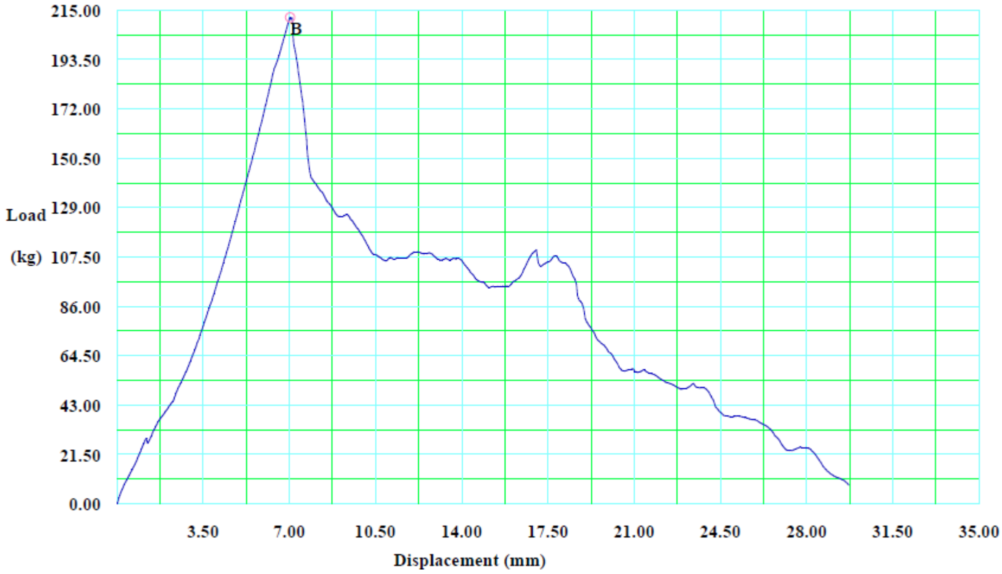

Figure 40 Load Vs Displacement Double Carbon 1 hour Treated

Figure 40 shows the variation of load with respect to displacement under tensile testing. It can be observed that as the load increases displacement increases. It can be noticed that a load of 211.8Kg, 1 hour cryogenically treated double layer carbon fiber was failed

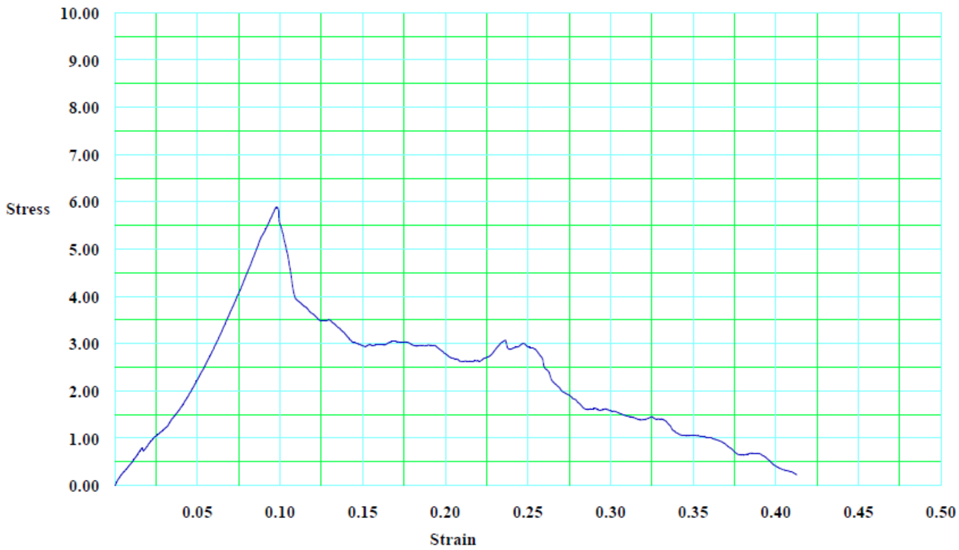

Figure 41 Stress Vs Strain Double Carbon 1 hour Treated

Figure 41 shows the variation of stress with respect to strain under tensile testing. It can be observed that as the stress increases strain is found to increase. It can be noticed that at a stress of 5.883 Kg/mm^2, 1 hour cryogenically treated double layer carbon fiber was failed.

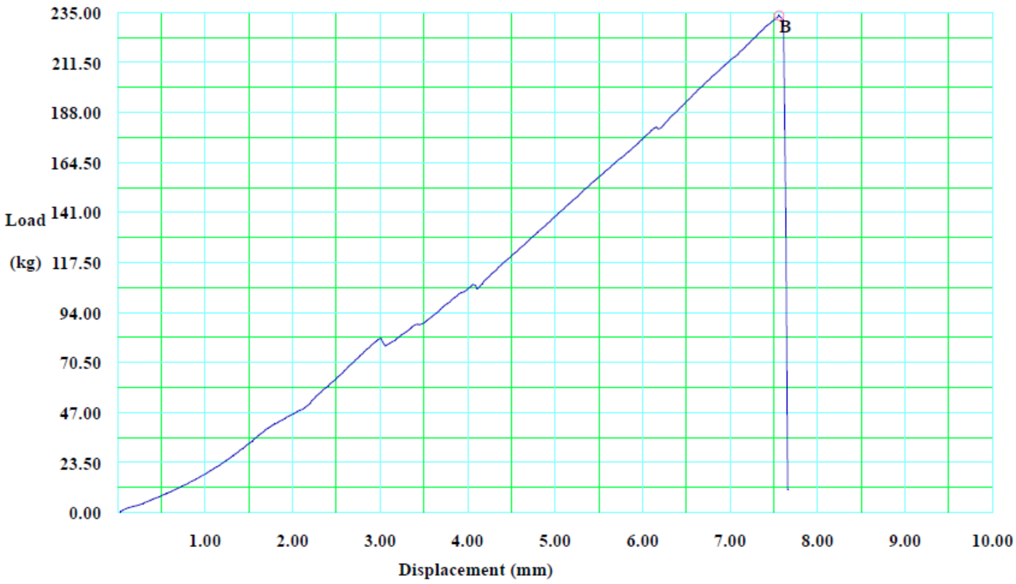

Figure 42 Load Vs Displacement Kevlar 1 hour Treated

Figure 42 shows the variation of load with respect to displacement under tensile testing. It can be observed that as the load increases displacement increases. It can be noticed that a load of 233.5Kg, 1 hour cryogenically treated Single layer kevlar fiber was failed

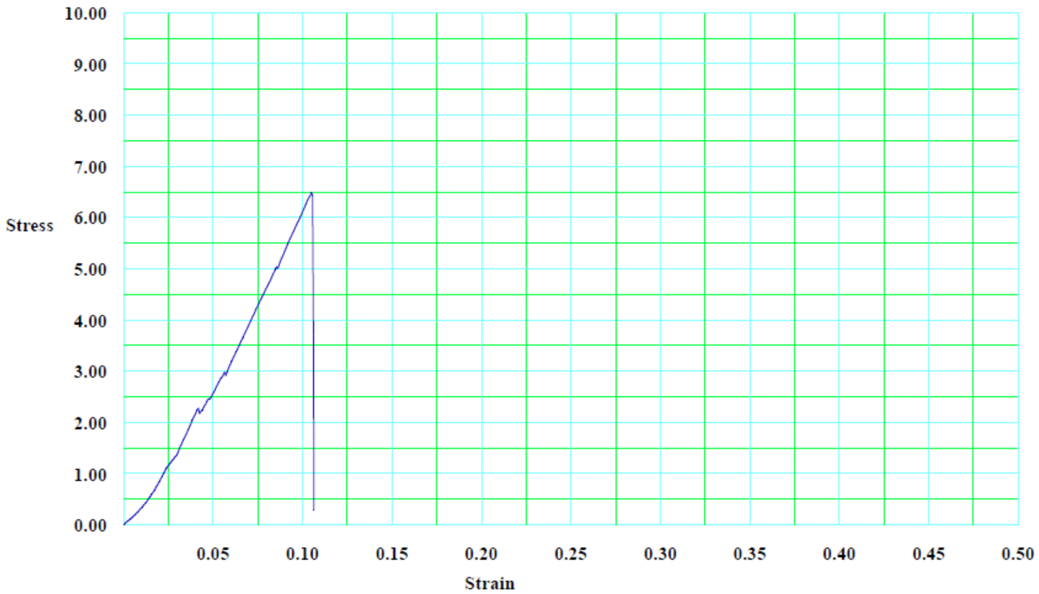

Figure 43Stress Vs Strain Kevlar 1 hour Treated

Figure 43 shows the variation of stress with respect to strain under tensile testing. It can be observed that as the stress increases strain is found to increase. It can be noticed that at a stress of 6.486 Kg/mm^2, 1 hour cryogenically treated Single layer kevlar fiber was failed.

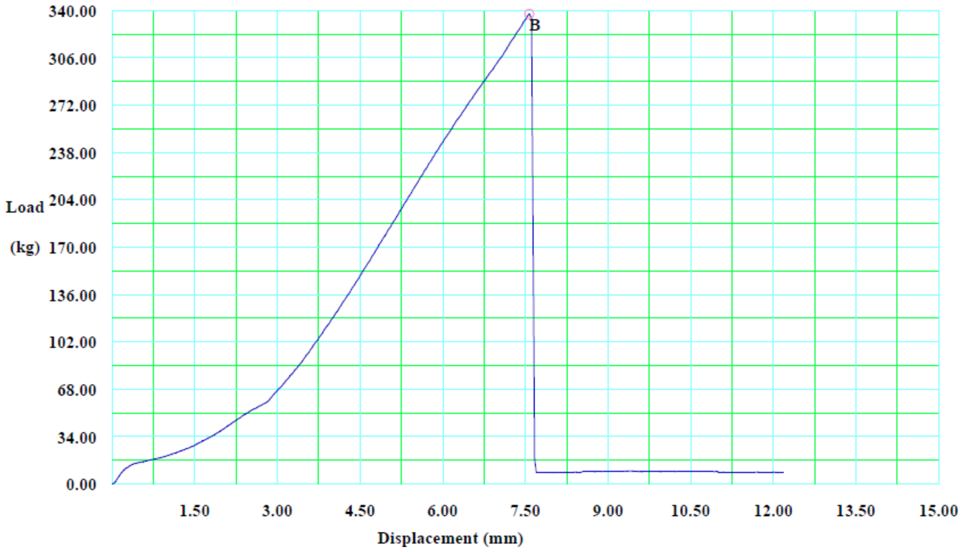

Figure 44 Load Vs Displacement Double Kevlar 1 hour Treated

Figure 44 shows the variation of load with respect to displacement under tensile testing. It can be observed that as the load increases displacement increases. It can be noticed that a load of 337.5Kg, 1 hour cryogenically treated double layer kevlar fiber was failed

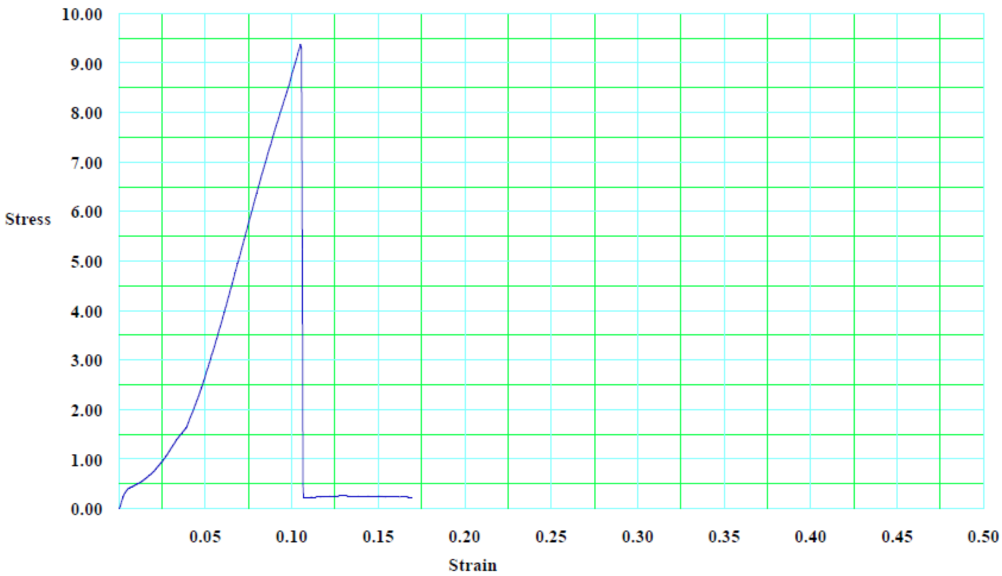

Figure 45 Stress Vs Strain Double Kevlar 1 hour Treated

Figure 45 shows the variation of stress with respect to strain under tensile testing. It can be observed that as the stress increases strain is found to increase. It can be noticed that at a stress of 9.375 Kg/mm^2, 1 hour cryogenically treated double layer kevlar fiber was failed.

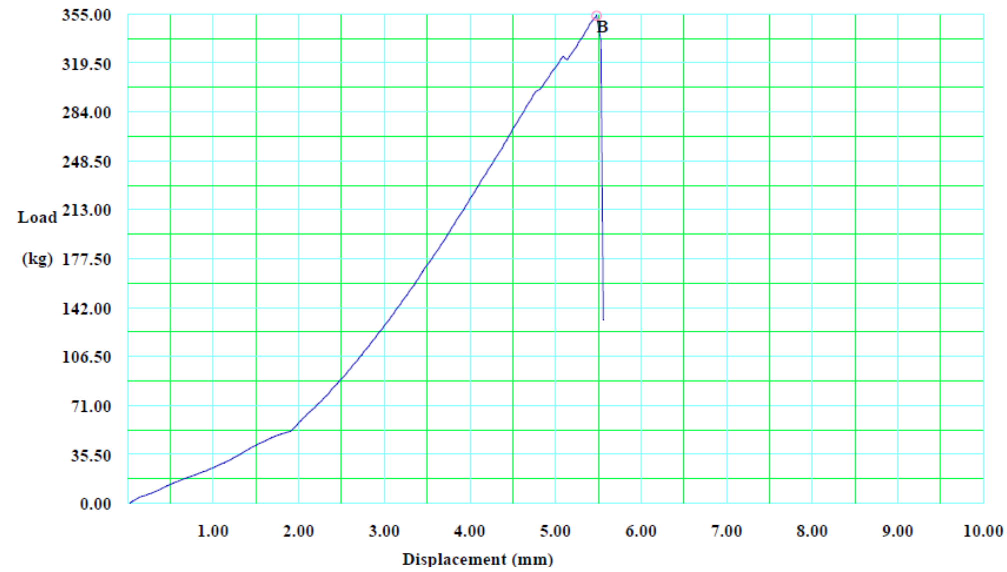

Figure 46 Load Vs Displacement Carbon Kevlar 1 hour Treated

Figure 46 shows the variation of load with respect to displacement under tensile testing. It can be observed that as the load increases displacement increases. It can be noticed that a load of 353.7Kg, 1 hour cryogenically treated carbon kevlar fiber was failed.

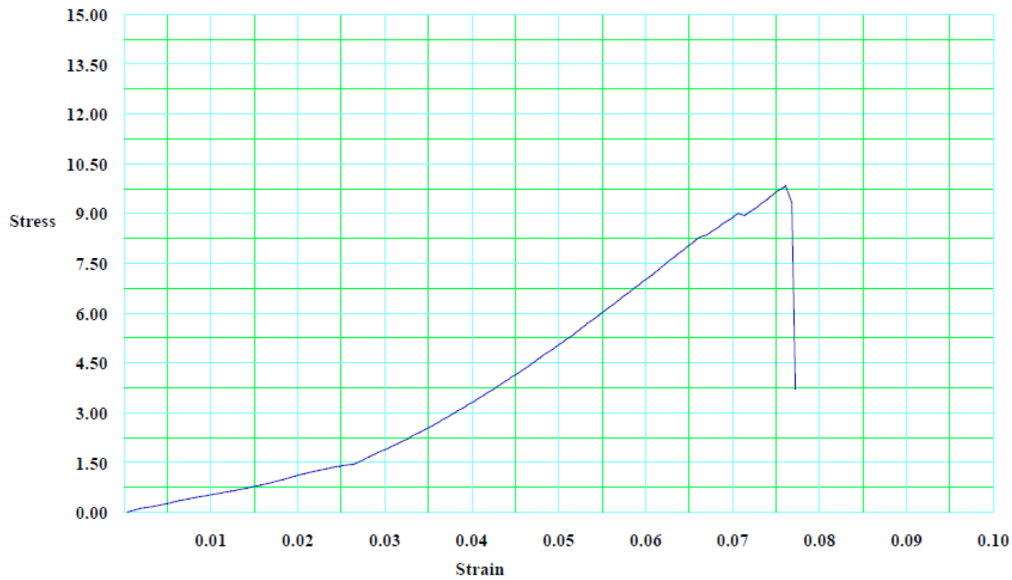

Figure 47 Stress Vs Strain Carbon Kevlar 1 hour Treated

Figure 47 shows the variation of stress with respect to strain under tensile testing. It can be observed that as the stress increases strain is found to increase. It can be noticed that at a stress of 9.825 Kg/mm2, 1 hour cryogenically treated carbon kevlar fiber was failed.

7.5 Flexural testing of 3 hour cryogenically treated composite fiber

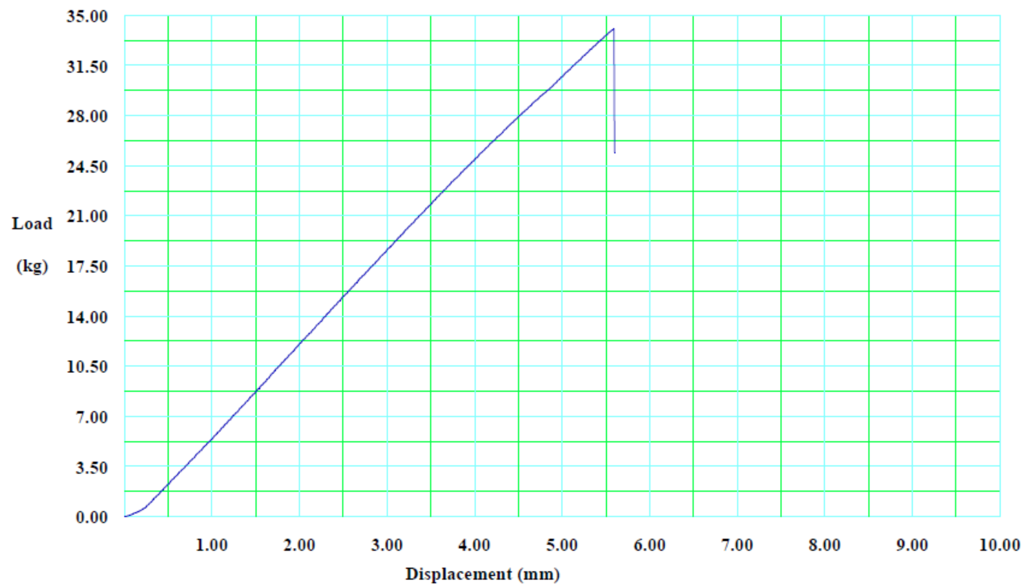

Figure 48 Load Vs Displacement Carbon 3 hour Treated

Figure 48 shows the variation of load with respect to displacement under flexural testing. It can be observed that as the load increases displacement increases. It can be noticed that a load of 34.06Kg, 3 hour cryogenically treated single layer carbon fiber was failed.

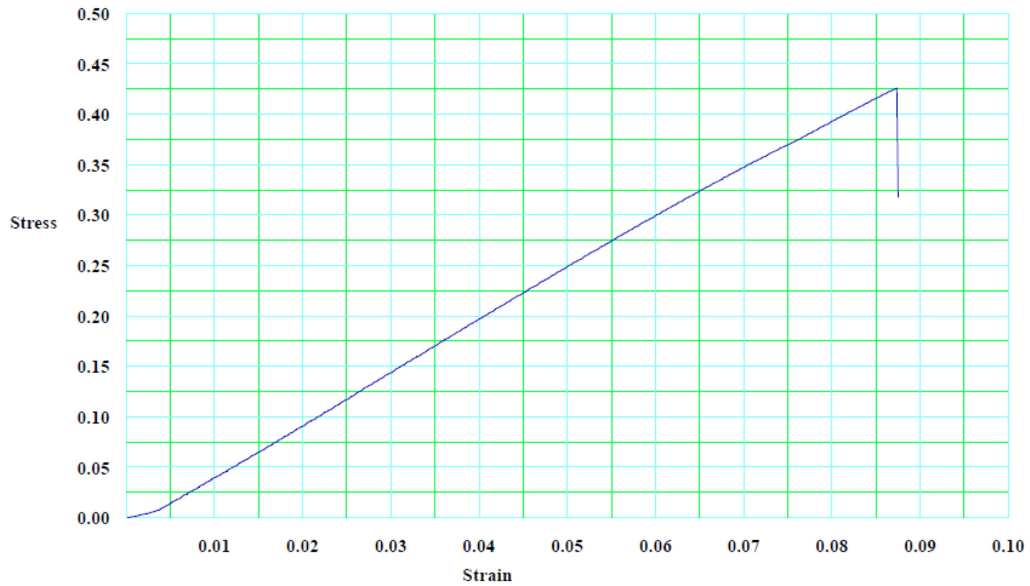

Figure 49 Stress Vs Strain Carbon 3 hour Treated

Figure 49 shows the variation of stress with respect to strain under flexural testing. It can be observed that as the stress increases strain is found to increase. It can be noticed that at a stress of 0.425 Kg/mm^2, 3 hour cryogenically treated single layer carbon fiber was failed.

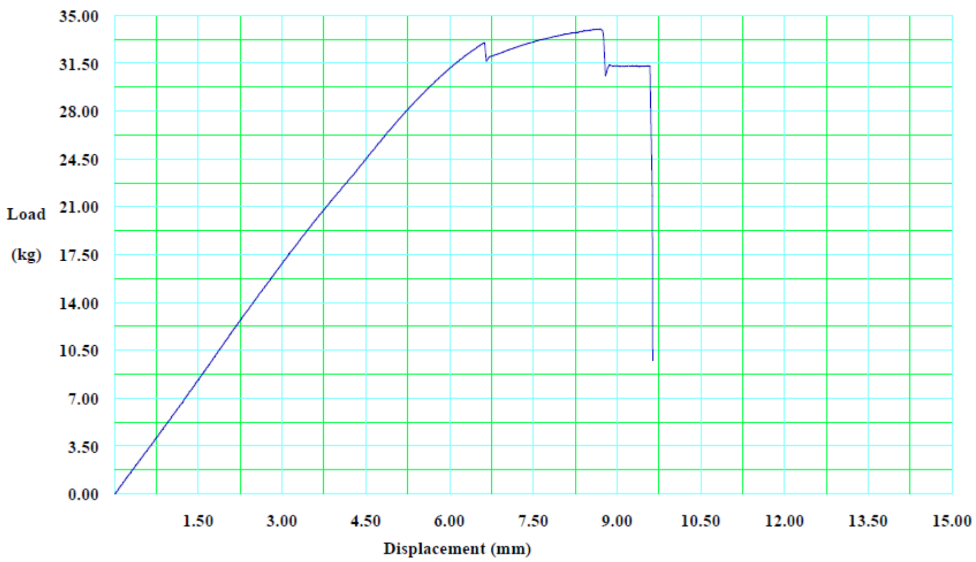

Figure 50Load Vs Displacement Double Carbon 3 hour Treated

Figure 50 shows the variation of load with respect to displacement under flexural testing. It can be observed that as the load increases displacement increases. It can be noticed that a load of 34.01Kg, 3 hour cryogenically treated double layer carbon fiber was failed.

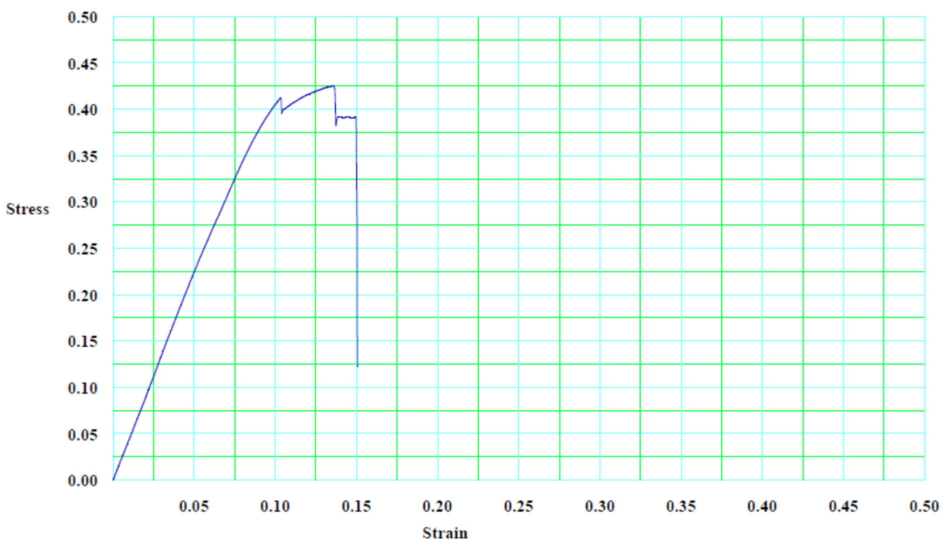

Figure 51 Stress Vs Strain Double Carbon 3 hour Treated

Figure 51 shows the variation of stress with respect to strain under flexural testing. It can be observed that as the stress increases strain is found to increase. It can be noticed that at a stress of 0.425 Kg/mm^2, 3 hour cryogenically treated double layer carbon fiber was failed.

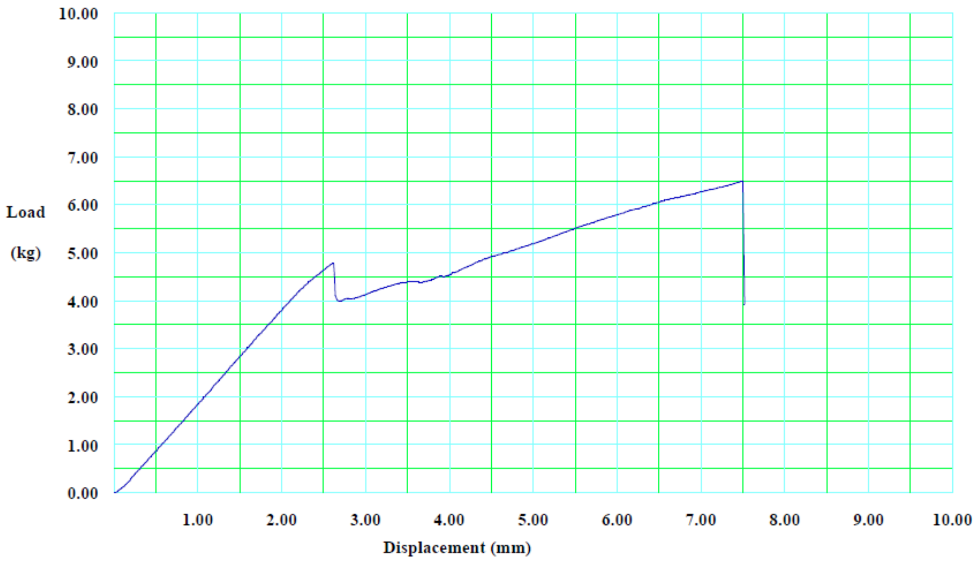

Figure 52 Load Vs Displacement Kevlar 3 hour Treated

Figure 52 shows the variation of load with respect to displacement under flexural testing. It can be observed that as the load increases displacement increases. It can be noticed that a load of 15.28Kg, 3 hour cryogenically treated single layer kevlar fiber was failed.

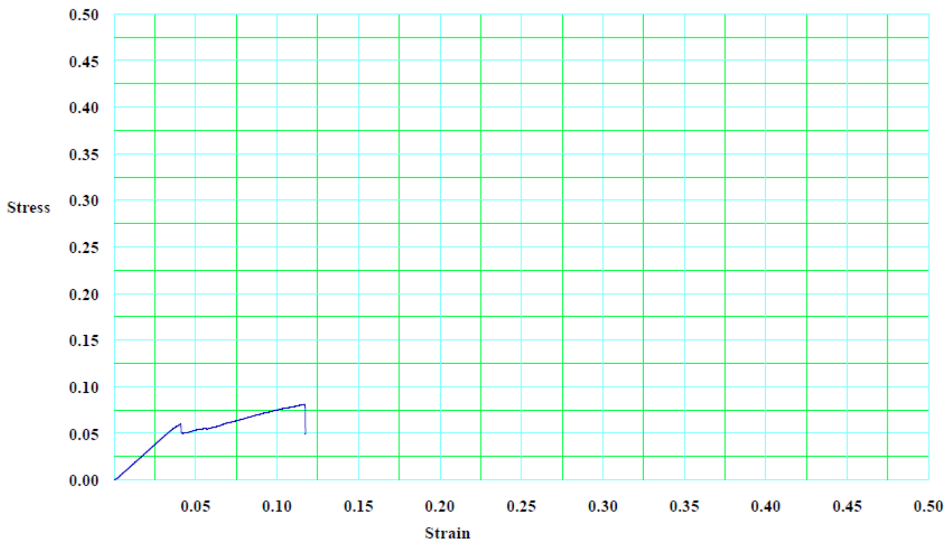

Figure 53 Stress Vs Stain Kevlar 3 hour Treated

Figure 53 shows the variation of stress with respect to strain under flexural testing. It can be observed that as the stress increases strain is found to increase. It can be noticed that at a stress of 0.191 Kg/mm^2, 3 hour cryogenically treated single layer kevlar fiber was failed.

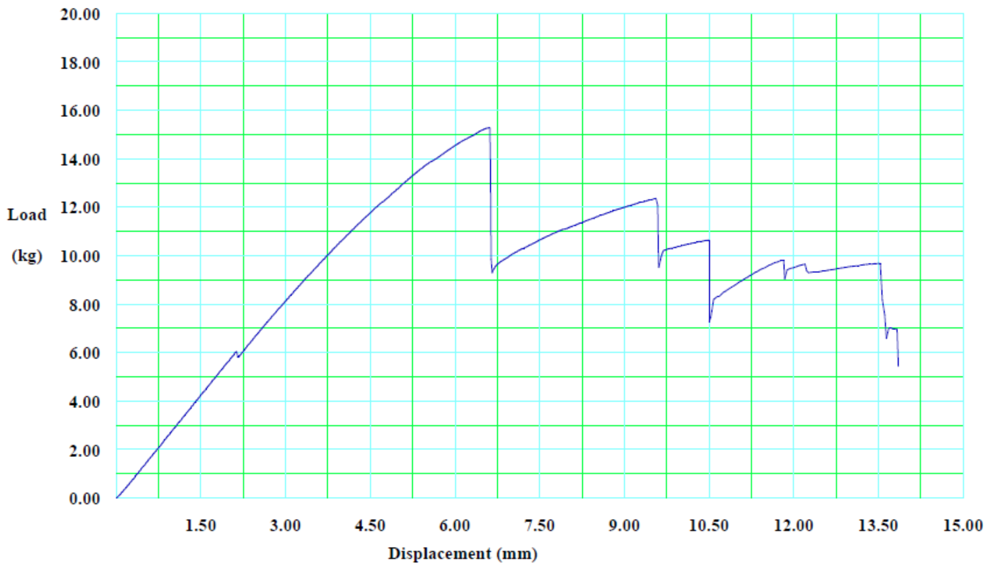

Figure 54 Load Vs Displacement Double Kevlar 3 hour Treated

Figure 54 shows the variation of load with respect to displacement under flexural testing. It can be observed that as the load increases displacement increases. It can be noticed that a load of 6.48Kg, 3 hour cryogenically treated double layer kevlar fiber was failed.

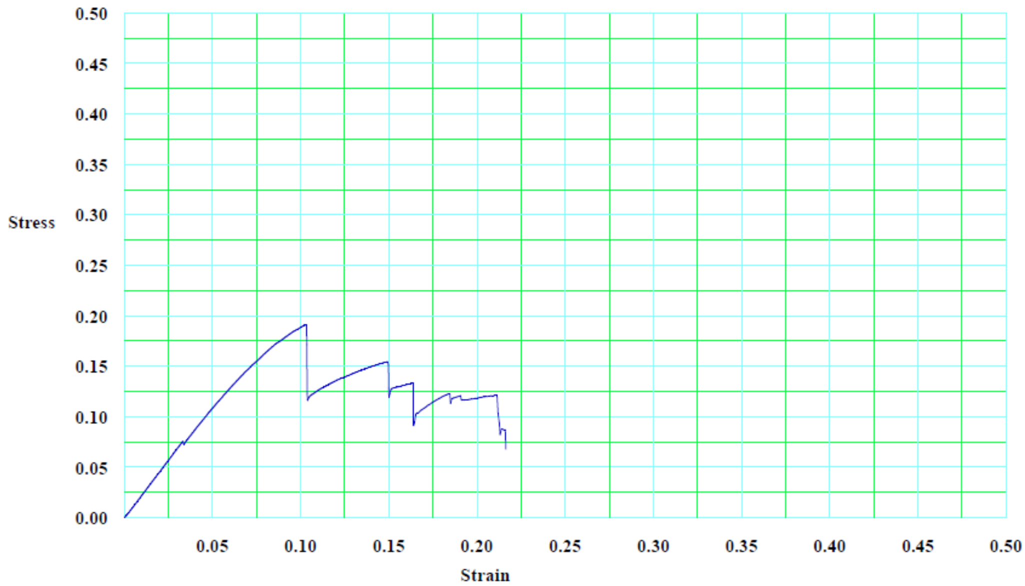

Figure 55 Stress Vs Stain Double Kevlar 3 hour Treated

Figure 55 shows the variation of stress with respect to strain under flexural testing. It can be observed that as the stress increases strain is found to increase. It can be noticed that at a stress of 0.081 Kg/mm^2, 3 hour cryogenically treated double layer kevlar fiber was failed.

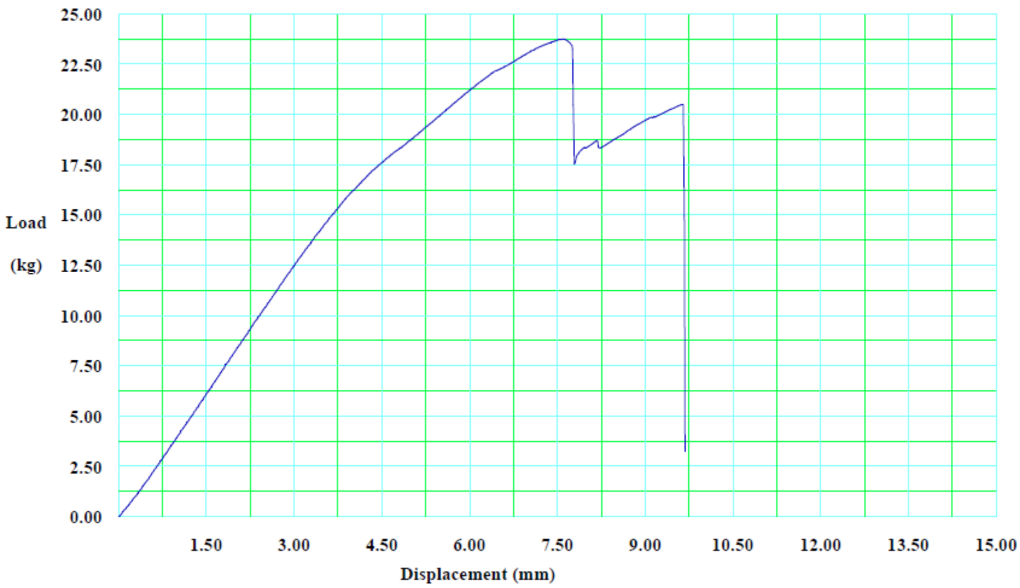

Figure 56 Load Vs Displacement Carbon Kevlar 3 hour Treated

Figure 56 shows the variation of load with respect to displacement under flexural testing. It can be observed that as the load increases displacement increases. It can be noticed that a load of 23.74Kg, 3 hour cryogenically treated carbon kevlar fiber was failed.

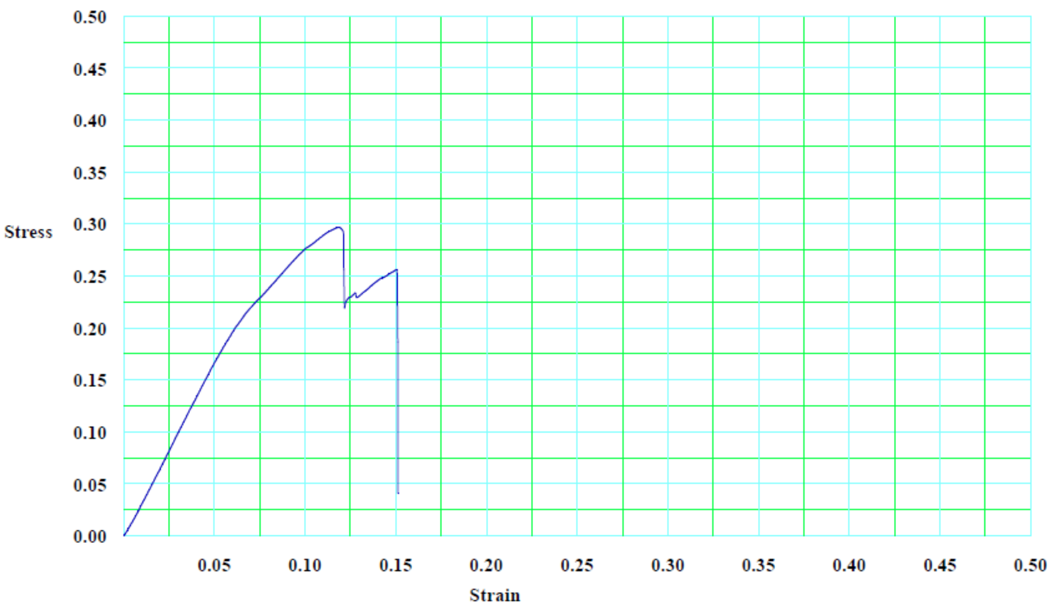

Figure 57 Stress Vs Stain Carbon Kevlar 3 hour Treated

Figure 57 shows the variation of stress with respect to strain under flexural testing. It can be observed that as the stress increases strain is found to increase. It can be noticed that at a stress of 0.296 Kg/mm^2, 3 hour cryogenically treated carbon kevlar fiber was failed.

7.6 Tensile testing of 3 hour cryogenically treated composite fiber

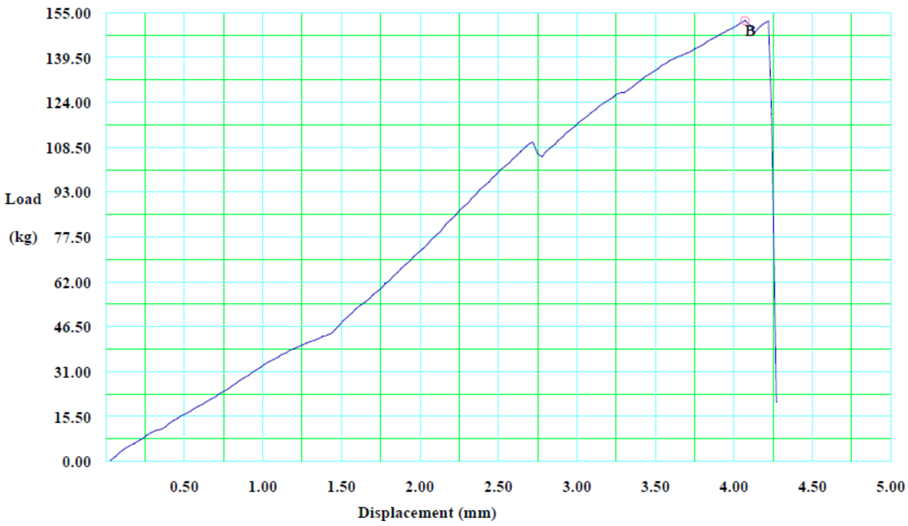

Figure 58 Load Vs Displacement Kevlar 3 hour Treated

Figure 58 shows the variation of load with respect to displacement under tensile testing. It can be observed that as the load increases displacement increases. It can be noticed that a load of 152.2Kg, 3 hour cryogenically treated single layer kevlar fiber was failed.

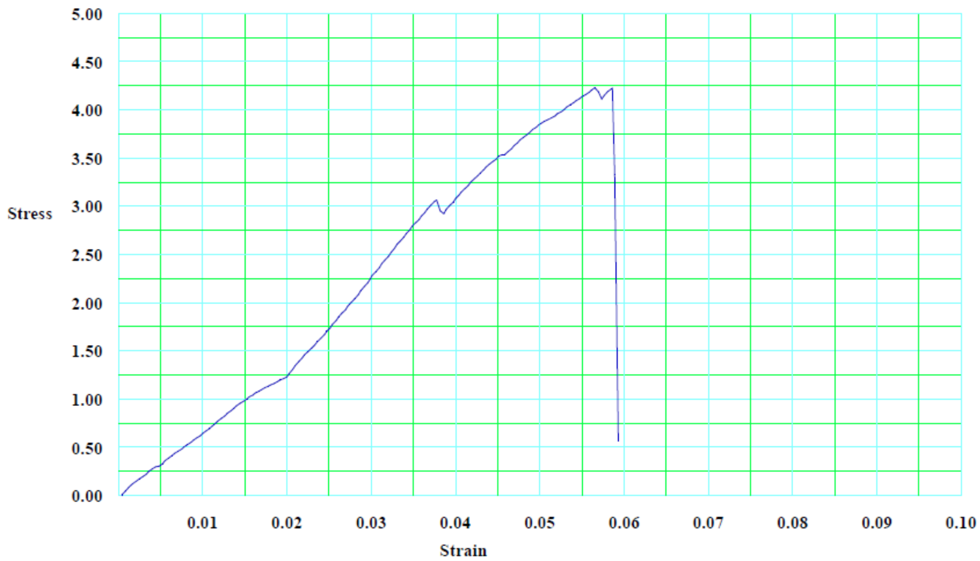

Figure 59 Stress Vs Strain Kevlar 3 hour Treated

Figure 59 shows the variation of stress with respect to strain under tensile testing. It can be observed that as the stress increases strain is found to increase. It can be noticed that at a stress of 4.227 Kg/mm^2, 3 hour cryogenically treated single layer kevlar fiber was failed.

7.7 Flexural testing of 1 hour cryogenically treated composite fiber after next day (24hour)

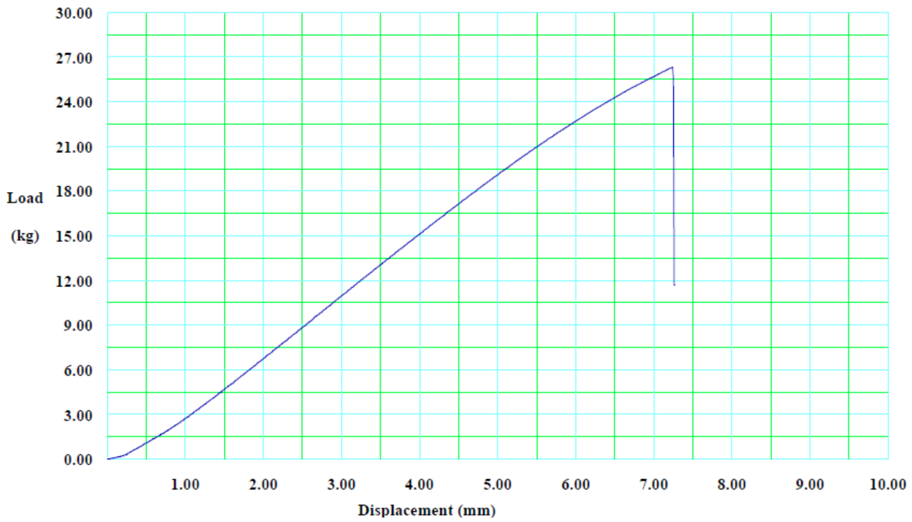

Figure 60Load Vs Displacement Carbon 1 hour Treated

Figure 60 shows the variation of load with respect to displacement under flexural testing. It can be observed that as the load increases displacement increases. It can be noticed that a load of 26.29Kg, 1 hour cryogenically treated after next day single layer carbon fiber was failed.

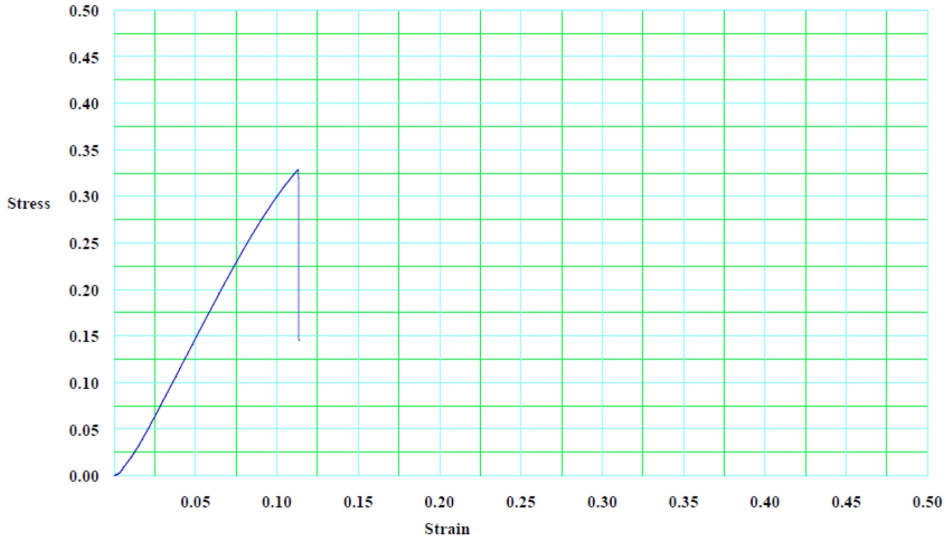

Figure 61 Stress Vs Strain Carbon 1 hour Treated

Figure 61 shows the variation of stress with respect to strain under flexural testing. It can be observed that as the stress increases strain is found to increase. It can be noticed that at a stress of 0.3365 Kg/mm^2, 1 hour cryogenically treated after next day single layer carbon fiber was failed.

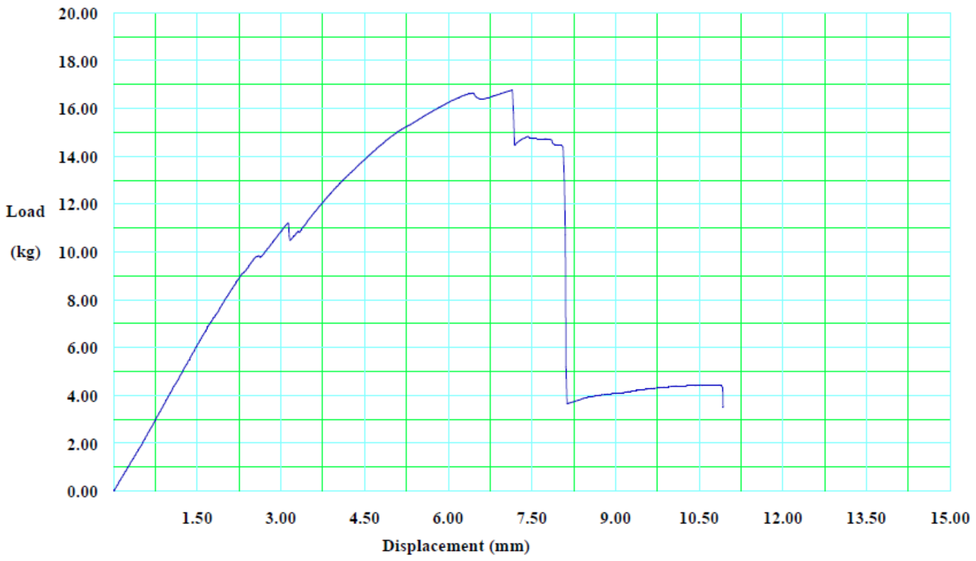

Figure 62 Load Vs Displacement Double Carbon 1 hour Treated

Figure 62 shows the variation of load with respect to displacement under flexural testing. It can be observed that as the load increases displacement increases. It can be noticed that a load of 16.76Kg, 1 hour cryogenically treated after next day double layer carbon fiber was failed.

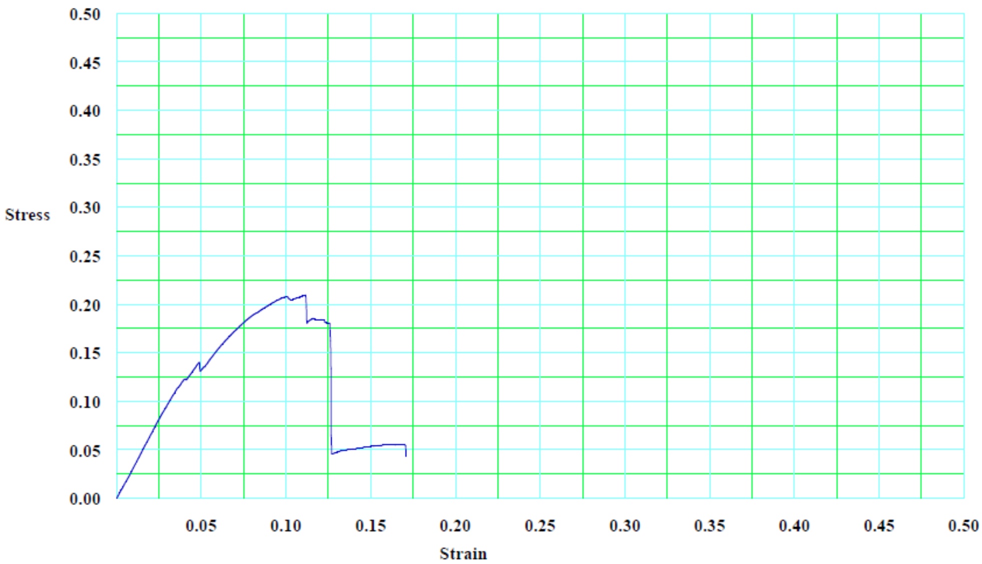

Figure 63 Stress Vs Strain Double Carbon 1 hour Treated

Figure 63 shows the variation of stress with respect to strain under flexural testing. It can be observed that as the stress increases strain is found to increase. It can be noticed that at a stress of 0.209 Kg/mm^2, 1 hour cryogenically treated after next day double layer carbon fiber was failed.

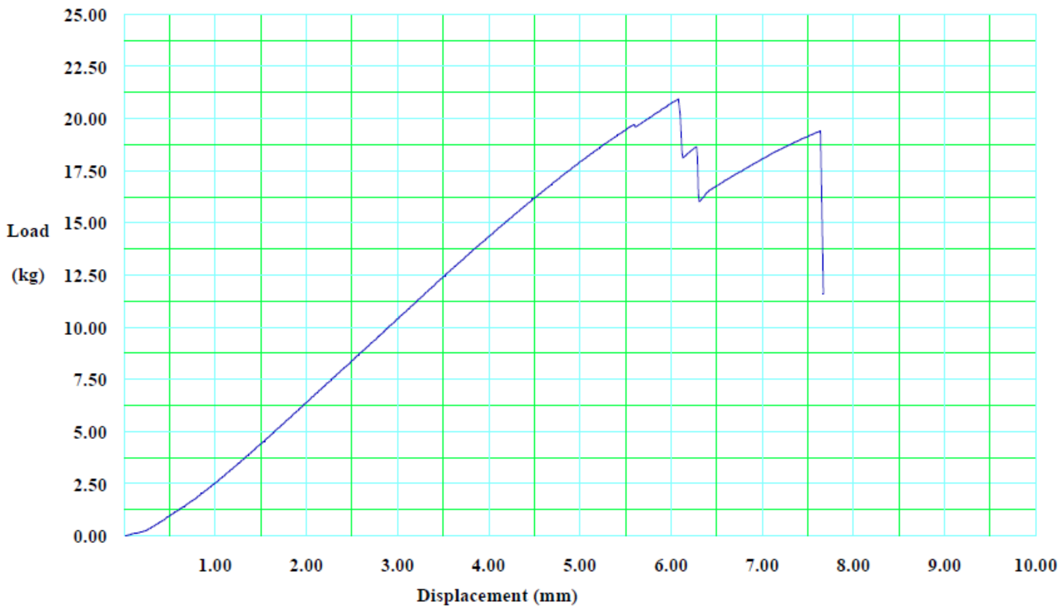

Figure 64 Load Vs Displacement Kevlar 1 hour Treated

Figure 64 shows the variation of load with respect to displacement under flexural testing. It can be observed that as the load increases displacement increases. It can be noticed that a load of 20.93Kg, 1 hour cryogenically treated after next day single layer kevlar fiber was failed.

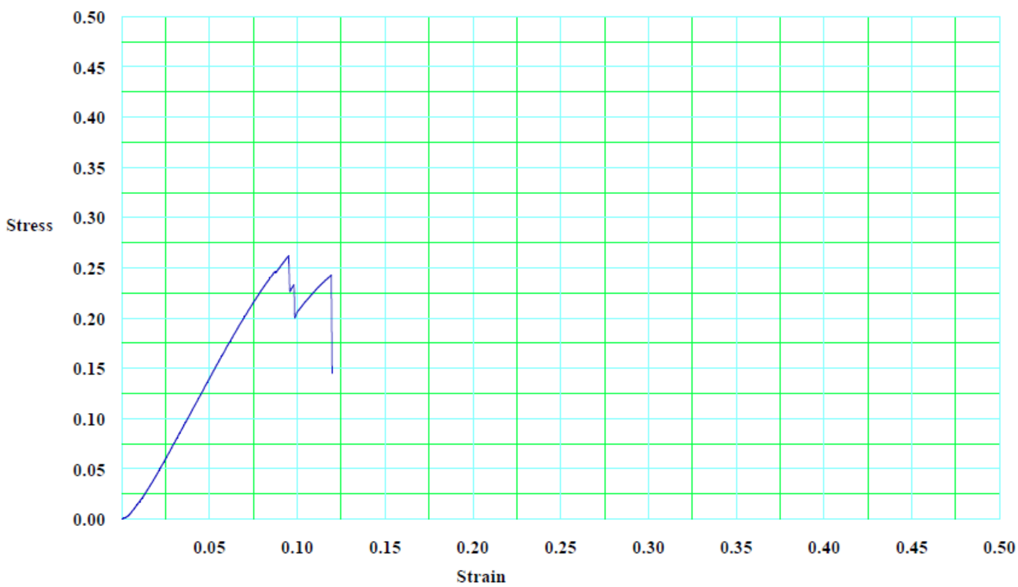

Figure 65 Stress Vs Strain Kevlar 1 hour Treated

Figure 65 shows the variation of stress with respect to strain under flexural testing. It can be observed that as the stress increases strain is found to increase. It can be noticed that at a stress of 0.261 Kg/mm^2, 1 hour cryogenically treated after next day single layer kevlar fiber was failed.

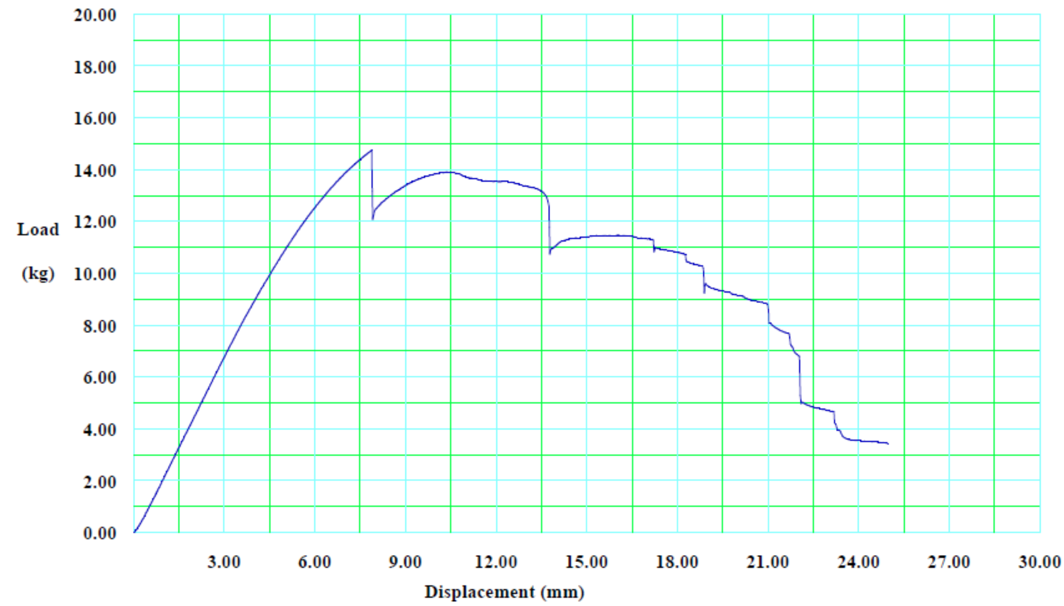

Figure 66 Load Vs Displacement Double Kevlar 1 hour Treated

Figure 66 shows the variation of load with respect to displacement under flexural testing. It can be observed that as the load increases displacement increases. It can be noticed that a load of 14.74Kg, 1 hour cryogenically treated after next day double layer kevlar fiber was failed.

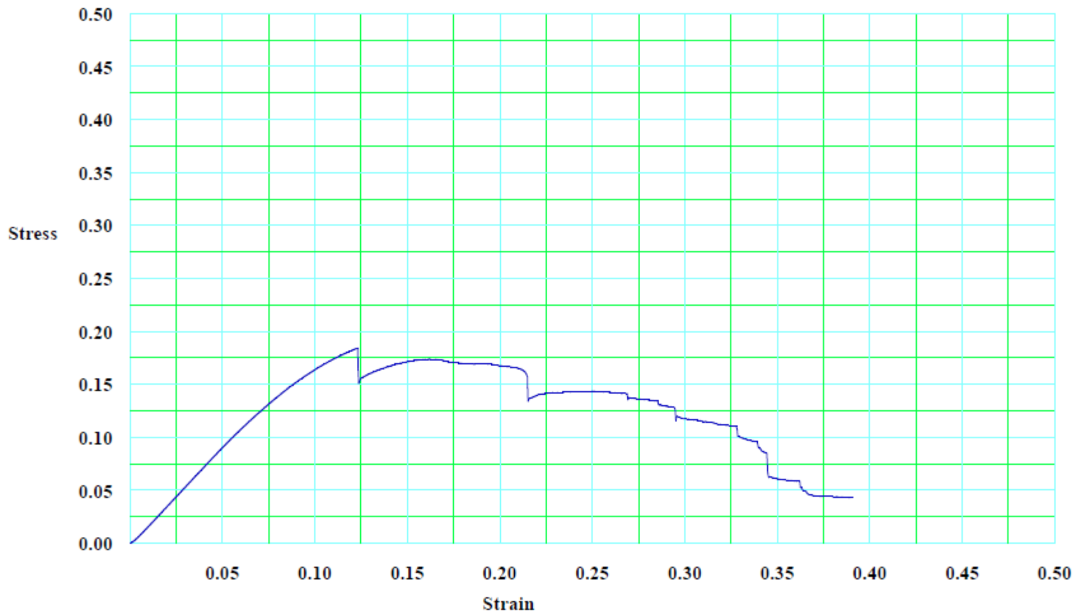

Figure 67 Stress Vs Strain Double Kevlar 1 hour Treated

Figure 67 shows the variation of stress with respect to strain under flexural testing. It can be observed that as the stress increases strain is found to increase. It can be noticed that at a stress of 0.184 Kg/mm^2, 1 hour cryogenically treated after next day double layer kevlar fiber was failed.

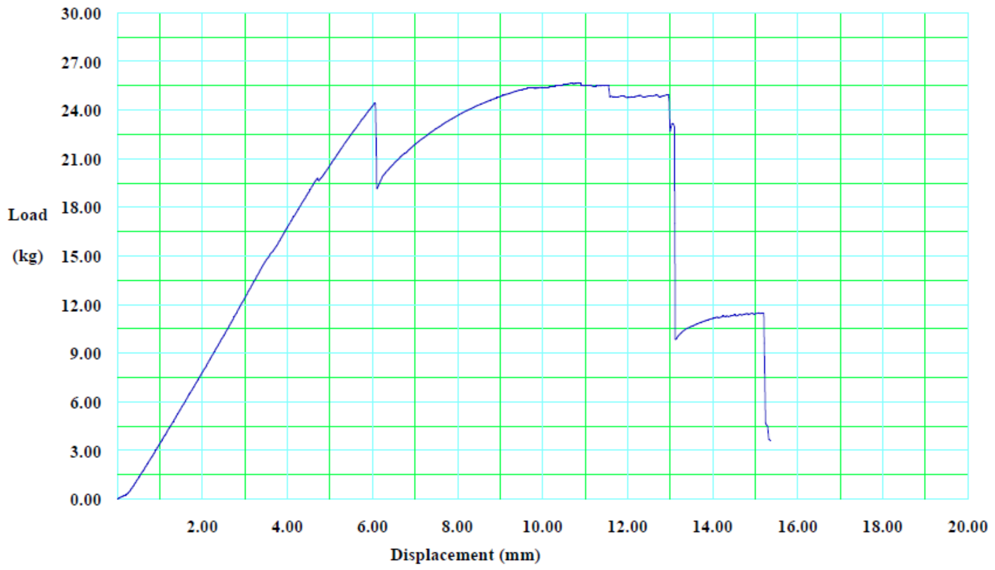

Figure 68 Load Vs Displacement Carbon Kevlar 1 hour Treated

Figure 68 shows the variation of load with respect to displacement under flexural testing. It can be observed that as the load increases displacement increases. It can be noticed that a load of 25.67Kg, 1 hour cryogenically treated after next day carbon kevlar fiber was failed.

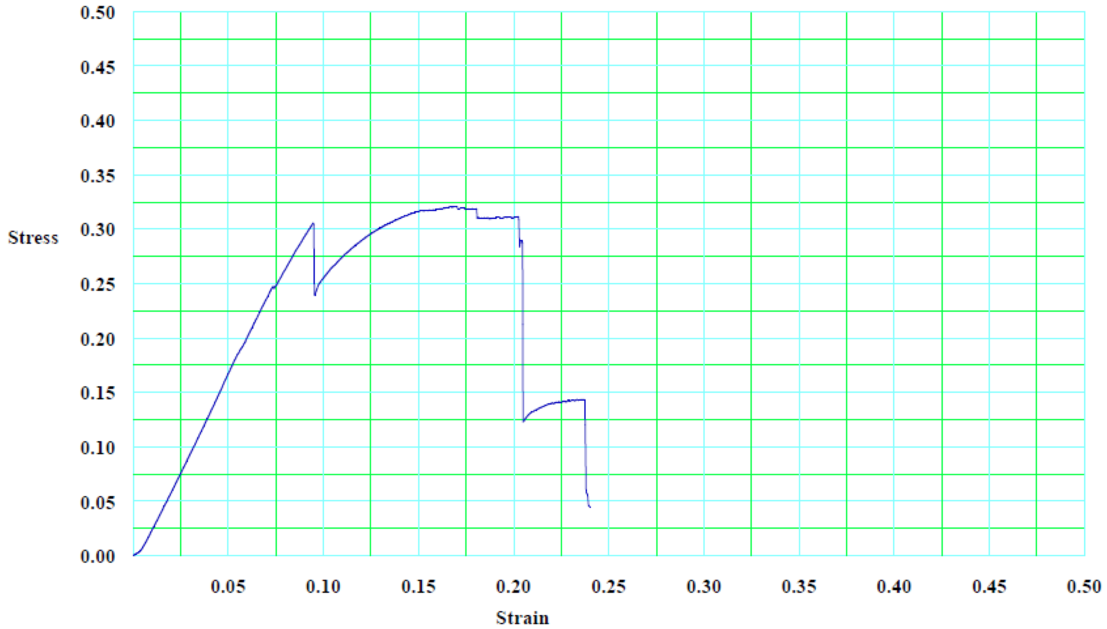

Figure 69 Stress Vs Strain Carbon Kevlar 1 hour Treated

Figure 69 shows the variation of stress with respect to strain under flexural testing. It can be observed that as the stress increases strain is found to increase. It can be noticed that at a stress of 0.320 Kg/mm^2, 1 hour cryogenically treated after next day carbon kevlar fiber was failed.

7.8 Tensile testing of 1 hour cryogenically treated composite fiber after next day (24hour)

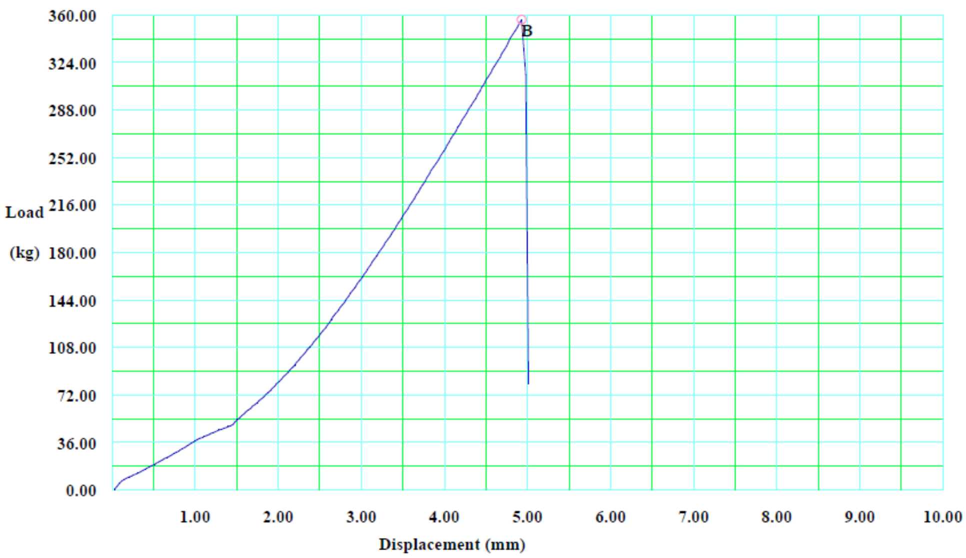

Figure 70Load Vs Displacement Carbon 1 hour Treated

Figure 70 shows the variation of load with respect to displacement under tensile testing. It can be observed that as the load increases displacement increases. It can be noticed that a load of 356.5Kg, 1 hour cryogenically treated after next day single layer carbon fiber was failed.

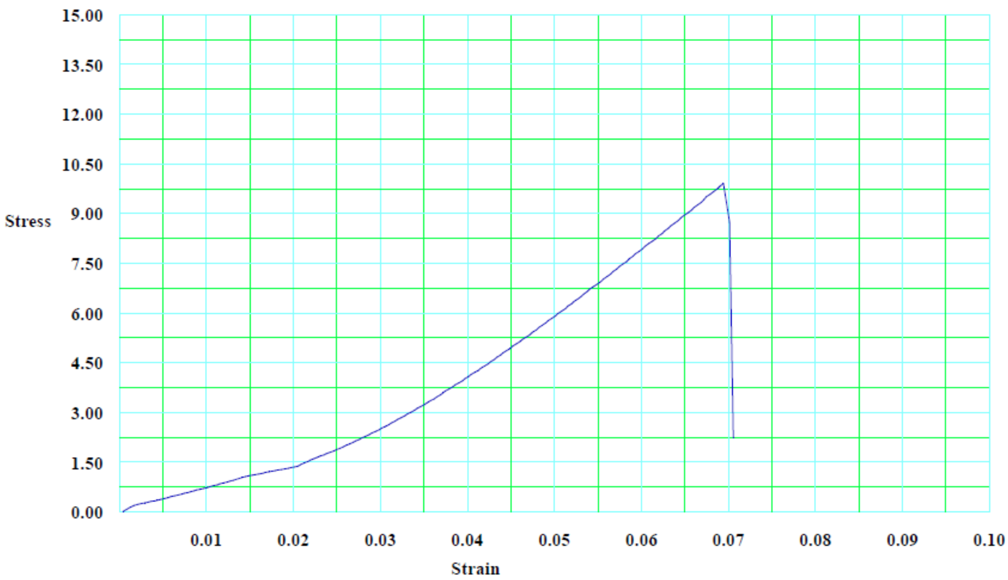

Figure 71 Stress Vs Strain Carbon 1 hour treated

Figure 71 shows the variation of stress with respect to strain under tensile testing. It can be observed that as the stress increases strain is found to increase. It can be noticed that at a stress of 9.902 Kg/mm^2, 1 hour cryogenically treated after next day single layer carbon fiber was failed.

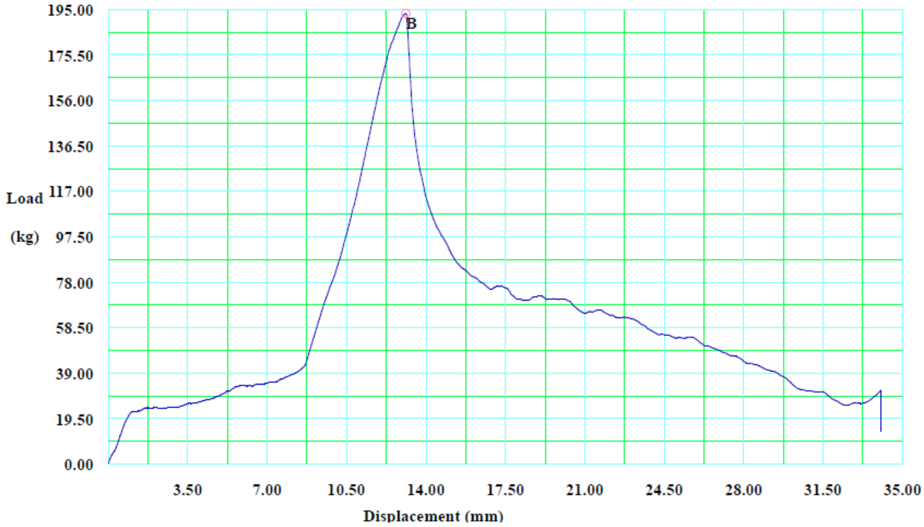

Figure 72 Load Vs Displacement Double Carbon 1 hour Treated

Figure 72 shows the variation of load with respect to displacement under tensile testing. It can be observed that as the load increases displacement increases. It can be noticed that a load of 193.3 Kg, 1 hour cryogenically treated after next day double layer carbon fiber was failed.

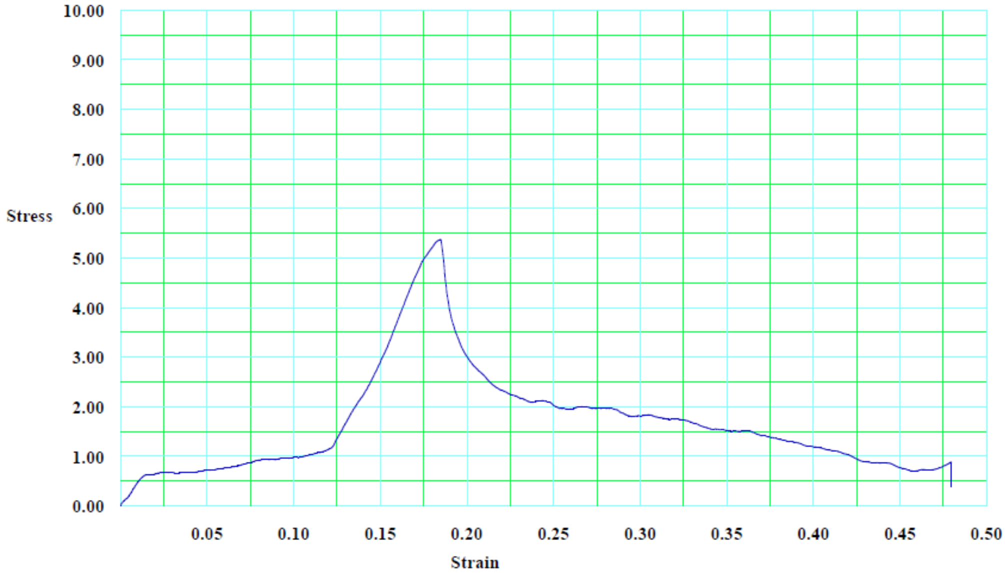

Figure 73 Stress Vs Strain Double Carbon 1 hour Treated

Figure 73 shows the variation of stress with respect to strain under tensile testing. It can be observed that as the stress increases strain is found to increase. It can be noticed that at a stress of 5.369 Kg/mm^2, 1 hour cryogenically treated after next day double layer carbon fiber was failed.

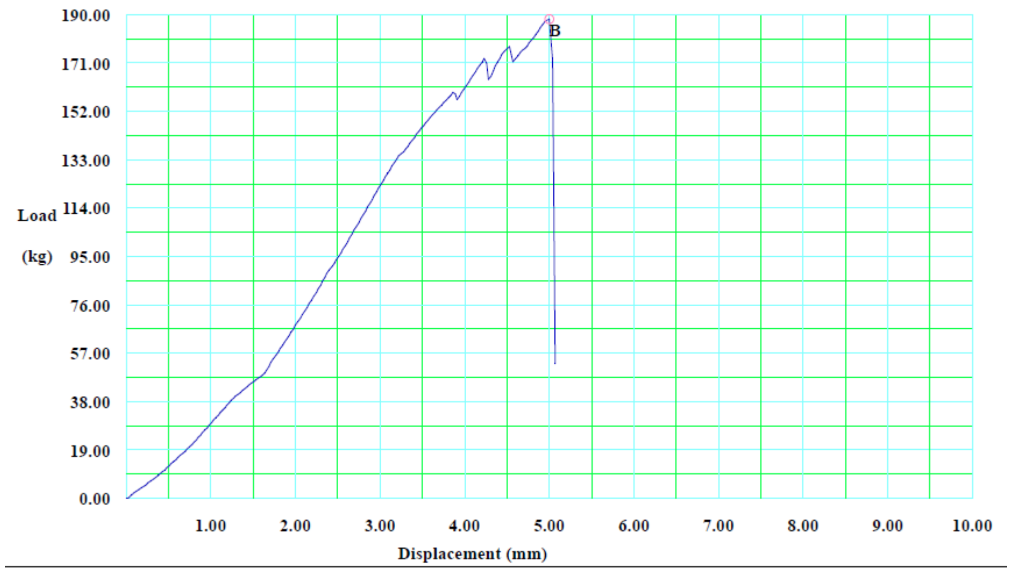

Figure 74 Load Vs Displacement Kevlar 1 hour Treated

Figure 74 shows the variation of load with respect to displacement under tensile testing. It can be observed that as the load increases displacement increases. It can be noticed that a load of 193.3 Kg, 1 hour cryogenically treated after next day single layer kevlar fiber was failed.

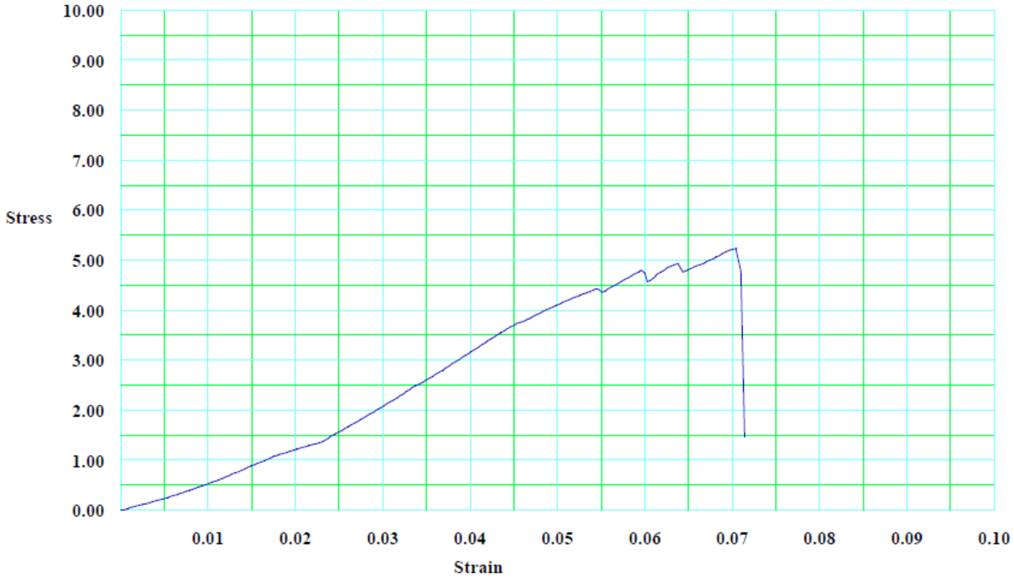

Figure 75 Stress Vs Strain Kevlar 1 hour Treated

Figure 75 shows the variation of stress with respect to strain under tensile testing. It can be observed that as the stress increases strain is found to increase. It can be noticed that at a stress of 5.369 Kg/mm^2, 1 hour cryogenically treated after next day single layer kevlar fiber was failed.

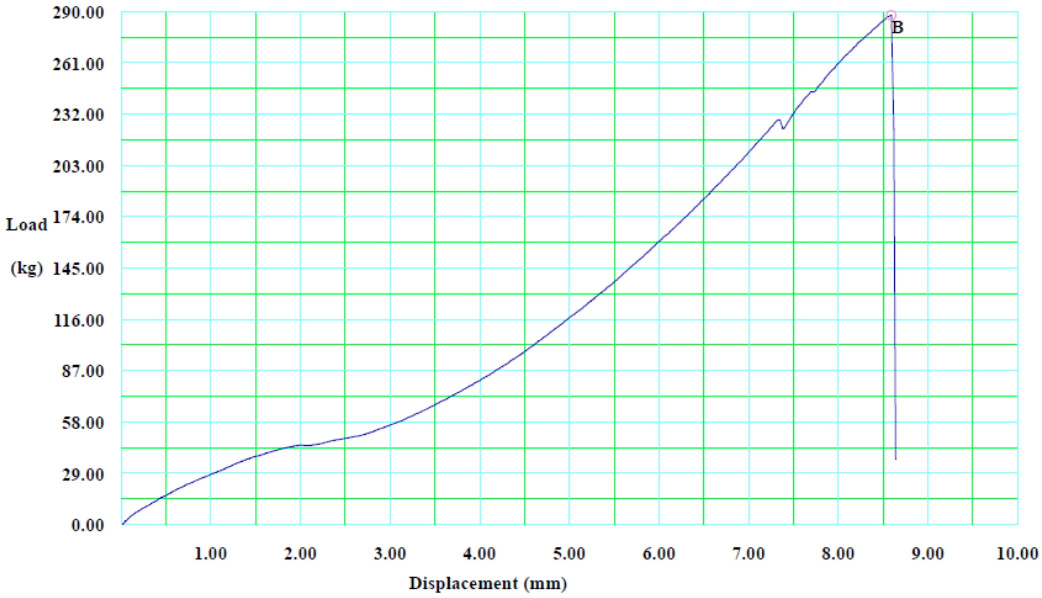

Figure 76 Load Vs Displacement Double Kevlar 1 hour Treated

Figure 76 shows the variation of load with respect to displacement under tensile testing. It can be observed that as the load increases displacement increases. It can be noticed that a load of 287.8 Kg, 1 hour cryogenically treated after next day double layer kevlar fiber was failed.

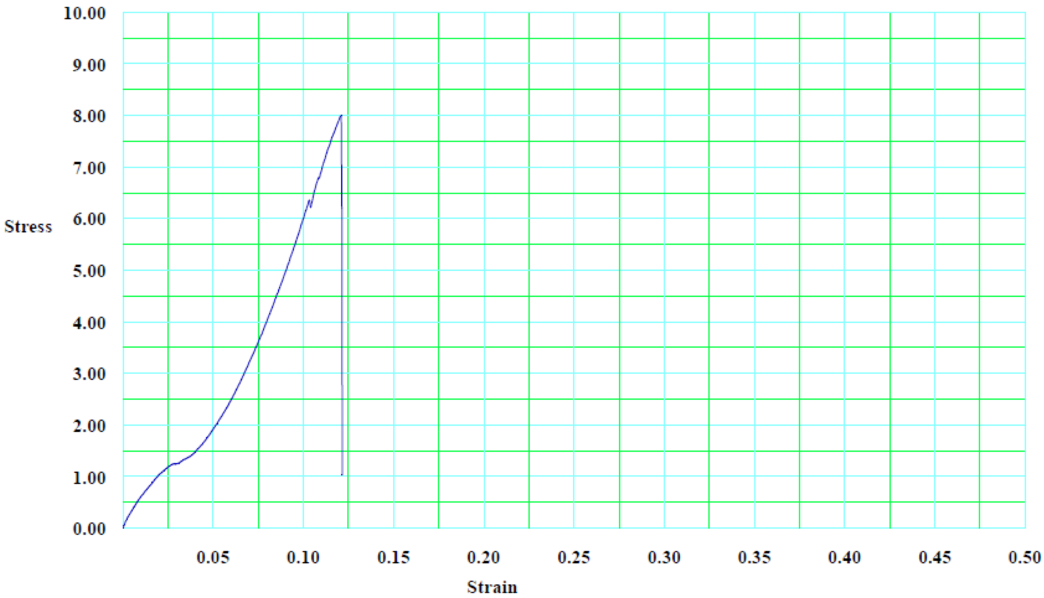

Figure 77 Stress Vs Strain Double Kevlar 1 hour Treated

Figure 77 shows the variation of stress with respect to strain under tensile testing. It can be observed that as the stress increases strain is found to increase. It can be noticed that at a stress of 7.994 Kg/mm^2, 1 hour cryogenically treated after next day double layer kevlar fiber was failed.

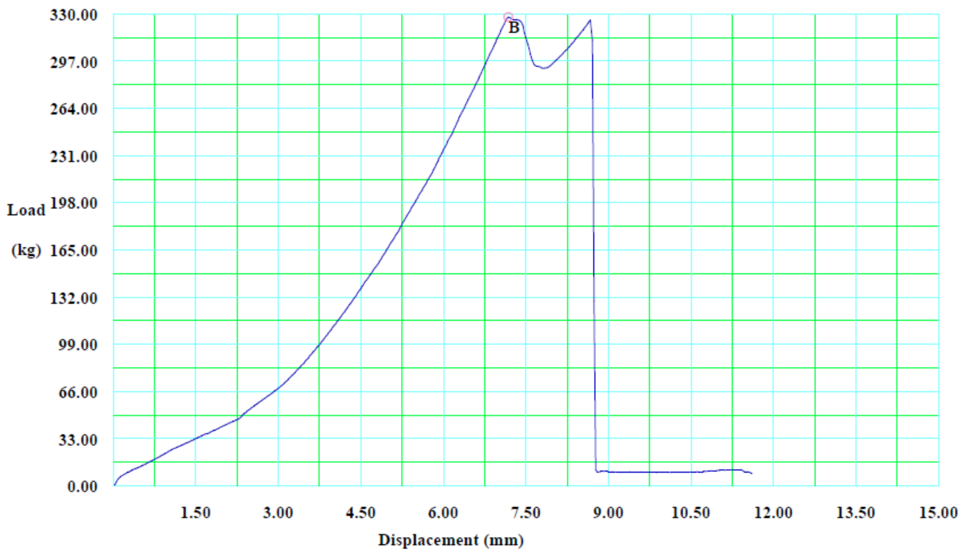

Figure 78 Load Vs Displacement Carbon Kevlar 1 hour Treated

Figure 78 shows the variation of load with respect to displacement under tensile testing. It can be observed that as the load increases displacement increases. It can be noticed that a load of 327.8 Kg, 1 hour cryogenically treated after next day carbon kevlar fiber was failed.

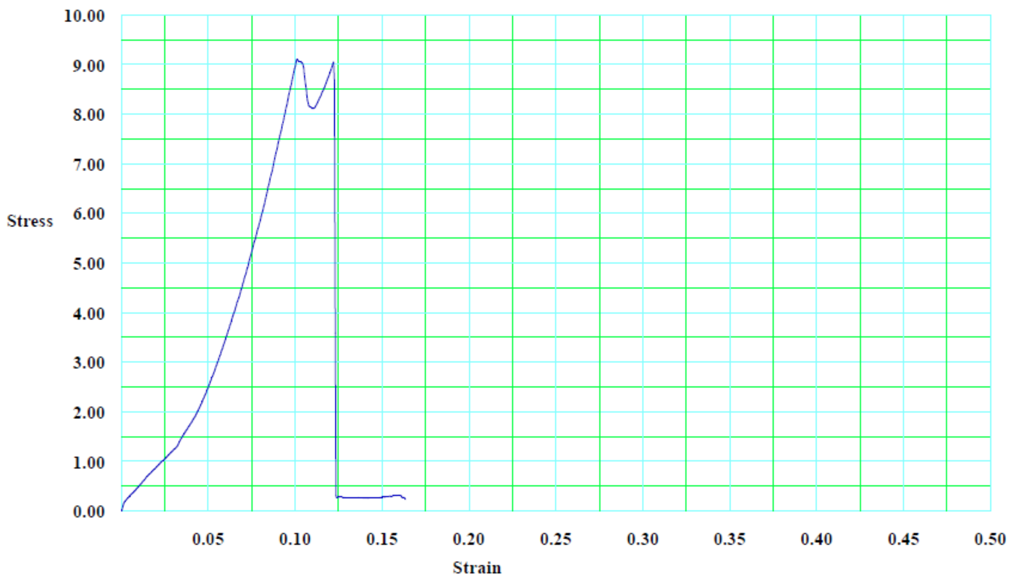

Figure 79 Stress Vs Strain Carbon Kevlar 1 hour Treated

Figure 79 shows the variation of stress with respect to strain under tensile testing. It can be observed that as the stress increases strain is found to increase. It can be noticed that at a stress of 9.105 Kg/mm^2, 1 hour cryogenically treated after next day carbon kevlar fiber was failed.

7.9 Flexure testing of 3 hour cryogenically treated composite fiber after next day (24hour)

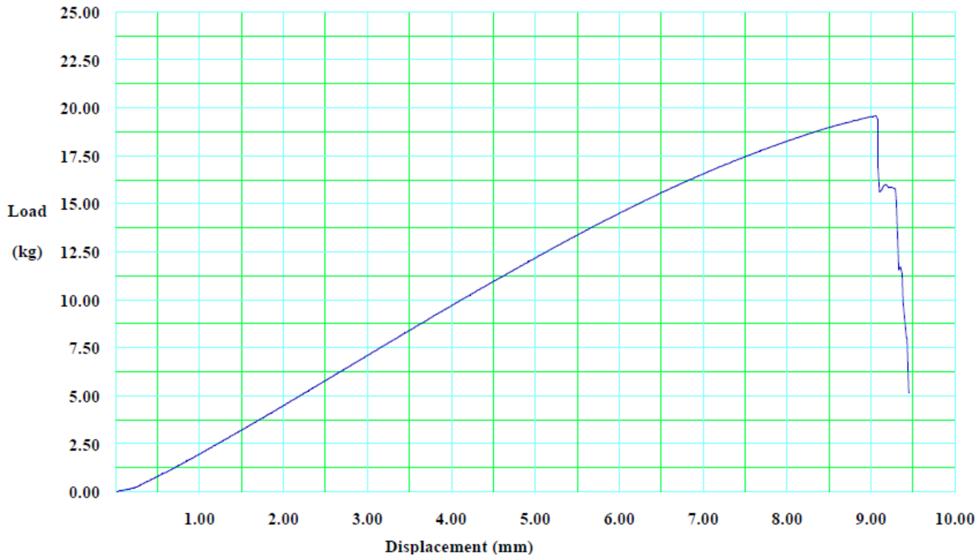

Figure 80Load Vs Displacement Carbon 3 hour Treated

Figure 80 shows the variation of load with respect to displacement under flexure testing. It can be observed that as the load increases displacement increases. It can be noticed that a load of 19.58 Kg, 3 hour cryogenically treated after next day single layer carbon fiber was failed.

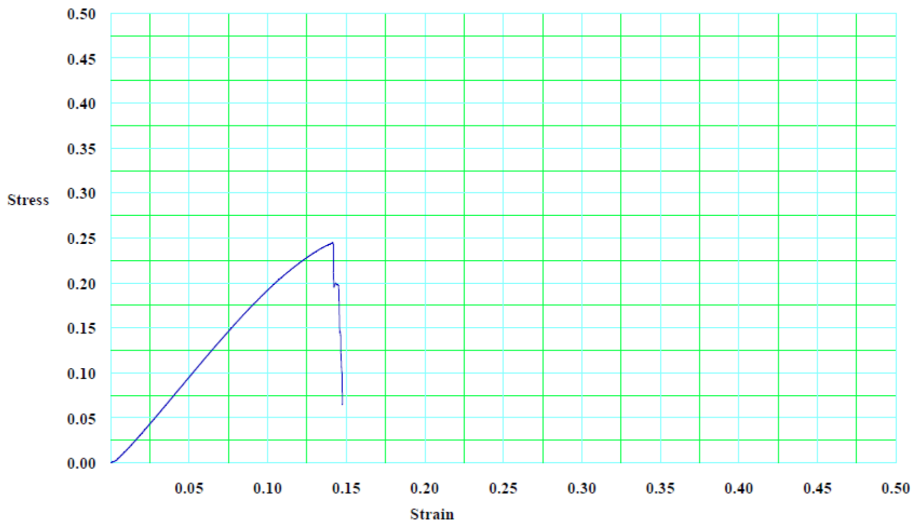

Figure 81 Stress Vs Strain Carbon 3 hours Treated

Figure 81 shows the variation of stress with respect to strain under flexure testing. It can be observed that as the stress increases strain is found to increase. It can be noticed that at a stress of 0.244 Kg/mm^2, 3 hour cryogenically treated after next day single layer carbon fiber was failed.

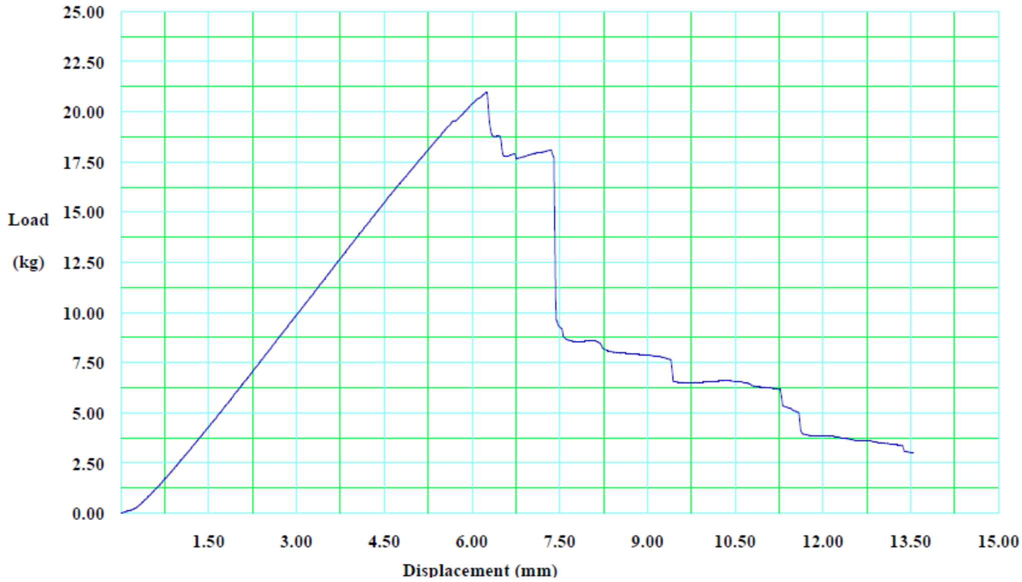

Figure 82 Load Vs Displacement Double Carbon 3 hour Treated

Figure 82 shows the variation of load with respect to displacement under flexure testing. It can be observed that as the load increases displacement increases. It can be noticed that a load of 20.98 Kg, 3 hour cryogenically treated after next day double layer carbon fiber was failed.

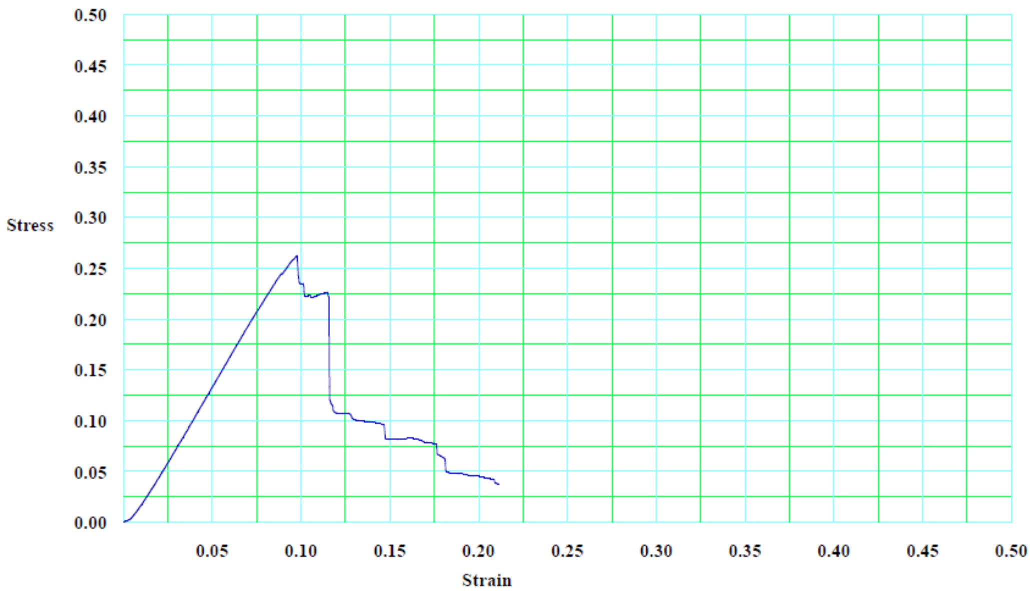

Figure 83 Stress Vs Strain Double Carbon 3 hours Treated

Figure 83 shows the variation of stress with respect to strain under flexure testing. It can be observed that as the stress increases strain is found to increase. It can be noticed that at a stress of 0.262 Kg/mm^2, 3 hour cryogenically treated after next day double layer carbon fiber was failed.

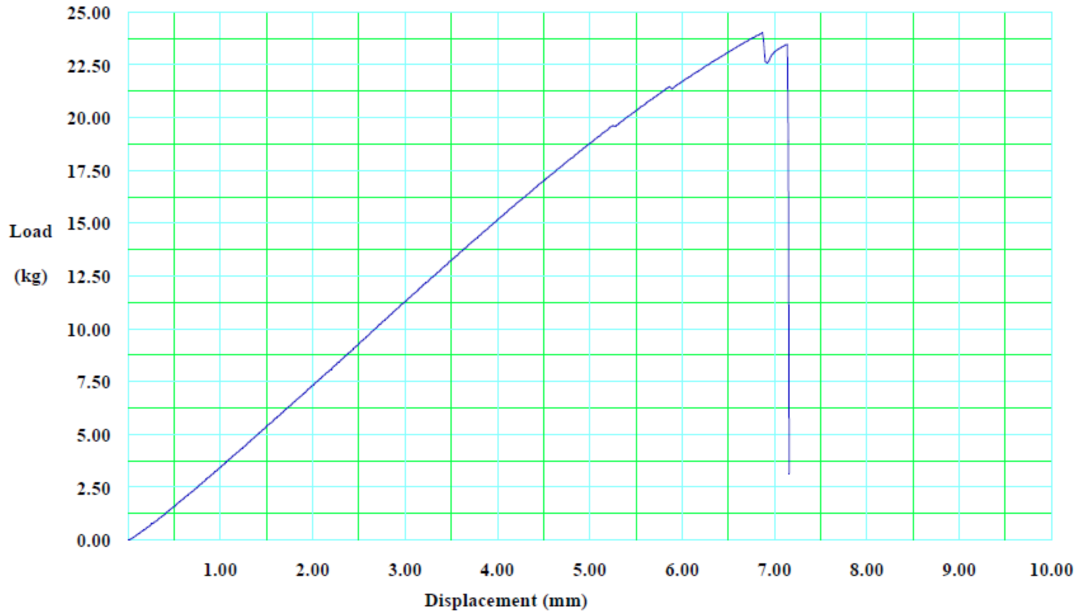

Figure 84 Load Vs Displacement Kevlar 3 hours Treated

Figure 84 shows the variation of load with respect to displacement under flexure testing. It can be observed that as the load increases displacement increases. It can be noticed that a load of 24 Kg, 3 hour cryogenically treated after next day single layer kevlar fiber was failed.

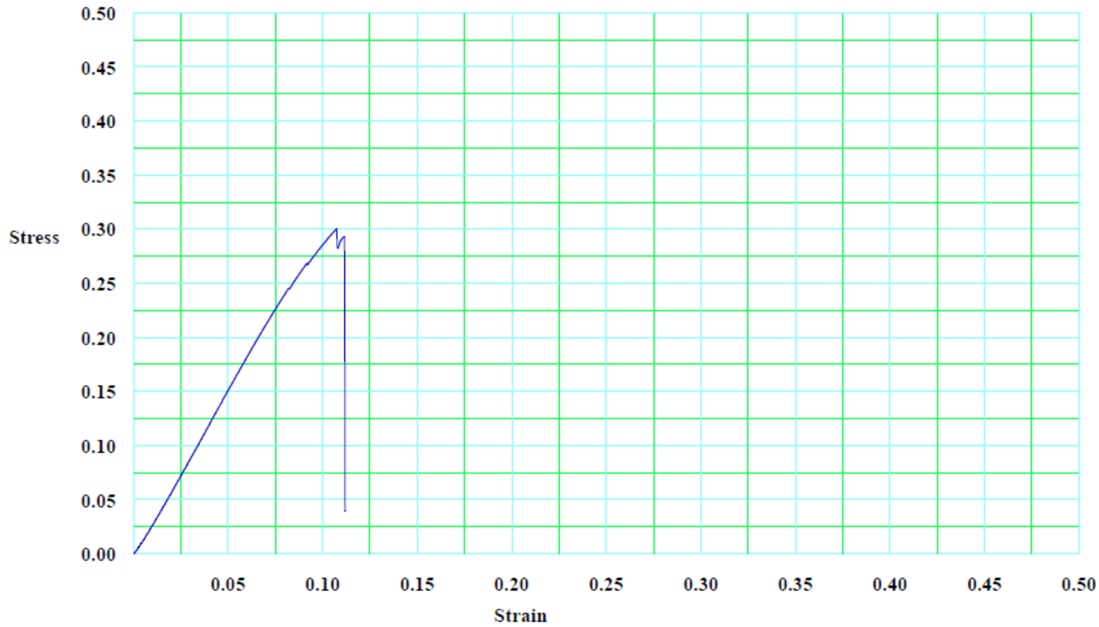

Figure 85 Stress Vs Strain Kevlar 3 hour Treated

Figure856 shows the variation of stress with respect to strain under flexure testing. It can be observed that as the stress increases strain is found to increase. It can be noticed that at a stress of 0.3 Kg/mm^2, 3 hour cryogenically treated after next day single layer kevlar fiber was failed.

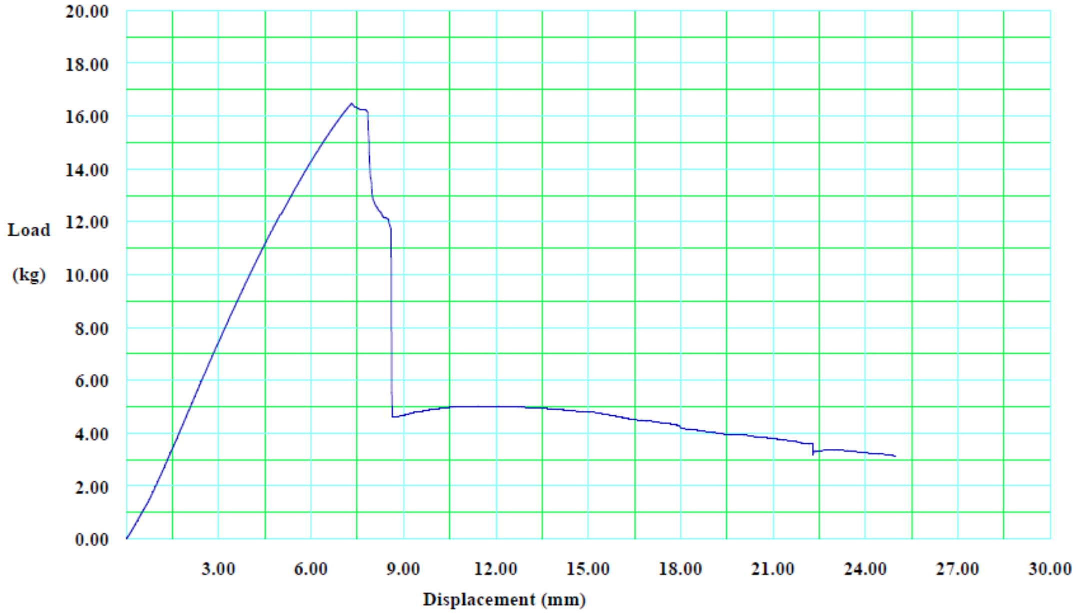

Figure 86 Load Vs Displacement Double Kevlar 3 hour Treated

Figure 86 shows the variation of load with respect to displacement under flexure testing. It can be observed that as the load increases displacement increases. It can be noticed that a load of 16.47 Kg, 3 hour cryogenically treated after next day double layer kevlar fiber was failed.

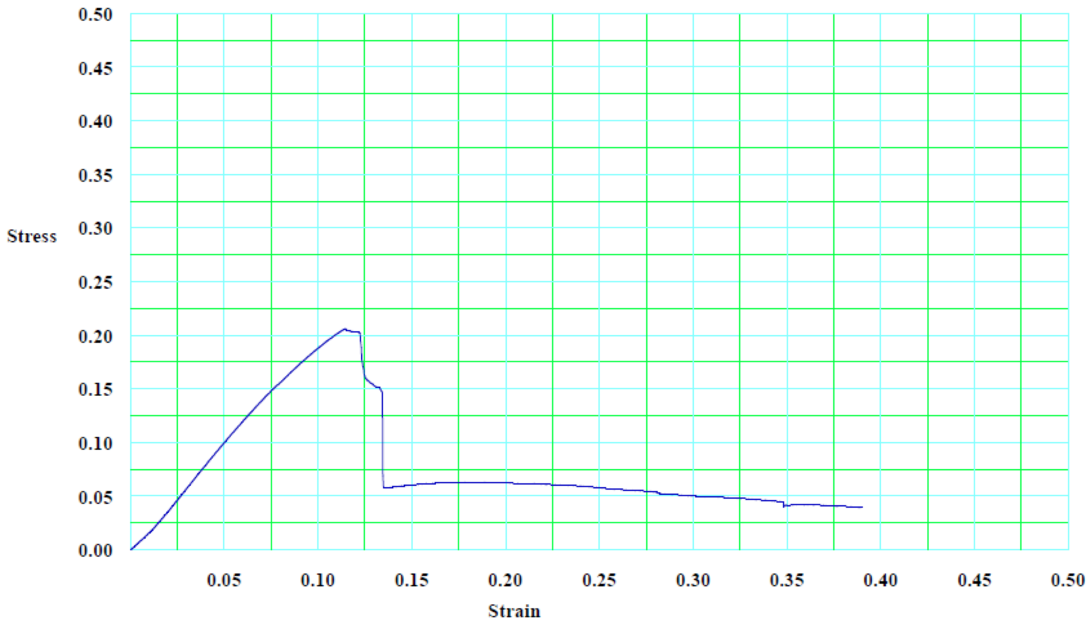

Figure 87 Stress Vs Strain Double Kevlar 3 hour Treated

Figure 87 shows the variation of stress with respect to strain under flexure testing. It can be observed that as the stress increases strain is found to increase. It can be noticed that at a stress of 0.205 Kg/mm^2, 3 hour cryogenically treated after next day double layer kevlar fiber was failed.

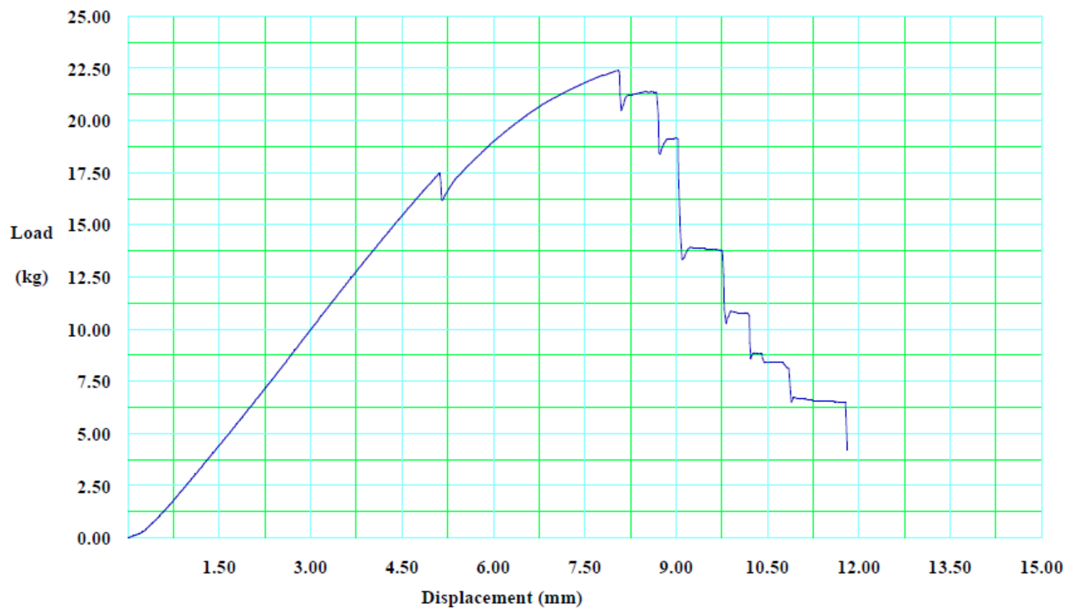

Figure 88 Load Vs Displacement Carbon Kevlar 3 hour Treated

Figure 88 shows the variation of load with respect to displacement under flexure testing. It can be observed that as the load increases displacement increases. It can be noticed that a load of 22.4 Kg, 3 hour cryogenically treated after next day carbon kevlar fiber was failed.

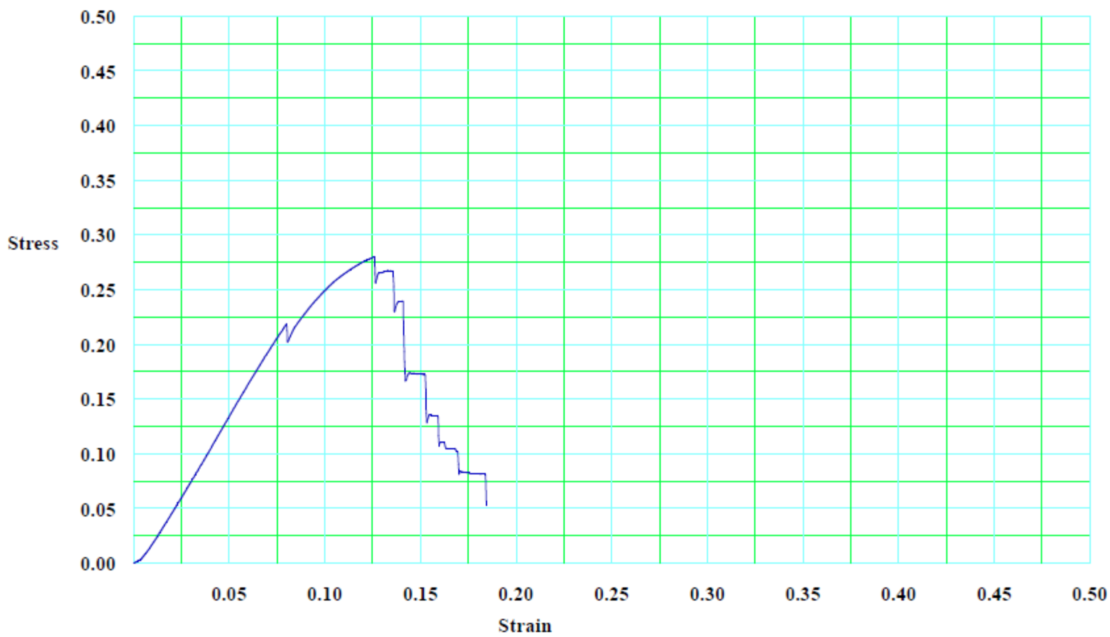

Figure 89 Stress Vs Strain Carbon Kevlar 3 hour Treated

Figure 89 shows the variation of stress with respect to strain under flexure testing. It can be observed that as the stress increases strain is found to increase. It can be noticed that at a stress of 0.28 Kg/mm^2, 3 hour cryogenically treated after next day carbon kevlar fiber was failed.

7.10 Tensile testing of 3 hour cryogenically treated composite fiber after next day (24hour)

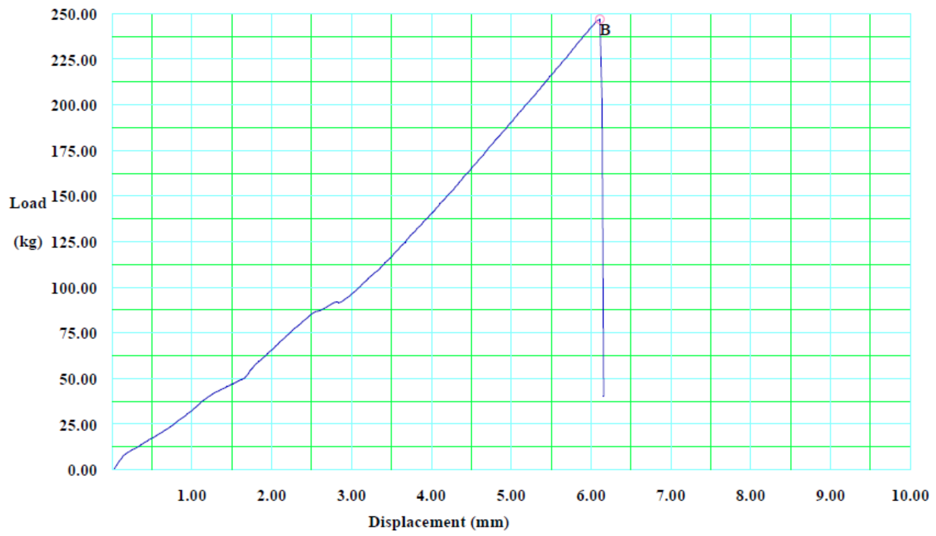

Figure 90oad Vs Displacement Carbon 3 hour Treated

Figure 90 shows the variation of load with respect to displacement under tensile testing. It can be observed that as the load increases displacement increases. It can be noticed that a load of 246.9 Kg, 3 hour cryogenically treated after next day single layer carbon fiber was failed.

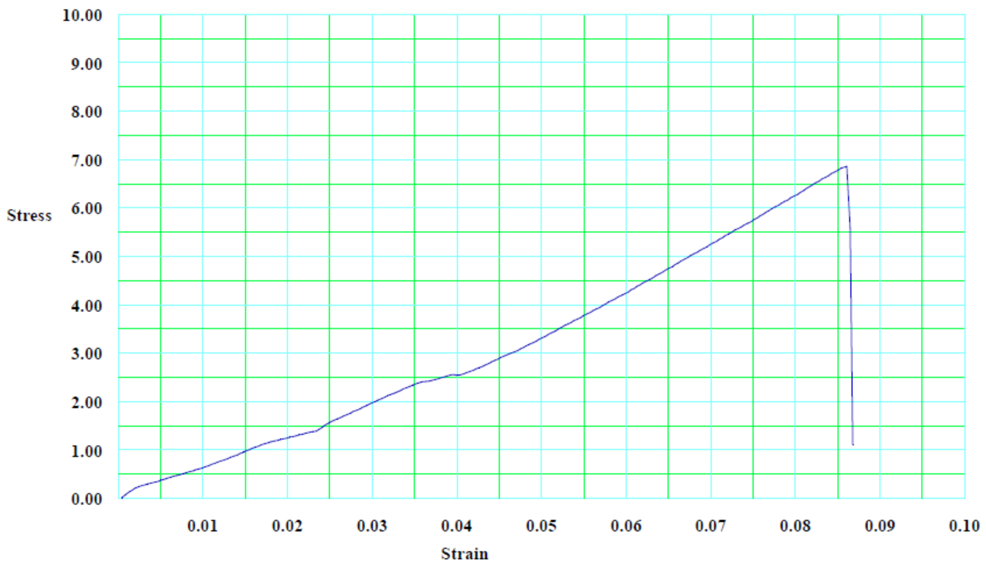

Figure 91Stress Vs Strain Carbon 3 hour Treated

Figure 91 shows the variation of stress with respect to strain under tensile testing. It can be observed that as the stress increases strain is found to increase. It can be noticed that at a stress of 6.858 Kg/mm^2, 3 hour cryogenically treated after next day single layer carbon fiber was failed.

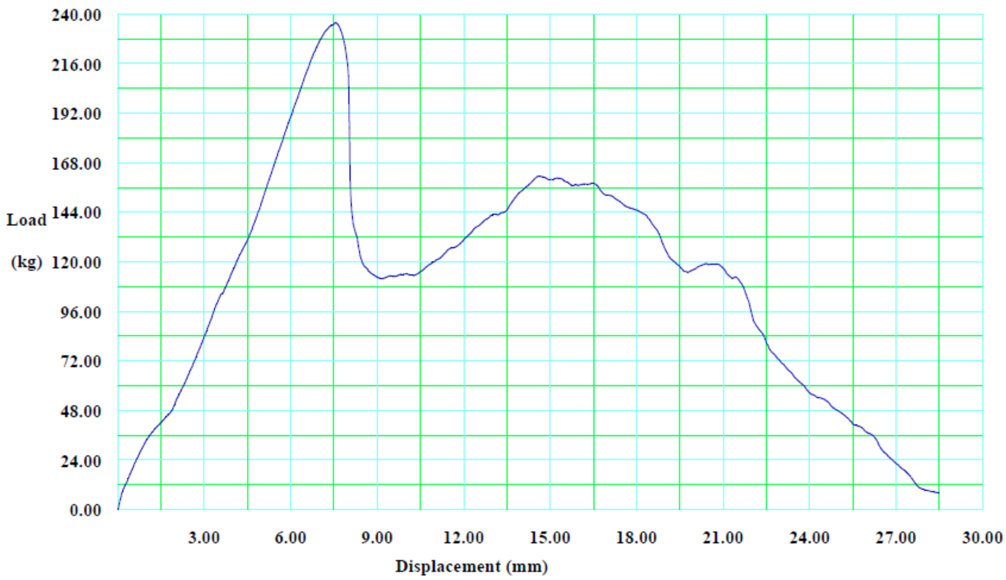

Figure 92Load Vs Displacement Double Carbon 3 hour Treated

Figure 92 shows the variation of load with respect to displacement under tensile testing. It can be observed that as the load increases displacement increases. It can be noticed that a load of 235.7 Kg, 3 hour cryogenically treated after next day double layer carbon fiber was failed.

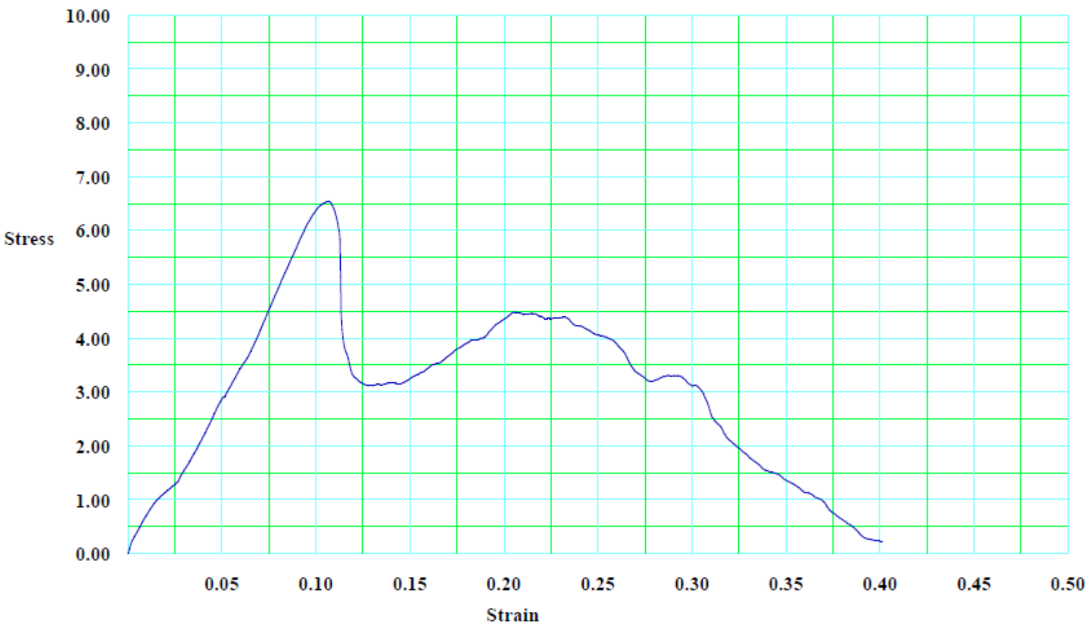

Figure 93 Stress Vs Strain Double Kevlar 3 hour Treated

Figure 93 shows the variation of stress with respect to strain under tensile testing. It can be observed that as the stress increases strain is found to increase. It can be noticed that at a stress of 6.547 Kg/mm^2, 3 hour cryogenically treated after next day double layer carbon fiber was failed.

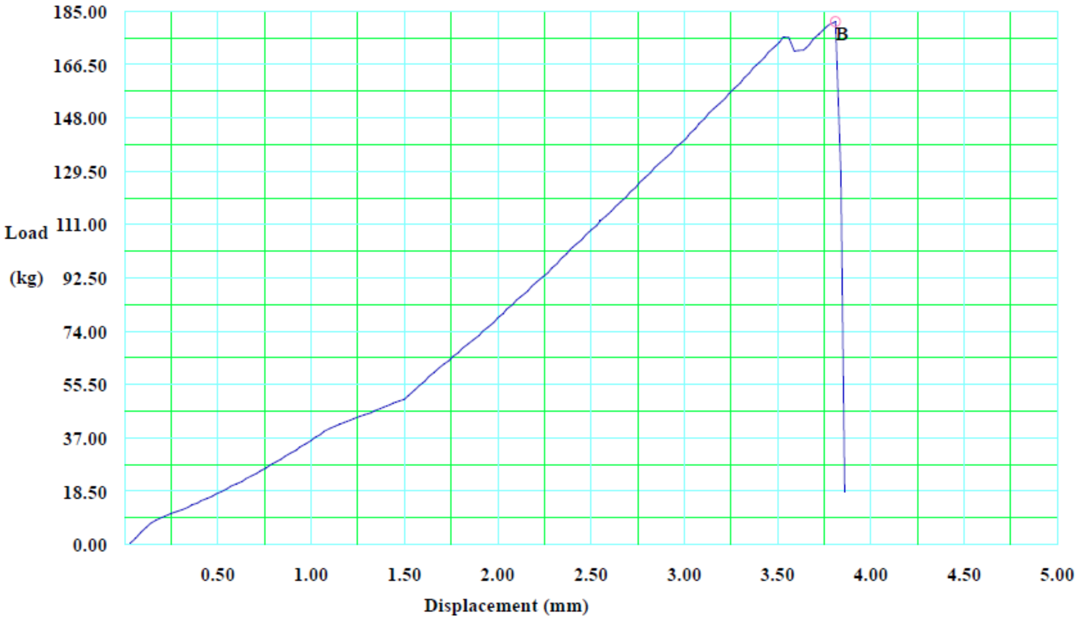

Figure 94 Load Vs Displacement Kevlar 3 hour Treated

Figure 94 shows the variation of load with respect to displacement under tensile testing. It can be observed that as the load increases displacement increases. It can be noticed that a load of 181.4 Kg, 3 hour cryogenically treated after next day single layer kevlar fiber was failed.

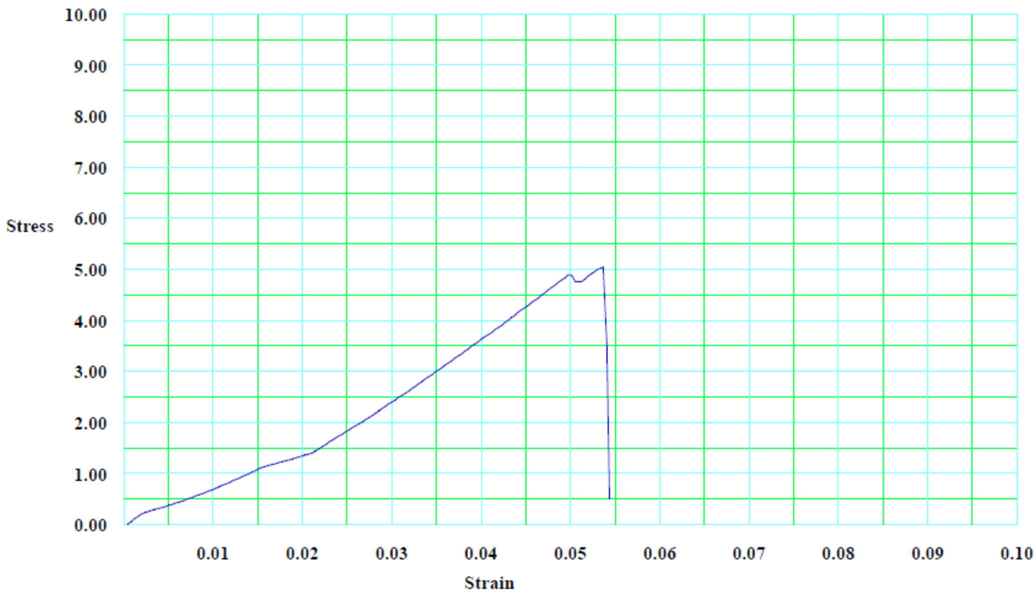

Figure 95Stress Vs Strain Kevlar 3 hour Treated

Figure 95 shows the variation of stress with respect to strain under tensile testing. It can be observed that as the stress increases strain is found to increase. It can be noticed that at a stress of 5.038 Kg/mm^2, 3 hour cryogenically treated after next day single layer kevlar fiber was failed.

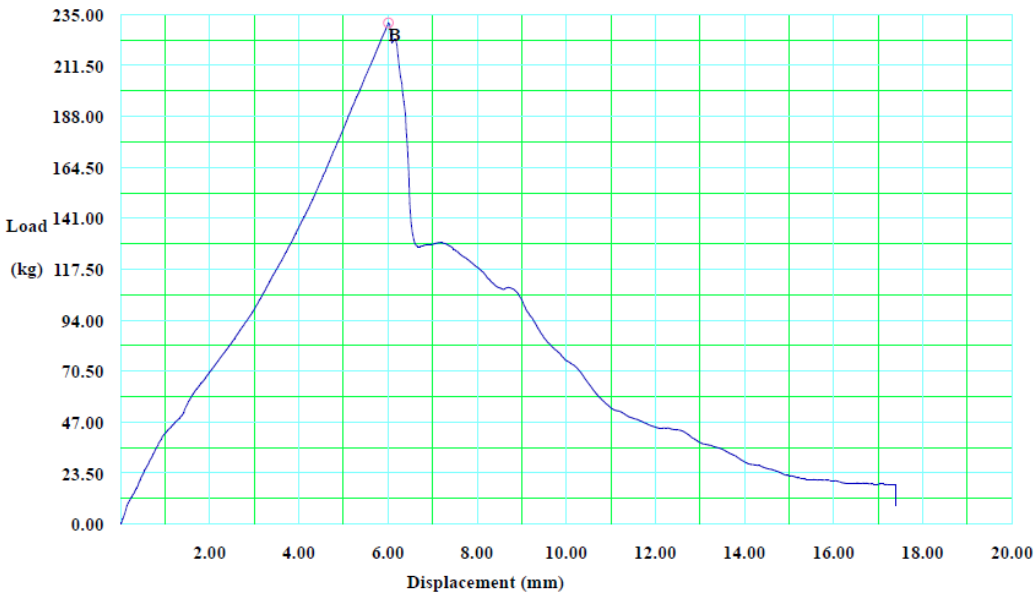

Figure 96 Load Vs Displacement Double Kevlar 3 hour Treated

Figure 96 shows the variation of load with respect to displacement under tensile testing. It can be observed that as the load increases displacement increases. It can be noticed that a load of 231.1 Kg, 3 hour cryogenically treated after next day double layer kevlar fiber was failed.

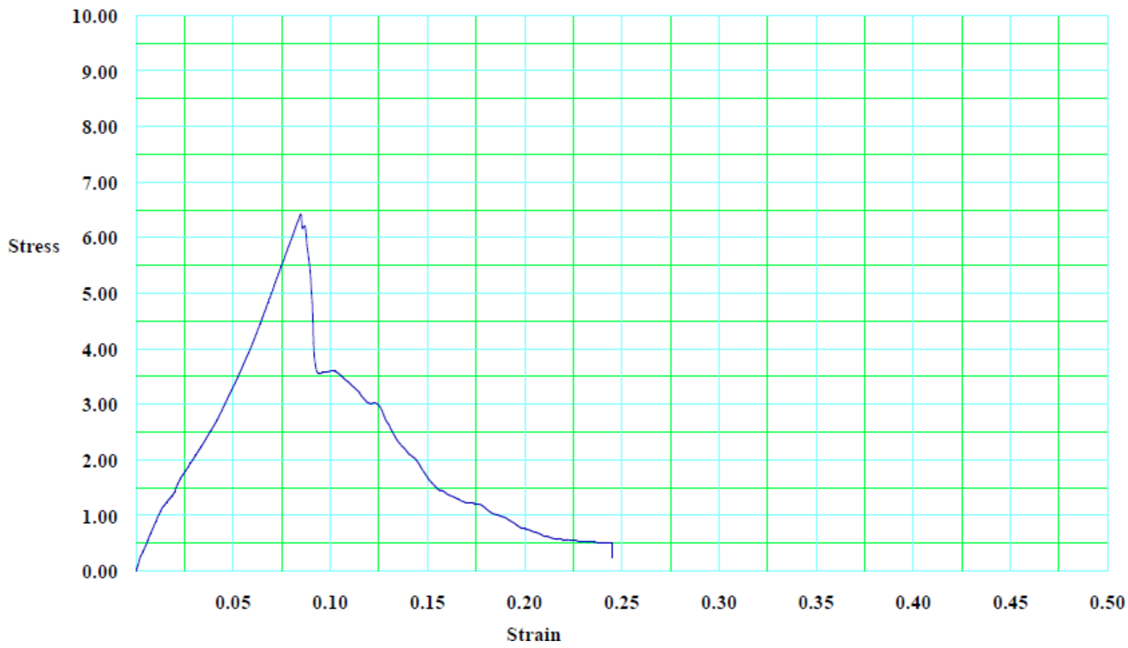

Figure 97 Stress Vs Strain Double Kevlar 3 hour Treated

Figure 97 shows the variation of stress with respect to strain under tensile testing. It can be observed that as the stress increases strain is found to increase. It can be noticed that at a stress of 6.419 Kg/mm^2, 3 hour cryogenically treated after next day double layer kevlar fiber was failed.

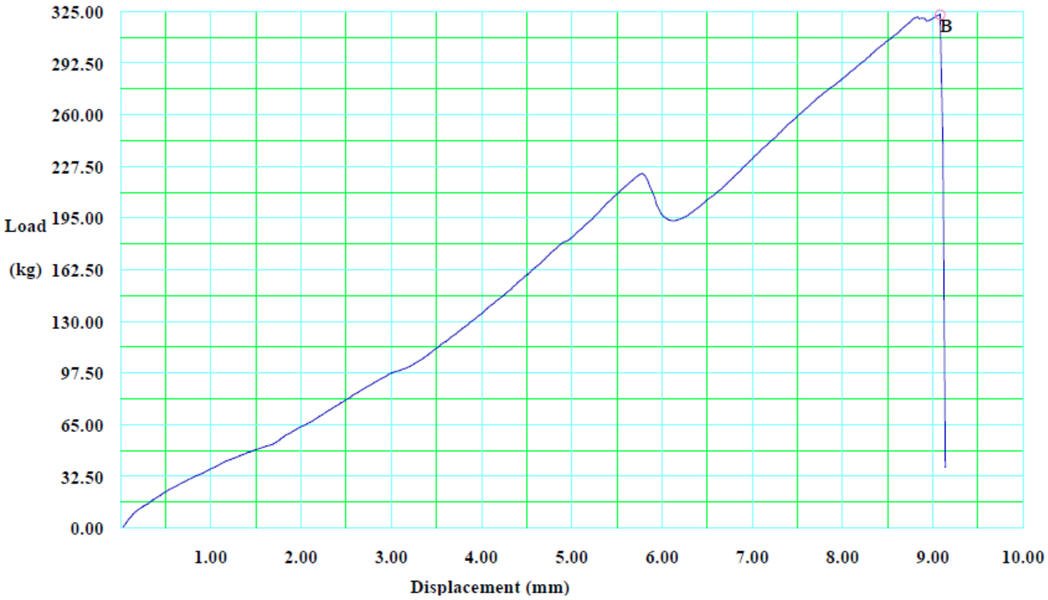

Figure 98 Load Vs Displacement Carbon Kevlar 3 hour Treated

Figure 98 shows the variation of load with respect to displacement under tensile testing. It can be observed that as the load increases displacement increases. It can be noticed that a load of 323 Kg, 3 hour cryogenically treated after next day carbon kevlar fiber was failed.

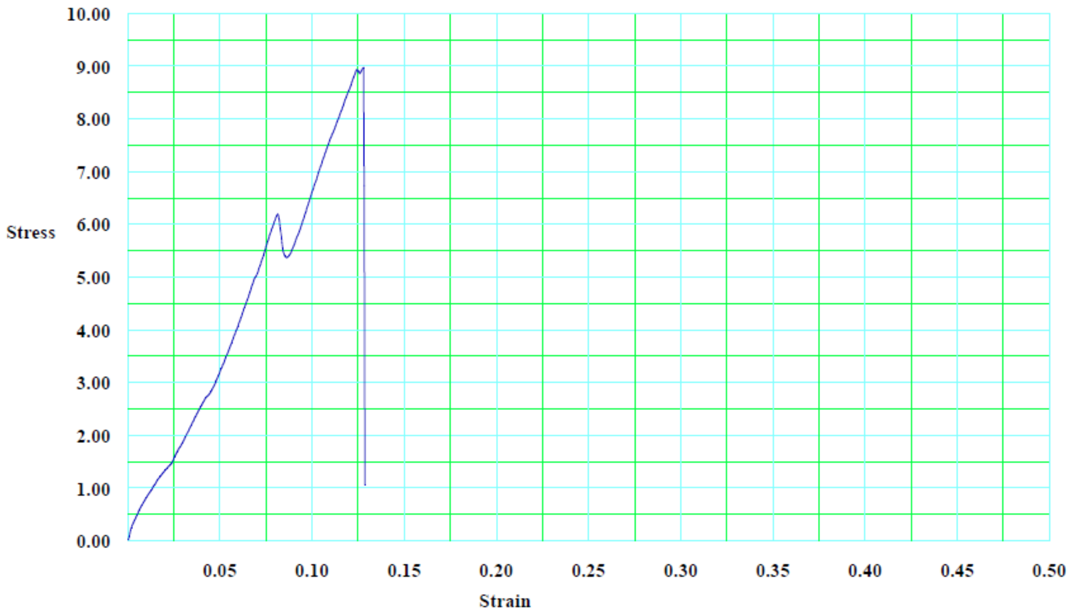

Figure 99Strss Vs Strain Carbon Kevlar 3 hour Treated

Figure 99 shows the variation of stress with respect to strain under tensile testing. It can be observed that as the stress increases strain is found to increase. It can be noticed that at a stress of 8.972 Kg/mm^2, 3 hour cryogenically treated after next day double layer carbon fiber was failed.

8 Experimental Work

8.1 Preparation of mold:-

For creating samples we need a mold of proper dimensions according to ASTM standards. We will prepare two different types of mold for 3-point testing and tensile testing

For 3 point bending test we are using ASTM 7264 i.e 32:1 length to thickness. According to this standard we have prepared a mould of 128mm length 4mm thickness and 20mm width. The mould was made by polycarbonate sheet. For smooth surface finishing the mould was cut by layer cutting. In a single plate 7 cutting was made for the samples

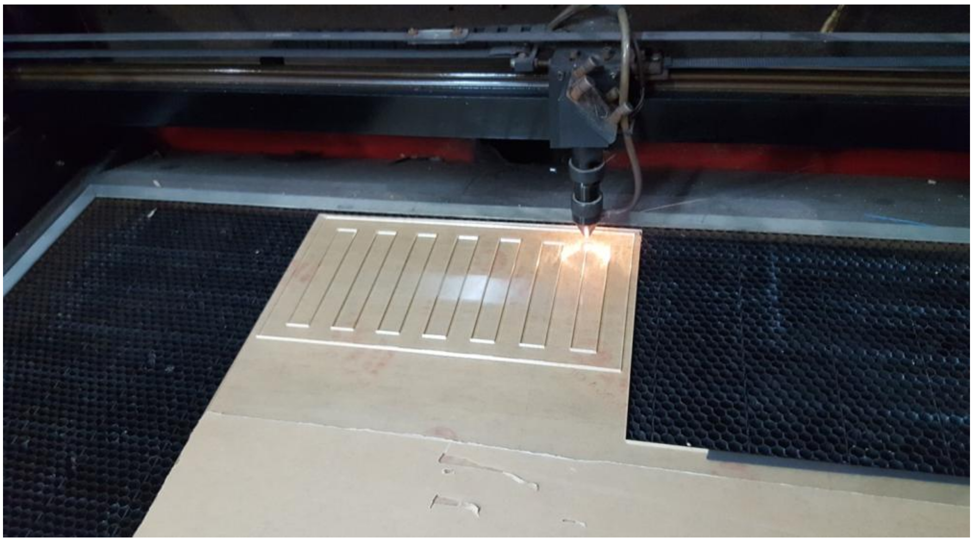

Figure 100 Mold Perpetration

8.2 Cutting of fibers:-

Marking was done on Carbon fiber and Kevlar fiber samples according to required size. A layer of tape or food wrap paper was past so that marking could be done upon them. The cutting was done by scissor.

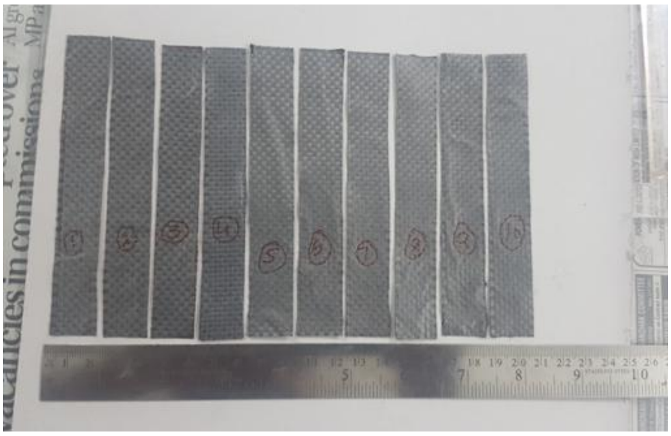

Figure 101 Cutting of Fibers

8.3 Preparation of epoxy:-

The epoxy was made my mixing resin and hardener in ration 100:30 by weight. Afterwards stir both the mixture vigorously for 10-15 minutes.

With the help of electronic digital scale weighing 100gm resin and 30gm hardener was stir vigorously until a proper single viscous solution is made.

a) Empty glass weight b) Glass weight with resin c)Glass weight with resin and hardener

Figure 102 Export Preparation

8.4 Sample perpetration:-

We have to prepare the samples of 3 point bending and tensile testing according to the ASTM standards. For preparing the samples we will use the polycarbonate sheet which is prepared by laser cutting.

A plain surface was used upon which the polycarbonate sheet was placed. The level of the surface was check by spirit level. The hole were made by using hand drill to be tightened by the 6mm long steel screw so that the epoxy should not get spread from one slots to other slots.

Figure 103 tightening the polycarbonate sheet

A layer of wax or oil courting was done with the help of brush all around the slots so that after curing samples can easily removed.

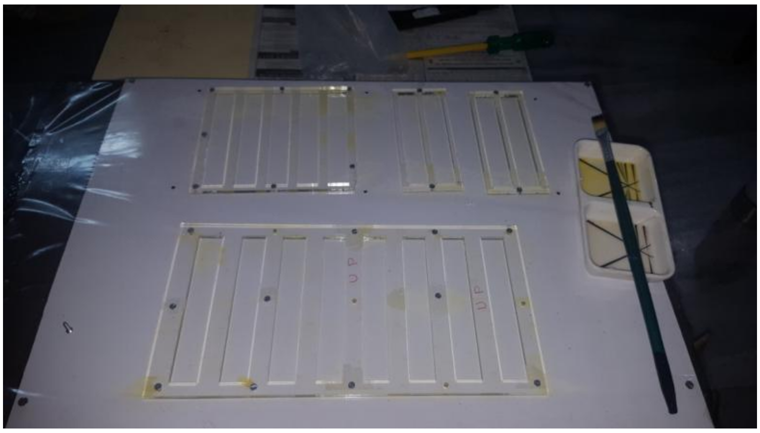

Figure 104Oil courting

A layer of epoxy was poured at the bottom of every slot. Afterwards the cutting of carbon fiber and kevlar fiber were place as per the requirement. Epoxy was filled on the top of the layer of every slot. It was kept at room temperature for 24 hours to get cure

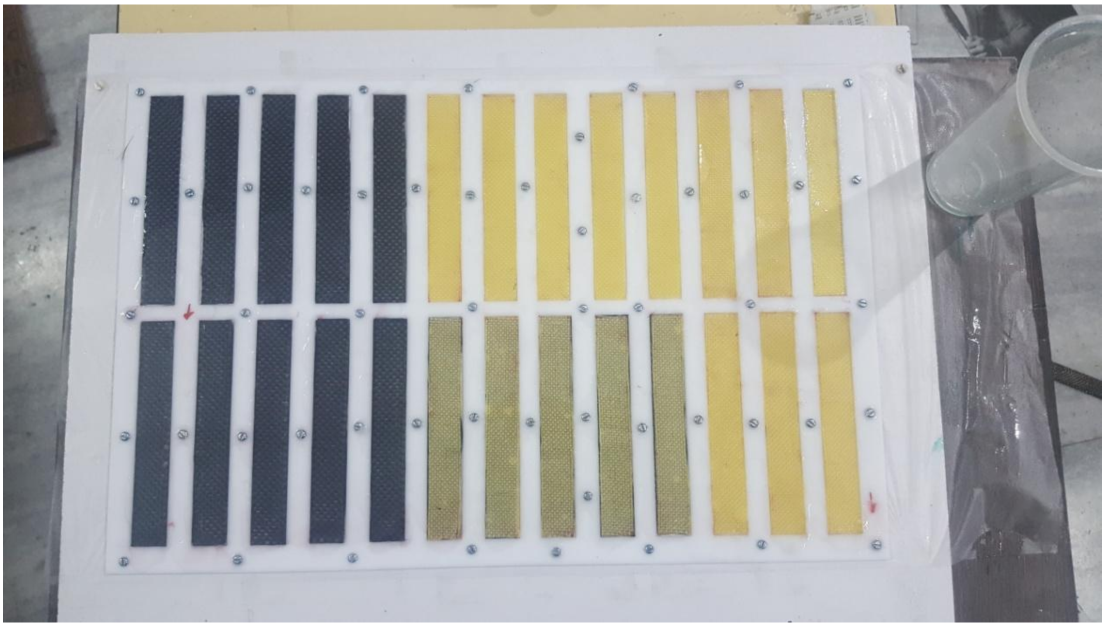

Figure 105 Curing of samples

After 24hour the epoxy was cure and the samples were removed from the polycarbonate sheet.

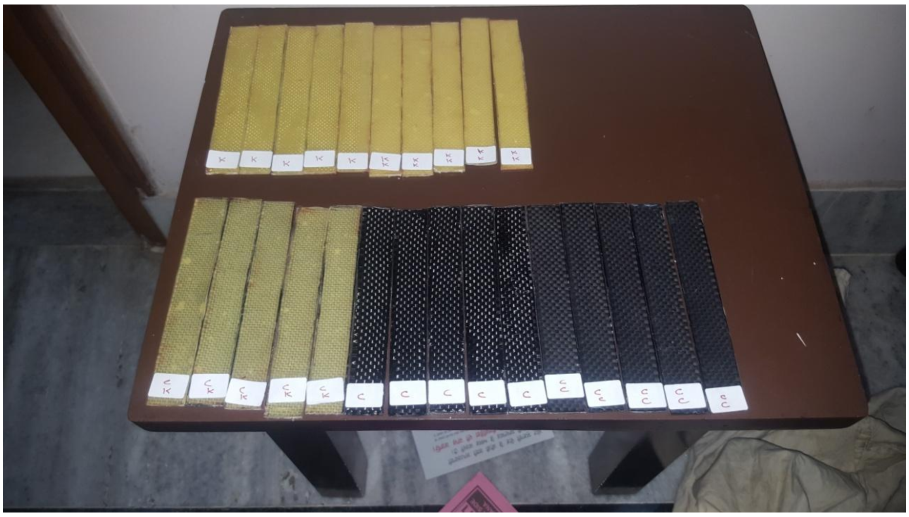

Figure 106 Samples

Universal Testing Machine for Composite Material was used for flexural and tensile testing. The graphs were generated with the help of software UTM 5.5.1 installed in the system attached to machine

Figure 107 Flexural & Tensile testing

Chapter 9

9 Conclusions and Future Scope

9.1 Conclusions

In case of Single Layer Carbon Fiber, the peak load capacity for flexural testing varies from 21.26 to 34.06 kg for untreated and immediate 3hr treated fiber respectively. There is an increase about 60% in peak load capacity.

In case of Double Layer Carbon Fiber, the peak load capacity for flexural testing various from 25.38 to 34.01 for untreated and 3 hour treated fiber respectively. There is an increase about 34% in peak load capacity.

In case of Carbon Kevlar Fiber, the peak load capacity for flexural testing various from 24.14 to 25.67 for untreated and after next day of 3 hour treated fiber respectively. There is an increase about 6% in peak load capacity.

In case of Single Layer Carbon Fiber, the peak load capacity for tensile testing various from 311.3 to 356.5 for untreated and after nest day of 1 hour treated fiber respectively. There is an increase about 14% in peak load capacity.

In case of Single Layer Kevlar Fabric, the peak load capacity for tensile testing various from 198 to 233.5 for untreated and immediate 1 hour treated fiber respectively. There is an increase about 18% in peak load capacity.

In case of Double Layer Kevlar Fabric, the peak load capacity for tensile testing various from 297.9 to 337.5 for untreated and immediate 1 hour treated fiber respectively. There is an increase about 13% in peak load capacity.

In case of Carbon Kevlar Fiber, the peak load capacity for tensile testing various from 300.3 to 353.7 for untreated and immediate 1 hour treated fiber respectively. There is an increase about 18% in peak load capacity.

9.2 Future Scope

- ✓ The composite materials with cryogenic treatment find applications in different fields of engineering. The technological advancements can be achieved with increasing the number of samples by arranging the layers of fiber layout.
- ✓ The time interval gap can also be changed with low time gaps in between
- ✓ We can use other fiber such as glass fibers to get the better outcome.
- ✓ Sudden change in temperature causes a damage to samples, in order to avoid such circumstances, one can do control cryogenic treatment in controlled environment.

REFERENCES

[1] Hong-xiao CHI, Dang-shen MA, Qi-long YONG, Li-zhi WU, Zhan-pu ZHANG, Yong-wei WANG, Effect of Cryogenic Treatment on Properties of Cr8-Type Cold Work Die Steel, Journal of Iron and Steel Research, International, Volume 17, Issue 6, June 2010, Pages 43-46, 59.

[2] Gang Wang, Kaixuan Gu, Zhongjia Huang, Pengfei Ding, Improving the wear resistance of as-sprayed WC coating by deep cryogenic treatment, Materials Letters, Volume 185, 15 December 2016, Pages 363-365.

[3] Mahdi Koneshlou, Kaveh Meshinchi Asl, Farzad Khomamizadeh, Effect of cryogenic treatment on microstructure, mechanical and wear behaviors of AISI H13 hot work tool steel, Cryogenics, Volume 51, Issue 1, January 2011, Pages 55-61.

[4] S. Zhirafar, A. Rezaeian, M. Pugh, Effect of cryogenic treatment on the mechanical properties of 4340 steel, Journal of Materials Processing Technology, Volume 186, Issues 1–3, 7 May 2007, Pages 298-303.

[5] A. Bensely, L. Shyamala, S. Harish, D. Mohan Lal, G. Nagarajan, Krzysztof Junik, A. Rajadurai, Fatigue behaviour and fracture mechanism of cryogenically treated En 353 steel, Materials & Design, Volume 30, Issue 8, September 2009, Pages 2955-2962.

[6] Flávio J. da Silva, Sinésio D. Franco, Álisson R. Machado, Emmanuel O. Ezugwu, Antônio M. Souza Jr., Performance of cryogenically treated HSS tools, Wear, Volume 261, Issues 5–6, 20 September 2006, Pages 674-685.

[7] Joel Hemanth, Tribological behavior of cryogenically treated B4Cp/Al–12% Si composites, Wear, Volume 258, Issues 11–12, June 2005, Pages 1732-1744.

[8] A. Idayan, A. Gnanavelbabu, K. Rajkumar, Influence of Deep Cryogenic Treatment on the Mechanical Properties of AISI 440C Bearing Steel, Procedia Engineering, Volume 97, 2014, Pages 1683-1691.

[9] S. Harish, A. Bensely, D. Mohan Lal, A. Rajadurai, Gyöngyvér B. Lenkey, Microstructural study of cryogenically treated En 31 bearing steel, Journal of Materials Processing Technology, Volume 209, Issue 7, 1 April 2009, Pages 3351-3357.

[10] Hadi Ghasemi Nanesa, Mohammad Jahazi, Alternative phase transformation path in cryogenically treated AISI D2 tool steel, Materials Science and Engineering: A, Volume 634, 14 May 2015, Pages 32-36.

[11] N.B. Dhokey, J. Dandawate, H. Gangurde, A. Harle, Metallurgical investigation of cryogenically cracked M35 tool steel, Engineering Failure Analysis, Volume 21, April 2012, Pages 52-58

[12] A. Akhbarizadeh, A. Shafyei, M.A. Golozar, Effects of cryogenic treatment on wear behavior of D6 tool steel, Materials & Design, Volume 30, Issue 8, September 2009, Pages 3259-3264.

[14] D. Das, A.K. Dutta, K.K. Ray, Correlation of microstructure with wear behaviour of deep cryogenically treated AISI D2 steel, Wear, Volume 267, Issues 9–10, 9 September 2009, Pages 1371-1380

[15] Guo Jia, Chen Liubiao, Gu Kaixuan, Wang Junjie, A Cryogenic Treatment System for Treating Large Rolls, Physics Procedia, Volume 67, 2015, Pages 367-372

[16] hen-hui XIE, Ji-wu HUANG, Yun-feng TANG, Li-ning GU, Effects of deep cryogenic treatment on microstructure and properties of WC–11Co cemented carbides with various carbon contents, Transactions of Nonferrous Metals Society of China, Volume 25, Issue 9, September 2015, Pages 3023-3028.

[17] Yinnan Zhang, Fujun Xu, Chuyang Zhang, Junjie Wang, Zhemin Jia, David Hui, Yiping Qiu, Tensile and interfacial properties of polyacrylonitrile-based carbon fiber

after different cryogenic treated condition, Composites Part B: Engineering, Volume 99, 15 August 2016, Pages 358-365

[18] Fujun Xu, Wangxizi Fan, Yinnan Zhang, Yang Gao, Zhemin Jia, Yiping Qiu, David Hui, Modification of tensile, wear and interfacial properties of Kevlar fibers under cryogenic treatment, Composites Part B: Engineering, Volume 116, 1 May 2017, Pages 398-405

[19] Yiqin Shao, Fujun Xu, Wei Liu, Mengjie Zhou, Wei Li, David Hui, Yiping Qiu, Influence of cryogenic treatment on mechanical and interfacial properties of carbon nanotube fiber /bisphenol-F epoxy composite, Composites Part B: Engineering, Available online 31 May 2017, ISSN 1359-8368

[20] M. Araghchi, H. Mansouri, R. Vafaei, Yina Guo, A novel cryogenic treatment for reduction of residual stresses in 2024 aluminum alloy, Materials Science and Engineering: A, Volume 689, 24 March 2017, Pages 48-52.

[21] B. Podgornik, I. Paulin, B. Zajec, S. Jacobson, V. Leskovšek, Deep cryogenic treatment of tool steels, Journal of Materials Processing Technology, Volume 229, March 2016, Pages 398-406.

[22] Sirui Fu, Bowen Yu, Lingyan Duan, Hongwei Bai, Feng Chen, Ke Wang, Hua Deng, Qin Zhang, Qiang Fu, Combined effect of interfacial strength and fiber orientation on mechanical performance of short Kevlar fiber reinforced olefin block copolymer, Composites Science and Technology, Volume 108, 25 February 2015, Pages 23-31

[23] Rongxian Ou, Hui Zhao, Shujuan Sui, Yongming Song, Qingwen Wang, Reinforcing effects of Kevlar fiber on the mechanical properties of wood-flour/high-density-polyethylene composites, Composites Part A: Applied Science and Manufacturing, Volume 41, Issue 9, September 2010, Pages 1272-1278