Experimental Study of effect of Temperature on Mechanical Properties of Rachis Fibre Composite

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Abstract

The results demonstrate that the mechanical performance of the peacock's feather shaft has been refined through multiple structural adaptations. This research is expected to enhance our understanding of nature-inspired structure–The main goal of this research is to effectively harness the inherent properties of natural fibres in composite with polymer resins. The study investigates the effect of temperature on distinctive mechanical characteristics of the peacock feather shaft, with particular emphasis on the influence of temperature on this composite structure. The feather shaft has naturally evolved to be lightweight while achieving an optimal balance between strength and flexibility. A comprehensive analysis is conducted on the hierarchical architecture of the peacock's tail feather shaft and its components, including variations in geometry and material composition. In addition, the study examines the mechanisms responsible for strength enhancement, stiffness, and toughness, as well as the deformation and failure behaviour of the feather shaft property relationships and support the development of advanced synthetic composites and high-performance materials for future applications.

Key Words – Effect of temperature on composite, Rachis Fibre, Natural Composite Fibre, Composite Fibre, Peacock Feather Rachis Fibre, Mechanical Properties of Natural Fibre.

1. **Introduction -** A composite material consists of two or more distinct materials combined at the microscopic level, each possessing different chemical characteristics. This combination produces a material that is heterogeneous on a microscopic scale but appears uniform when viewed macroscopically. It is important to differentiate composite materials from alloys or metals containing impurities. In alloys, the individual constituents cannot be distinguished in a cross-sectional view, whereas in composites, the individual components and their interfaces can be clearly identified.

According to the ASTM guidelines, a composite material is defined as an engineering material formed from two or more insoluble constituents that together exhibit properties unattainable by any of the components alone. This definition highlights the critical role of interaction between the constituent materials and clearly distinguishes composites from alloys and impurity-containing metals.

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- One way to classify composites is by their reinforcing phases, which fall into three main types:

a) Fibre-reinforced composites
b) Flake reinforced composites
c) Particle reinforced composites

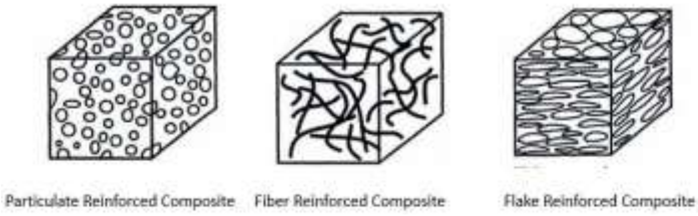
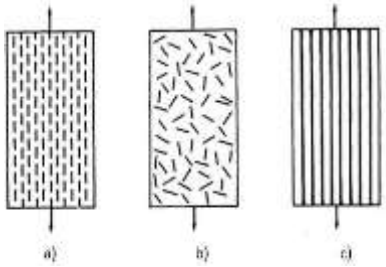


Figure 1.1: Classification of a composite according to the structure of reinforcement used

- The other way of classification of composite material is on the basis of physical structure and geometry are classified into three types and are shown in fig - 1.2:

1. Discontinuous Fibres (Unidirectional)
2. Discontinuous Fibres (Randomly Arranged)
3. Continuous Parallel

Figure 1.2: a) Discontinuous fibres (unidirectional) b) Discontinuous fibres (random) c) Continuous fibres



- **Natural Fibers -** In a fibre-reinforced composite material, fibres are the main components. They make up the majority of the composite's volume and bear most of the load on the structure. Choosing the right type of fibre, the correct volume fraction, length, and orientation is crucial, as it impacts important characteristics such as density, tensile, modulus, fatigue strength, compressive, flexural strength, electrical and thermal conductivities.
Types of fibres especially natural fibres on the basis of their sources are mentioned below in the figure – 1.3

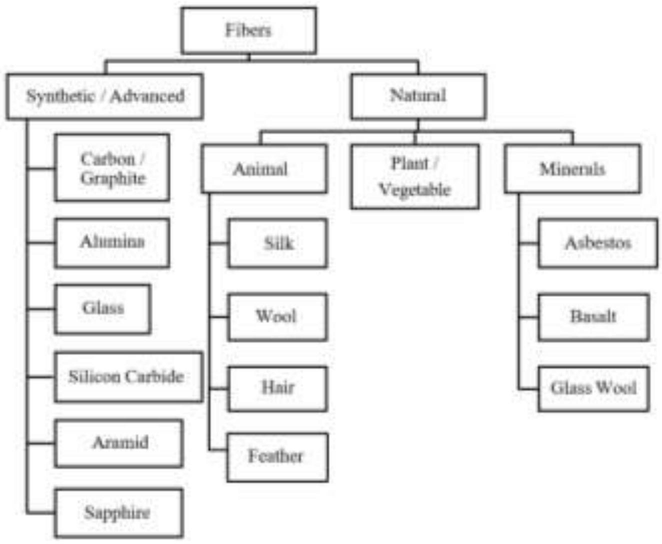


Figure 1.3: Classification of Fibres on the basis of source

- **Structure of Natural Fibre –**

Natural fibres are composed of five main structural constituents: cellulose microfibrils (fibres), hemicellulose (primary wall), lignin (non-crystalline region), pectin, and waxes (cuticle). Cellulose is a natural polymer made up of repeating D-anhydroglucose units. Hemicellulose consists of a group of polysaccharides that form five- and six-carbon ring sugars. Lignin is a complex, hydrophobic, and insoluble hydrocarbon polymer, while pectin comprises a class of heteropolysaccharides. Waxes are made up of various types of alcohols.

Functionally, natural fibres behave as composite materials, where amorphous substances such as hemicellulose, pectin, and wax serve as a matrix that binds the cellulose microfibrils together. Hemicellulose forms hydrogen bonds with the microfibrillar cellulose and acts as a binding agent, whereas lignin functions as a coupling component that enhances the stiffness of the cellulose–hemicellulose composite

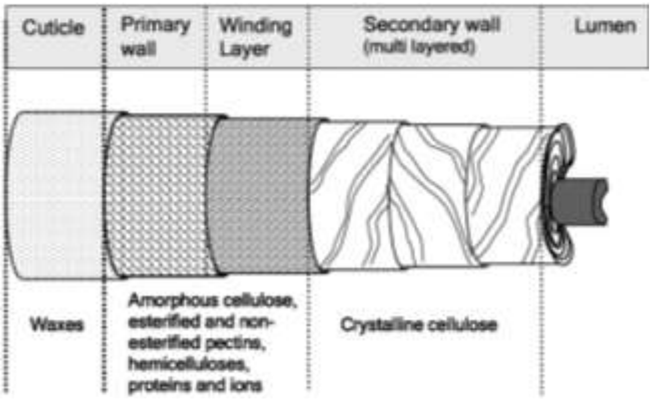


Figure 1.4: Structure of General Natural Fibre

- **Peacock Feather Fibre -** Lightweight cellular solids or foams and foam-filled structures have attracted great attention owing to their unique properties, such as outstanding kinetic energy absorption efficiency from impacts, high strength-to-density ratio, and good insulation ability. The fibre of this feather is collected from the shell of the Rachis only, in this fibre the filled foamy, soft and spongy part has not been taken. The source of the fibre has been shown in figure below.

Figure 1.5: Peacock Feather Fibre

2. Material and Methodology-

This chapter contains all the details about the experimental procedure and materials that were considered for the fabrication of the composite and the test procedure followed for testing.

2.1 Materials –

The raw materials used for fabrication are as follows-

a) Peacock Rachis Fibre
b) Epoxy Resin
c) Hardener

a) Peacock Rachis Fibre -

Naturally shed tail coverts, measuring around 100-105 cm in length, were purchased from a local farm at a price of 5 Rs per piece. The feather shafts were extracted by removing the vanes of the feathers. The colorful, delicate sections of the feathers were then cut off, and the top layer of fibers, which resembled plastic and were either white or sometimes transparent, was peeled away. This layer, which had no use in the composite material, coated a foam-like structure. The remaining fibers were then cut to an appropriate length based on the size of the testing specimen.

b) Epoxy Resin-

Epoxy resin is a type of reactive polymer and prepolymer that contains epoxide groups. These resins can react either with themselves, facilitated by catalysts, or with various co-reactants such as amines, thiols, and phenols. Epoxy resin is widely used across various applications, processes, and industries due to its superior mechanical properties, as well as its enhanced resistance to heat and chemicals compared to other resins. As a result, it is particularly suited for manufacturing aircraft components. Epoxy resin is also known as polyepoxides. I have used Araldite Xin.

c) Hardener –

A hardener is used along with the epoxy resin in order to make it solidify. It is also a liquid part that mixes in a proper proportion with the epoxy and lets it remain in a steady state to get it solidified. After mixing the hardener with the epoxy, it will be solidified within the period mentioned in the description and will be transparent in nature. There are many different kinds of hardeners based on chemical compositions. In this composite, I have used sulfur thiol hardener.

Figure 2.1: Epoxy Resin and Hardener

2.2 Preparation of Test Specimen

We can divide the composite preparation into three broader tasks which are-

2.2.1 Preparation of required Fibers
2.2.2 Preparation of Mould
2.2.3 Preparation of Epoxy-Resin mixture

a) Preparation of fibres -

First, remove the colorful, delicate sections of the feather—while these parts are visually appealing, they are not needed for our purpose. Next, peel away the white, plastic-like fibrous layer. The remaining interior portion of the feather resembles a soft, cushioning material. Finally, cut the long white fibers into smaller pieces, sized according to the requirements.

b) Preparation of mould –

First, cut the iron sheet into long strips according to the dimensions of the specimen. Then, join these pieces together using nails or adhesive. To create a leak-proof mold, I lined the sheet with non-adhesive lubricant and coated it with wax or oil. This prevents the mold from sticking to or bonding with the composite material.

Figure 2.2: Mould

c) Preparation of Specimen –

Pour the epoxy resin into a container and measure its weight. Then, add the hardener in a ratio of one-third of the epoxy's weight, as specified in the epoxy resin instructions. Ensure this ratio is maintained throughout the mixture. Stir the solution for about 5 minutes until it becomes a nearly homogeneous, transparent mixture.

Next, pour the epoxy-resin mixture into the mold and carefully place the fibers into it. Align all the fibers parallel to each other, ensuring they are positioned longitudinally.

Figure 2.3: Preparation of Specimen

2.3 Testing of specimen-

a) Tensile testing –

ASTM D3039 tensile testing is used to measure the force required to break a polymer composite specimen and the extent to which the specimen stretches or elongates to that breaking point. Tensile tests produce a stress-strain diagram, which is used to determine tensile modulus.

The dimensions of the specimen are Length (L) = 240mm
Breadth (b) = 25mm and Thickness/Depth (t/d) = 25mm.

A typical test speed for standard test specimens is 2 mm/min (0.05 in/min). An extensometer or strain gauge is used to determine elongation and tensile modulus. For ASTM D3039 the test speed can be determined by the material specification or time to failure (1 to 10 minutes).

The specimens may fail if the load keeps on increasing after an ultimate tensile point. The tensile test arrangement is shown in Figure 2.4

Figure 2.4: Tensile Test

b) Flexural Testing –

Bending test in composite materials is used to determine the flexural strength and stiffness of a solid laminate or sandwich construction. The specimen is loaded in a horizontal position in a three-point or four- point loading configuration in a flexural test. The test fixture has a support point near each edge of the beam and a loading nose with one (third-point loading) or two (four-point loading) configurations, Length (L) = 240mm, Breadth (b) = 25mm and Depth/Thickness (d/t) = 15mm. The Flexural test arrangement is shown in Figure 2.4

Figure 2.4: Flexural Test

3. Result and Analysis –

This section shows the result of different test which performed on several specimens, including tensile and flexural test. All test were performed under controlled circumstances and with precise and latest technical machinery.

3.1 Tensile Testing –

The results which are obtained from the Tensile strength test, on the UTM (Universal Testing Machine) machine. These results are calculated based on the graphs produced by UTM between the load and elongation. In the Load-Elongation curve, the load is on the y- axis and elongation is on the x-axis. The results are shown in the table below.

3.1.1 Tensile Testing of Specimen at 50° Celsius-

- **S-1 (a)**
- Cross-Section Area = 625.15 mm^2
- Peak Load (P_1) = 6.681 KN
- Ultimate Tensile Stress (σu) = 10.687 MPa
- Yield Stress (σy) = 3.170 MPa
- Strain at Ultimate Strength point (ε_1) = 0.02
- Maximum Elongation = (δ_1) = 4.60 mm
- Young’s Modulus/Modulus of Elasticity = E_1 = 534.4133 MPa

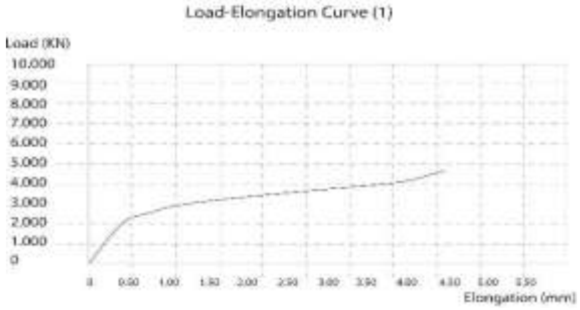


Figure 3.1: Load-Elongation curve of tensile test for Specimen- S-1 (a) at 50 Degree Celsius

❖ **S-1 (b)**

From the below graph we can draw following important points-

- Cross-Section Area = 623.50 mm^2
- Peak Load (P_2) = 6.552 KN
- Ultimate Tensile Stress (σu) = 10.51 MPa
- Yield Stress (σy) = 3.09 MPa
- Strain at Ultimate Strength point (ε_2) = 0.01875
- Maximum Elongation = (δ_2) = 4.48 mm
- Young's Modulus/Modulus of Elasticity = E_2 = 560.268 MPa

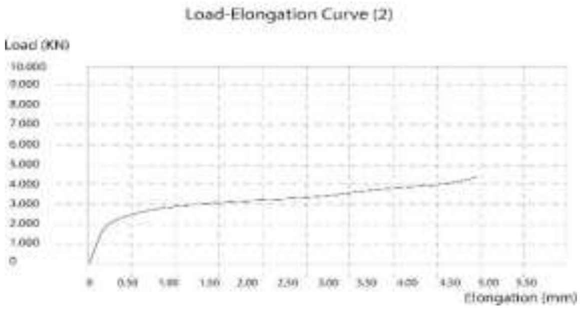


Figure 3.2: Load-Elongation curve of tensile test for Specimen- - S-1 (b) at 50 Degree Celsius

3.1.2 Tensile Testing of Specimen at room Temperature-

❖ **S-2 (a)**

From the below graph following important points can be noted-

- Cross-Section Area = 625.25 mm^2
- Peak Load (P_3) = 6.901 KN
- Ultimate Tensile Stress (σu) = 11.013 MPa
- Yield Stress (σy) = 3.15MPa
- Strain at Ultimate Strength point (ε_3) = 0.01870
- Maximum Elongation = (δ_3) = 4.55 mm
- Young's Modulus/Modulus of Elasticity

= E_3 = 588.913 MPa

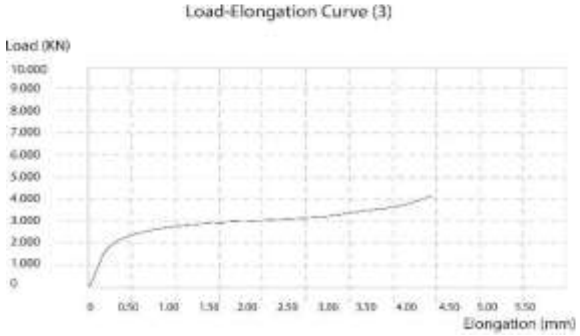


Figure 3.3: Load-Elongation curve of tensile test for Specimen- - S-2 (a) at Room Temperature

❖ **S-2 (b)**

From the below data points following important points can be noted-

- Cross-Section Area = 625.86 mm^2
- Peak Load (P4) = 6.940 KN
- Ultimate Tensile Stress (σu) = 11.016 MPa
- Yield Stress (σy) = 2.772 MPa
- Strain at Ultimate Strength point (ε4) = 0.0204
- Maximum Elongation = (δ4) = 4.88 mm
- Young's Modulus/Modulus of Elasticity

= E4 = 540.00 MPa

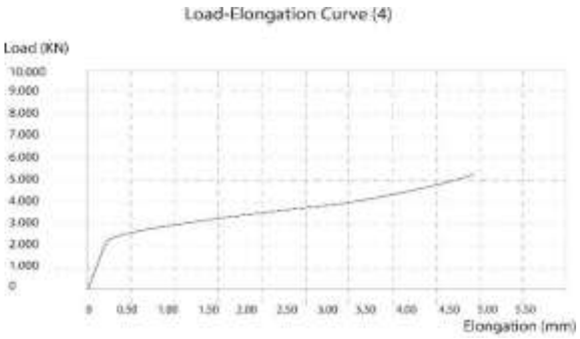


Figure 3.4: Load-Elongation curve of tensile test for Specimen- - S-2 (b) at Room Temperature

3.1.3 Tensile Testing of Specimen at 0° Celsius-

❖ **S-3 (a)**

❖ From the below graph following important points can be noted-

- Cross-Section Area = 625.00 mm^2
- Peak Load (P3) = 7.140 KN
- Ultimate Tensile Stress (σu) = 11.424 MPa
- Yield Stress (σy) = 2.856 MPa
- Strain at Ultimate Strength point (ε3) = 0.01860

- Maximum Elongation = (δ3) = 4.45 mm
- Young's Modulus/Modulus of Elasticity

= E3 = 614.19 MPa

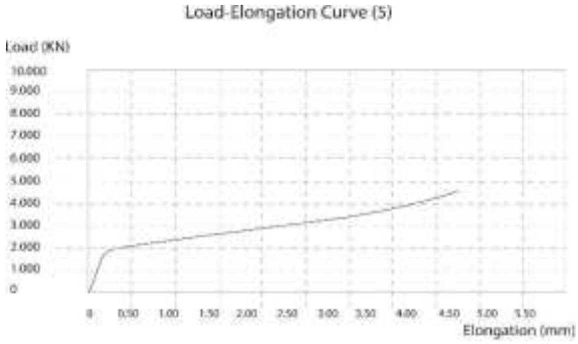


Figure 3.5: Load-Elongation curve of tensile test for Specimen- - S-3 (a) at Zero Degree Celsius

❖ **S-3 (b)**

From the below data points following important points can be noted-

- Cross-Section Area = 625.35 mm^2
- Peak Load (P4) = 7.223 KN
- Ultimate Tensile Stress (σu) = 11.55 MPa
- Yield Stress (σy) = 2.88 MPa
- Strain at Ultimate Strength point (ε4) = 0.022
- Maximum Elongation = (δ4) = 4.92 mm
- Young's Modulus/Modulus of Elasticity

= E4 = 525.015 MPa

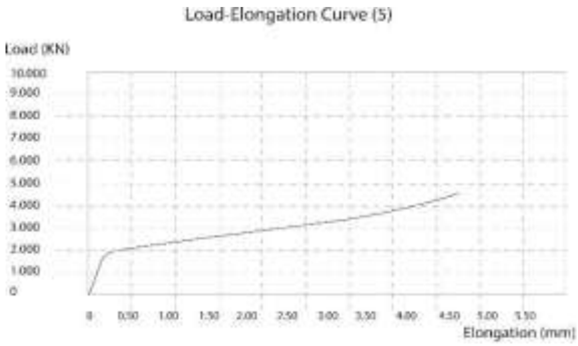


Figure 3.6: Load-Elongation curve of tensile test for Specimen- S-3 (b) at Zero Degree Celsius

The values for cross-sections area (C.S.A.), Length (L), Ultimate Tensile Stress (T.S), Change in length and Young's Modulus (E) are mentioned below in table – 3.1

3.2 Final Average values derived from the tensile test results-

The average values of all the parameters and properties obtained from different specimens and their testing has to be calculated to get the approximated better and precise result are calculated below-

3.2.1 Average value of Tensile Testing of Specimen at 50° Celsius-

- Average cross-section Area (CSA)=624.3 mm^2
- Average peak load = 6.616 KN
- Average Yield Tensile Stress = (σ_y) = 3.13 MPa
- Average Ultimate Tensile Stress = (σ_u) = 10.5985 MPa
- Average elongation (δ) = 4.54 mm
- Average strain (ε) = 0.01935
- Average modulus of elasticity (E) =574.34 MPa

3.2.2 Average value of Tensile Testing of Specimen at Room Temperature -

- Average cross-section Area (CSA)= 625.55 mm^2
- Average peak load = 6.920 KN
- Average Yield Tensile Stress = (σ_y) = 2.961 MPa
- Average Ultimate Tensile Stress = (σ_u) = 11.0145 MPa
- Average elongation (δ) = 4.715 mm
- Average strain (ε) = 0.01955
-
- Average modulus of elasticity (E) = 564.4565 MPa

3.2.3 Average value of Tensile Testing of Specimen at 0° Celsius-

- Average cross-section Area (CSA)=625.17mm^2
- Average peak load = 7.1815 KN
- Average Yield Tensile Stress = (σ_y) = 2.868 MPa
- Average Ultimate Tensile Stress = (σ_u) = 11.487 MPa
- Average elongation (δ) = 4.685 mm
- Average strain (ε) = 0.0203
- Average modulus of elasticity (E) = 569.6025 MPa

3.3 Flexural testing-

Flexural strength is the measure of a material’s property to resist The Flexural is a combination of three properties: Tensile, Compression and Shear, All three loads act on the component simultaneously and tend to fail, much earlier to its yielding point.

❖ **Specimen F-1**

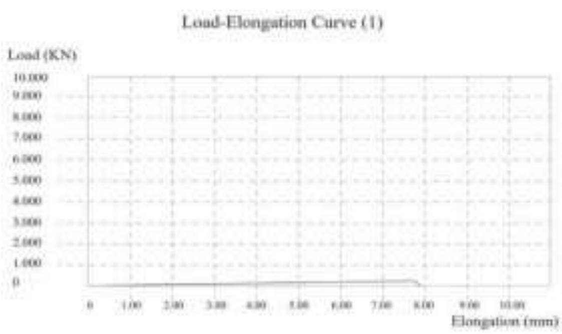


Figure 3.7: Load-Elongation Curve for Flexural Test (F-1) Specimen

Data which can be interpreted from the given graph.

- Peak Flexural Force (Fm) = 665 N
- Flexural Stress (σF) = 106.4 MPa
- Flexural Modulus (Ef) = 7526.50
- MPa Deflection (y) = 7.8mm

❖ **Specimen F-2**

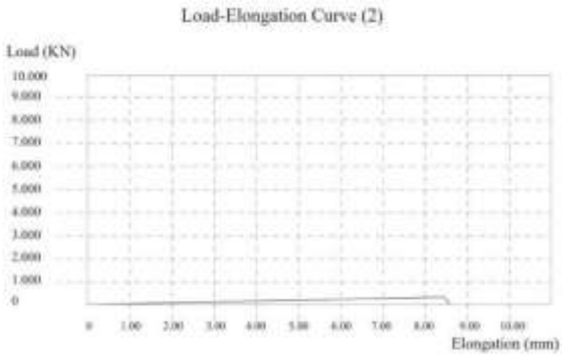


Figure 3.8: Load-Elongation Curve for Flexural Test (F-2) Specimen

Data which can be interpreted from the given graph.

- Peak Flexural Force (Fm) = 788 N
- Flexural Stress (σF) = 126.08 MPa
- Flexural Modulus (Ef) = 7825.37 MPa
- MPa Deflection (y) = 8.5mm

❖ **Specimen F-3**

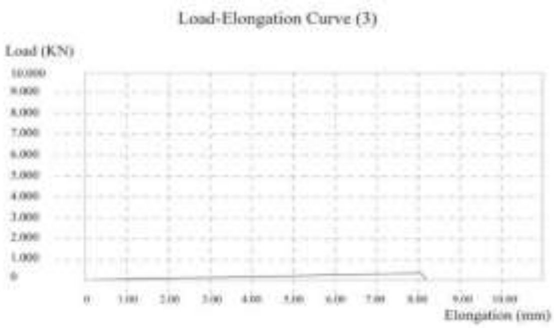


Figure 3.9: Load-Elongation Curve for Flexural Test (F-3) Specimen

Data which can be interpreted from the given graph.

- Peak Flexural Force (Fm) = 1075 N
- Flexural Stress (σF) = 172.0 MPa
- Flexural Modulus (Ef) = 7911.35 MPa
- Deflection (y) = 8.2 mm

4. Conclusion-

- Average elongation of specimen at 50 degree is 3.85% less than specimen at 25 degree and 3.19% less than the specimen at zero degree Celsius casted.

- Modulus of elasticity of 50 degree casted specimen is 1.75% higher than the specimen casted at 25 degree and 0.83% higher than specimen casted at Zero degree celsius.

- Peak load capacity of Zero degree specimen is 4.59% higher than specimen at 25 degree and 7.88% higher than specimen at fifty degree casted and maintained.
- The material is **Brittle in nature** according to the stress-strain curve.

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