International Journal of Scientific Research and Modern Technology (IJSRMT) ijsrmt.com
Volume 3, Issue 12, 2024
DOI: https://doi.org/10.5281/zenodo.14608479

Measurement of Strength Property of Finger Root Natural Fibre Reinforced Polymer Composite

Ibeawuchi Matthew Ebika[1]

Ogbonna George Ekwueme[2]

Prince Kelechi Uwaga[3]

Uzodinma B. Ogbuagu[4]

A research based project submitted to the department of civil engineering college of engineering and engineering technology, Michael Okpara University of Agriculture, Umudike, Abia state.

In partial fufilment for the requirements for the award of bachelor of engineering (B.Eng) degeree in civil engineering

Publication Date: 2025/01/13

Ebika, I. M., EKWUEME, O. G., UWAGA, P. K., & OGBUAGU, U. B. (2025). Measurement of Strength Property of Finger Root Natural Fibre Reinforced Polymer Composite. *International Journal of Scientific Research and Modern Technology*, *3*(12), 72–105. https://doi.org/10.5281/zenodo.14608479

TABLE OF CONTENT

ABSTRACT

This research investigates the mechanical properties of finger-root natural fiber-reinforced polymer composites (FRPC) for potential use in construction and other structural applications. The study explores the extraction, pre-treatment, and chemical modification of finger-root fibers to enhance compatibility with polyester resin. Key mechanical properties, including tensile strength, flexural strength, and creep behavior, were evaluated experimentally using standard ASTM methods. Results show that treated fibers exhibited improved tensile strength (79.6 N/mm^2) compared to untreated fibers, with minimal creep deformation (2.0870e-004 sec^{-1}), highlighting their suitability for load-bearing applications. The findings suggest that finger-root fibers, as renewable and low-cost reinforcements, offer a sustainable alternative to synthetic fibers like glass and carbon. These composites demonstrate potential for reducing structural self-weight, promoting eco-friendly practices, and lowering production costs in the construction industry. Recommendations are made for future applications and optimization in industrial-scale production.

CHAPTER ONE
INTRODUCTION

The construction industry is revolutionizing in two ways: One way is the development of construction techniques, such as using automated tool in construction. The other is the advancement in high-performance construction materials, such as the introduction of high strength concrete. Among these high-performance materials is composites made from fibre reinforced polymer (FRP), which is gradually gaining acceptance from civil engineers. In the past decades, research and development of fibers and matrix materials and fabrication process related to construction industry have grown rapidly. Their advantages over other traditional construction materials are their high tensile strength to weight ratio, ability to be molded into various shapes, and potential resistance to environmental conditions, resulting in potentially low maintenance cost. These properties make FRP composite a good alternative for innovative construction. (Chakrapan, 2004).

Fibre-reinforced plastic (FRP) (also fibre-reinforced polymer) is a composite material made of a polymer matrix reinforced with fibres. The fibres are usually glass, carbon, basalt or aramid, although other fibres such as paper or wood or asbestos have been sometimes used. The polymer is usually an epoxy, vinylester or polyester thermosetting plastic, and phenol formaldehyde resins are still in use. FRPs are commonly used in the aerospace, automotive, marine, construction industries and ballistic armor.

A. Origin

Polymer composites have enjoyed widespread use in the construction industry for many years in non-critical applications such as baths and vanities, cladding, decoration and finishing. In 1999, the construction sector was the world's second largest consumer of polymer composites representing 35% of the global market (Weaver, 1999).

Global polymer production on the scale present today began in the mid-20th century, when low material and productions costs, new production technologies and new product categories combined to make polymer production economical. The industry finally matured in the late 1970s when world polymer production surpassed that of Steel, making polymers the ubiquitous material that it is today. Fibre-reinforced plastics have been a significant aspect of this industry from the beginning. There are three important categories of fibre used in FRP, glass, carbon, and aramid.

Carbon fibre production began in the late 1950s and was used, though not widely, in British industry beginning in the early 1960s, aramid fibres were being produced around this time also, appearing first under the trade name Nomex by DuPont. Today each of these fibres is used widely in industry for any applications that require plastics with specific strength or elastic qualities. Glass fibres are the most common across all industries, although carbon-fibre and carbon-fibre-aramid composites are widely found in aerospace, automotive and sporting good applications. (Erhard, 2006).

B. Background of Study

Polymer composites are multi-phase materials produced by combining polymer resins such as polyester, vinyl ester and epoxy, with fillers and reinforcing fibres to produce a bulk material with properties better than those of the individual base materials. Fillers are often used to provide bulk to the material, reduce cost, lower bulk density or to produce aesthetic features. Fibres are used to reinforce the polymer and improve mechanical properties such as stiffness and strength. High strength fibres of glass, aramid and carbon are used as the primary means of carrying load, while the polymer resin protects the fibres and binds them into a cohesive structural unit.

In recent times fibre composite materials have been increasingly considered for structural load bearing applications by the construction industry and have established themselves as a viable and competitive option for rehabilitation and retrofit of existing civil structures, as a replacement for steel in reinforced concrete and to a lesser extent new civil structures.

- *Characteristics of Composites*

A composite material consists of two phases. It consists of one or more discontinuous phases embedded in a continuous phase. The discontinuous phase is usually harder and stronger than the continuous phase and is called the reinforcement or the reinforcing material, whereas the continuous phase is termed as the matrix. The matrix is usually more ductile and less hard. It holds the dispersed phase and shares the load with it. Matrix is composed of any of the three basic material type i.e. polymers, metals or ceramics. The matrix forms the bulk form or the part of the composite. The secondary phase embedded in the matrix is a discontinuous phase. It is usually harder and stronger than the continuous phase. It serves to strengthen the composites and improves the overall mechanical properties of the matrix. Properties of composites are strongly dependent on the properties of their constituent materials, their distribution and the interaction among them. The composite properties may be the volume fraction sum of the properties of the constituents, or the constituents may interact in a synergistic way resulting in better properties. Apart from the nature of the constituent materials, the geometry of the reinforcement (shape, size and size distribution) influences the properties of the composite to a great extent. The concentration distribution and orientation of the reinforcement also affect the properties. The shape of the discontinuous phase (which may by spherical, cylindrical, or rectangular cross-sanctioned prisms or platelets), the size and size distribution, which controls the texture of the material and volume fraction determines the interfacial area, which plays an important role in determining the extent of the interaction between the reinforcement and the matrix.

Concentration, usually measured as volume or weight fraction, determines the contribution of a single constituent to the overall properties of the composites. It is not only the single most important parameter influencing the properties of the composites, but also an easily controllable manufacturing variable used to alter its properties (Prakash, 2009).

The fibre reinforced polymer composites (FRPs) are increasingly considered as an enhancement to and/or substitute for infrastructure components or systems that are constructed of traditional civil engineering materials, namely concrete and steel. FRP composites are lightweight, non-corrosive, exhibit high specific strength and specific stiffness, are easily constructed, and can be tailored to satisfy performance requirements. Due to these advantageous characteristics, FRP composites have been included in new construction and rehabilitation of structures through its use as reinforcement in concrete, bridge decks, modular structures, formwork, and external reinforcement for strengthening and seismic upgrade (Ravi et al, 2012).

C. Purpose of Research

The purpose of this research work is to measure the engineering properties of the fibre gotten from finger root plant (Boesenbergia rotunda)

D. Research Problem

The overall problem of this research work, measurement of the strength property of natural fiber reinforced polymer composite, is to produce high quality products at low cost for both designing and manufacturing engineers with increased performance characteristics.

E. Aim and Objectives

The aim of this project is to measure the strength properties of natural fiber reinforced polymer composite.

➢ *The Objectives are to:*

- Study the effects of chemical treatment on the fibre
- Measure and determine strength property of the composite
- Measure and determine physical properties of the of the fibres
- Produce natural fibre reinforced polymer composite
- Evaluate the efficiency and effectiveness of the produced composite mechanical properties, determined through simulation of available data generated, using MATLAB.

F. Scope of Work

The processes involved in the extraction and treatment of the fibre are outlined below:

➢ *Extraction*

The extraction of the fibre is gotten by a process called rating process.

Ratting Process is the process of aging the finger root stem in water to allow for partial decomposition of the tissues. The fibres you get from ratting process are the raw fibre.

➢ *Pre-Treatment*

This is the process, which is called **mercerization,** involves soaking known amount of the fibre (in grams) in a known concentration of sodium hydroxide (NaOH) solution for a known time. The essence of pre-treating the fibre is to make it compatible with the resin.

➢ *Treatment*

After the treatment of the fibre in a standardized solution of sodium hydroxide, the fibre is dried at room temperature and re-weighed. The fibre is treated using sodium chlorite solution ($NaOCl_2$). Three quantities of $NaOCl_2$ (2g, 6g and 10g) and 98g, 96g and 90g respectively is added to form a standard solution and the fibre is soaked in the solution for 10 minutes, 30 minutes and 50 minutes respectively.

CHAPTER TWO
LITERATURE REVIEW

This chapter X-rays some of the recent reports published in literature on fibre reinforced composites with special emphasis on the strength properties of these reinforced composites. As a result of the increasing demand for environmentally friendly materials, light and resilient materials and the desire to reduce the cost of traditional fibres (i.e., carbon, glass and aramid) reinforced petroleum-based composites, new bio-based composites have been developed. Series of research have begun to focus attention on natural fibre composites (i.e., bio composites), which are composed of natural or synthetic resins, reinforced with natural fibers (Mohanty, 2002).

Several writers (Karbhari *et al*. (1997)) and Aref and Parsons (1996)) have documented the deteriorating condition of bridges and other infrastructure facilities all over United States in recent years. This growing concern has prompted civil engineers to consider alternatives for conventional materials. In this effort to find a way to extend the life of structures and to make it easier to construct and maintain, the use of FRP materials has been recommended (Zureick *et al*. (1995)). One of the present areas of emphasis is the use of composite materials for the fabrication of lightweight bridge decks that can be deployed for replacement of deteriorating ones or for the erection of new ones. However, the application of composite materials to infrastructure has been limited due to the lack of material property uniformity or consistency, industry-recognized design criteria and standardized test methods as shown by Ballinger (1990). The introduction of mass-produced FRP structural shapes in bridges and highway applications dictates the necessity for a more complete understanding of the static behavior of these shapes for the types of load and strain ranges that are typically anticipated to optimize the design and evaluation techniques. Bank (1989) showed that because of the difference in mechanical properties between a full-size GFRP beam and a GFRP coupon, the full-size beam flexural modulus of pultruded GFRP beams is different from the coupon flexural modulus, and the coupon flexural modulus also differs from the longitudinal modulus. Due to these differences, it becomes necessary to conduct tests and study the behavior of full-size GFRP beams at component or beam level in addition to coupon level. Nagraj and Ganga Rao (1993) have characterized the behavior of pultruded GFRP box beams under static and fatigue or cyclic bending loads. The tests showed that the shear and interfacial slip between adjacent layers had significant influence on deflection and strain measurements.

Davalos and Qiao (1997) conducted a combined analytical and experimental evaluation of flexural-torsional and lateral-distortional buckling of FRP composite wide-flange beams. They also showed that in general buckling and deflections limits tend to be the governing design criteria for current FRP shapes. The structural efficiency of pultruded FRP components and systems in terms of joint efficiency, transverse load distribution, composite action between FRP components, and maximum deflections and stresses was analyzed by Sotiropoulos et al. (1994) by conducting experiments on several components. Structural performance of individual FRP components was established through three- and four-point bending tests. Barbero *et al*. (1991) gave a theoretical determination of the ultimate bending strength of GFRP beams produced by pultrusion process. Several I-beams and box beams were tested under bending and the failure modes have been described. The simultaneous determination of flexural and shear moduli using experimental method by three-point bending has been done by Fisher et al. (1981). The behavior of pultruded GFRP wide flange and box beams under static loads has been studied by Nagraj and Ganga Rao (1997). They also developed theoretical methods for bending and shear stiffness computations and compared them with experimental results.

Although structural engineers have a wide range of pultruded GFRP structural shapes, made of glass fibers and resins (polyester, vinyl ester, epoxy), at their disposal, (Prakash, 2001) provided structural design information pertaining to mechanical properties and failure modes of square hollow pultruded tubes made of glass fibers in vinyl ester resin when used as a primary load bearing member. The study also investigated the influence of shear, buckling, initial crookedness, and manufacturing defects (material non-uniformity or asymmetry) on the structural behavior of GFRP hollow tubes. Special emphasis was given to understanding the modes of failure under static loading. Several coupons consisting of single, double and a four-layered tube assembly were tested under static flexural loading. The coupons consisted of 76 mm square hollow pultruded GFRP tubes with a thickness of 6.35 mm. The coupons were tested to failure under flexural loading and data obtained for deflection and strain were evaluated. The results obtained were compared with those from the finite element analysis (FEA). The stress distribution and modes of failure, determined by the tests, were verified numerically. The validation model allows one to investigate the feasibility of the design and to predict the behavior of the bridge. The knowledge and data gained from these tests will be used to analyze the response of the GFRP composite materials and of various assemblies built out of it, especially regarding bridge deck applications.

Currently, studies on the use of lignocelluloses biofibres in place of synthetic fibres as reinforcing materials are being pursued vigorously (Singha, 2002; Panthapulakkal, 2006). These bio-fibres are being extensively used to produce cost-effective eco-friendly bio-composites (Sain, 1994).

The advantages of natural fibres over traditional reinforcing materials such as glass fibre, carbon fibre etc. are their specific strength properties, easy availability, light weight, ease of separation, enhanced energy recovery, high toughness, non-corrosive nature, low density, low cost, good thermal properties, reduced tool wear, reduced dermal and respiratory irritation, less abrasion to processing equipment, renewability and biodegradability (Singha, 2004). It has been observed that natural fibre reinforced composites have properties like traditional synthetic fibre reinforced composites. Natural fibre composites have been studied and reviewed by several researchers (Dufresne, 1997). During the past decade, several significant industries such as the automotive, construction or packaging industries have shown massive interest in the progress of new bio-composites materials. One of the most appropriate examples of this is the substitution of inorganic fibres such as glass or aramid fibres by natural fibres (Bledzki, 1999). All these properties have made natural fibres very attractive for various industries currently engaged in searching for new and alternate products to synthetic fibre reinforced composites.

Natural fibers exhibit many advantageous properties; they are low-density materials offering significant cost advantages and ease of processing along with being a highly renewable resource, in turn reducing the dependency on foreign and domestic petroleum oil. Recent advances in the use of natural fibers (e.g., flax, cellulose, jute, hemp, straw, switch grass, kenaf, coir and bamboo) in composites have been reviewed by several authors (Conrad, 2008).

A. Classification of Composite Materials

Composite materials are commonly classified at the following two distinct levels:

➢ *Classification Based on Matrix Constituent*

The major composite classes include Organic Matrix Composites (OMCs), Metal Matrix Composites (MMCs) and Ceramic Matrix Composites (CMCs). The term organic matrix composite is generally assumed to include two classes of composites, namely Polymer Matrix Composites (PMCs) and carbon matrix composites commonly referred to as carbon-carbon composites.

- *Organic Matrix Composites (OMCs)*

✓ *Polymer Matrix Composites (PMC)*

Polymers make ideal materials as they can be processed easily, possess lightweight, and desirable mechanical properties. It follows, therefore, that high temperature resins are extensively used in aeronautical applications.

Two main kinds of polymers are **thermosets** and **thermoplastics**. Thermosets have qualities such as a well-bonded three-dimensional molecular structure after curing. They decompose instead of melting on hardening. Changing the basic composition of the resin is enough to alter the conditions suitably for curing and determining its other characteristics. They can be retained in a partially cured condition too over prolonged periods of time, rendering Thermosets very flexible. Thus, they are most suited as matrix bases for advanced conditions fibre reinforced composites.

- *Metal Matrix Composites (MMC)*

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

Most metals and alloys make good matrices. However, practically, the choices for low temperature applications are not many. Only light metals are responsive, with their low density proving an advantage. Titanium, Aluminum and magnesium are the popular matrix metals currently in vogue, which are particularly useful for aircraft applications. If metallic matrix materials have to offer high strength, they require high modulus reinforcements. The strength-to-weight ratios of resulting composites can be higher than most alloys.

The melting point, physical and mechanical properties of the composite at various temperatures determine the service temperature of composites. Most metals, ceramics and compounds can be used with matrices of low melting point alloys. The choice of reinforcements becomes more stunted with an increase in the melting temperature of matrix materials.

- *Ceramic Matrix Materials (CMM)*

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

High **modulus of elasticity** and low tensile strain, which most ceramics possess, have combined to cause the failure of attempts to add reinforcements to obtain strength improvement. This is because at the stress levels at which ceramics rupture, there is insufficient elongation of the matrix which keeps composite from transferring an effective quantum of load to the reinforcement and the composite may fail unless the percentage of fiber volume is high enough. Material is reinforcement to utilize the higher tensile strength of the fiber, to produce an increase in load bearing capacity of the matrix. Addition of high-strength fiber to a weaker ceramic has not always been successful and often the resultant composite has proved to be weaker. The use of reinforcement with high modulus of elasticity may take care of the problem to some extent and present pre-stressing of the fiber in the ceramic matrix is increasingly resorted to as an option. When ceramics have a higher thermal expansion coefficient than reinforcement materials, the resultant composite is unlikely to have a superior level of strength. In that case, the composite will develop strength within ceramic at the time of cooling resulting in microcracks extending from fiber to fiber within the matrix. Microcracking can result in a composite with tensile strength lower than that of the matrix. Figure 2.0 shows the classification matrix materials.

➢ *Classification Based on Reinforcements*

Reinforcements for the composites can be fibers, fabrics particles or whiskers.

Fibers are essentially characterized by one very long axis with the other two axes either often circular or near circular. Particles have no preferred orientation and so do their shape. Whiskers have a preferred shape but are small both in diameter and length as compared to fibers. Figure 2.1 shows types of reinforcements in composites.

Reinforcing constituents in composites, as the word indicates, provides the strength that makes the composite what it is. But they also serve certain additional purposes of heat resistance or conduction, resistance to corrosion and provide rigidity. Reinforcement can be made to perform all or one of these functions as per the requirements.

A reinforcement that embellishes the matrix strength must be stronger and stiffer than the matrix and capable of changing failure mechanism to the advantage of the composite. This means that the ductility should be minimal or even nil the composite must behave as brittle as possible.

- *Fibre Reinforced Composites/Fibre Reinforced Polymer (FRP) Composites*

Fibers are the important class of reinforcements, as they satisfy the desired conditions and transfer strength to the matrix constituent influencing and enhancing their properties as desired.

Glass fibers are the earliest known fibers used to reinforce materials. Ceramic and metal fibers were subsequently found out and put to extensive use, to render composites stiffer more resistant to heat. Fibers fall short of ideal performance due to several factors. The performance of a fiber composite is judged by its length, shape, orientation, and composition of the fibers and the mechanical properties of the matrix. The orientation of the fiber in the matrix is an indication of the strength of the composite and the strength is greatest along the longitudinal direction of fiber. This doesn't mean the longitudinal fibers can take the same quantum of load irrespective of the direction in which it is applied. Optimum performance from longitudinal fibers can be obtained if the load is applied along its direction. The slightest shift in the angle of loading may drastically reduce the strength of the composite.

Unidirectional loading is found in a few structures and hence it is prudent to give a mix of orientations for fibers in composites particularly where the load is expected to be the heaviest.

B. Application of Polymer Composites

Composites have over the years gained acceptance in various Engineering fields such in aeronautics, automobile, marine Engineering, etc. Civil engineering is no exception as the material is fast gaining acceptance in the field to replace the hitherto dominant reinforced concrete. The construction sector is one of the world's largest consumers of polymer composites. Unreinforced polymer composite materials have been used by the construction industry for many years in non-load bearing applications such as trimmings, kitchenware, vanity and cladding. In the last decade, there has been a concerted effort to migrate reinforced polymer composites (RPCs) into the construction industry for use in primary load bearing applications. Potential advantages commonly expounded by proponents of RPC materials include high specific strength, high specific stiffness, tailorable durability, good fatigue performance, versatile fabrication and lower maintenance costs. As a result, reinforced polymer composites are being investigated in applications such as rehabilitation and retrofit, alternative reinforcement for concrete and, in rare cases, entire fibre composite structures. (Humphreys, 2002).

➢ *Application of Fibre Composite in Construction*

Although the use of structural fibre composites in critical load-bearing applications is relatively rare, one of its most common uses in the construction industry is repair of existing structures. The material is also used as a replacement for steel in reinforced and stressed concrete and in very rare cases to produce new civil structures almost entirely out of fibre composites.

➢ *Application in Rehabilitation and Retrofitting*

The widespread deterioration of infrastructure in Canada, the USA and Europe is well documented (Karbhari, 2000). The estimated cost to rehabilitate and retrofit existing infrastructure worldwide is around (Canadian) $900B (ISIS Annual Report 1997/1998). In Australia it is estimated that $500M per annum is required to repair and upgrade concrete structures (Oehlers, 2000).

Some traditional rehabilitation and retrofit methods use concrete or external steel sheets to re-introduce or improve structure properties such as strength and ductility. The ability of concrete to form complex shapes and its suitability to submerged installation has seen it used for encapsulation of elements such as bridge piers (Carse, 1997). Steel can be bonded or bolted to deteriorated concrete structures to provide strength and stiff improvements with relatively little additional weight. In the last decade the number of instances of fibre composites used as a surface layer that either protects and/or improves on the response of the encapsulated element has been increasing. In these cases, the materials are usually bonded externally to the structure in the form of tows (fibre bundles), fabrics, plates, strips and jackets. The advantages offered by composites in these forms include their ability to bond well to many substrate materials and to follow complex shapes. Composites also offer a potential benefit over isotropic retrofit materials, such as steel, by allowing enhancement of strength without increasing stiffness and vice versa. (Humphreys, 2002).

➢ *Application of Fibre Reinforced Composites in Concrete Structures*

Concrete reinforced with fibre reinforced polymer (FRP) materials has been under investigation since the 1960's. Unstressed FRP reinforcement has been developed in a number of forms including ribbed FRP rod similar in appearance to deformed steel reinforcing bar, undeformed E-glass and carbon fibre bar bound with polyester, vinylester or epoxy resin, E-glass mesh made from flat FRP bars and prefabricated reinforcing cages using flat bars and box sections. Stressed FRP reinforcement is also available, usually consisting of bundles of rods or strands of fibre-reinforced polymer running parallel to the axis of the tendon. These are used in a similar fashion to conventional steel tendons (Gowripolan, 2000). The durability performance of FRP reinforcements is considered by some to offer a possible solution to the problem of corrosion of steel reinforcement, a primary factor in reduced durability of concrete structures. Other reported advantages of FRP rebar include enhanced erection and handling speeds (Karbhari, 1999) and suitability to applications which are sensitive to materials which impede radio wave propagation and disturb electromagnetic fields.

C. Application of Fibre Composite in New Civil Structures

A small number of new loads bearing civil engineering structures have been made predominantly from FRP materials over the last three decades. These include compound curved roofs (Hollaway, 2002), pedestrian and vehicle bridges and bridge decks, energy absorbing roadside guardrails (Bank *et al*, 2000), building systems, modular rooftop cooling towers (Barbero *et al*, 1991), access platforms for industrial, chemical and offshore (Hale *et al*, 1997), electricity transmission towers, power poles, power pole cross-arms and light poles and marine structures such as seawalls and fenders.

The potential benefits offered by fibre composites include high specific strength and specific stiffness, tailorable durability, good fatigue performance and the potential to reduce long-term costs. However, in many cases these potential benefits are difficult to realize and are sometimes based on specious fact and irrelevant data. In addition to this, the lack of bona-fide applications has caused many constructors to be skeptical of the material's ability to provide a viable alternative to traditional materials. Many of the existing applications are experimental in nature and are aimed at demonstrating the ability of fibre composite materials to perform in certain applications. To this end they may be successful in terms of structural performance but offer little by way of meaningful financial performance data. (Humphreys, 2002).

D. Composite waste management, Control and Minimization

Polymeric materials reinforced with synthetic fiber such as glass, carbon and aramid provide advantages of high stiffness and strength to weight ratio, and their use is very well justified in varieties of applications. Despite these advantages, the widespread use of synthetic fiber-reinforced polymer composite is declining because of their higher cost and adverse environmental impact. On the other hand, the use of natural fiber to develop environmentally friendly green materials is attracting researches worldwide due to their advantages like biodegradability, high weight, low-cost and high specific strength compared to synthetic fiber.

The production of these fibres should be controlled so that the waste coming forth can be effectively managed and to check for its abuse.

CHAPTER THREE
MATERIALS AND METHOD

A. Materials Employed in this Research Work

The materials and experimental methods employed in this research work are fully outlined, arranged and described in detail in this chapter herein.

➢ *The Raw Materials used in this Work were:-*

- Natural plant stem finger root fiber
- Polyester-resin

Polyester-resin employed in this work has a density of 1100 kg/m3and modulus of 3.42GPa .The use of unsaturated polyester resin and additives lowers the viscosity of the resin and releases the free radicals in the polyester monomers, thereby increased the rate of polymerization reaction. Products produced with appropriate incorporation of the entire reactive raw materials, were characterized after production for adequate industrial production and laboratory analysis.

➢ *Chemicals utilized in both the extraction processes, treatment processes, modification processes as well as processing processes of both the finger root fibers and its composite material manufacture were:-*

- Water
- Detergents
- Sodium hydroxide treatment (NaOH treatment)
- Sodium chlorite treatment ($NaOCl_2$ treatment)

With the above chemicals and raw materials, the aim and objectives of this work were able to be achieved through the implementation of the purpose of the research and careful observations of the research limitations, justified by the motivation for the quest of the research results, embed in the composite surface response methodology analysis and characterization processes.

B. Methods of this Experimental Work

The methods employed in this research work are itemized below:

- Fibre Extraction
- Pre-Treatment of extracted fibre (mercerization)
- Treatment of the fibre
- Determination of Linear mass and Dry Bulk densities
- Laboratory determination of the diameter of the fibre using electronic venire calliper, intermittent applied force and corresponding extensions
- Production of polymer composites
- Modeling and optimization

➢ *Natural Finger Root Plant Fibre Extraction and Processing*

Fibres are gotten from both natural sources. Artificial fibre is synthetic, manufactured by man. An example of artificial fibre is e-glass fibre. Natural fibres are gotten from parts of plants and animals. An example is plant stem fibres which are natural fibres gotten from the stem of plants. The fibre for this research work is gotten from the stem of finger root plant. The extraction of the fibre is gotten by a process called ratting process.

Ratting Process is the process of aging the finger root stem in water to allow for partial decomposition of the tissues. Before aging, the stem is given a partial beating to aid the partial decomposition of the tissues. The fibre should not be left for so long in the water. This is to avoid absorption of water. After about two to three days, the fibre is washed with detergent and rinsed thoroughly with clean water to get a spongy fibre and dried at room temperature. The detergent should be rinsed off to prevent it from reacting with the fibre as this could affect the strength of the fibre. The fibres you get from ratting process are the raw fibres.

➢ *Finger Root Fibre Treatment and Modification*

After the extraction of the natural fibre, it is given treatment so as to modify its properties. There are two types of treatments given to any fibre. They are:

- Pre-treatment and
- Treatment

- *Pre-Treatment*

This process, which is called **mercerization,** involves soaking known quantity of the fibre (in grams) into a known concentration of sodium hydroxide (NaOH) solution (2wt%) for a known time (150 mins). The essence of pre-treating the fibre is to modify the surface of the fibre to make it compatible with the resin by increasing the wettability of the resin on the fibre. After the soaking period, the fibre is rinsed with distilled water.

- *Treatment*

After the treatment of the fibre in a standardized solution of sodium hydroxide, the fibre is dried at room temperature and re-weighed. The fibre is then treated using sodium chlorite solution ($NaOCl_2$). Three quantities of $NaOCl_2$ (2g, 6g and 10g) and 98g, 96g and 90g respectively is added to form a standard solution and the fibre is soaked in the solution for 10 minutes, 30 minutes and 50 minutes respectively.

C. Composite Sample Preparation

Treated finger-root fibers were chopped into different lengths respectively, measured according to different weight fractions and then molds were prepared for the processing procedures. The composite manufactured were achieved by the application of molding techniques.

At the completion of the manufacturing processes, composite laminate were demolded and cut according to the different test piece configurations and specifications with the help of a cutting machine.

For instance, tensile test, flexural test and creep test of the locally sourced finger root fibres reinforced with polyester resin according to test piece configuration specifications respectively were performed on a (H25KS).

D. Characterization of the Composites

Composites characterization is an engineering laboratory means of strength properties determination of samples produced (i.e. tensile, flexural and creep tests) carried out by experimental means, statistical equation evaluation or simply by industrial measurements.

➢ *Composite Tensile Test*

This is an engineering test of material to determine the forces that will pull the specimens apart and at what point specimens will break known as maximum tensile strength of the materials under test.

During the test, a uniaxial load is applied through both ends of the specimen at the ASTM standard test method for tensile properties of fiber-resin composites with the designation of D 3039. The tensile test was performed in a (H25KS) and the results were analyzed to calculate the tensile strength of composites samples from the equation below, we have:-

Tensile strength (∂ct) of Composite = $\frac{F}{A}$ (Hamcox *et al*, 1994) (1)

Where:-

∂ct = Tensile strength of composite

F = Applied uniaxial load on composite

A = Cross sectional area of composites.

➢ *Composite Flexural Test*

This is an engineering test of material to determine the forces that will bend the material until it breaks by the application of a load known as maximum flexural strength.

The SBS tests were conducted as per ASTM D 790 which used the same (H25KS). Span length of 300mm and the cross-head speed of 1mm/min were maintained.

The flexural strength (F.S) of the composite specimens were determined using the following equation below:-

$$\text{Flexural strength (F.S)} = \frac{3PL}{2b\,t^2} \quad \text{(Hamcox et al, 1994).} \qquad (2)$$

Where:-

F.S = flexural strength of composite.

P = Applied load

L = Span length of the sample

b = Width of the specimen

t = Thickness of the specimen

- *Composite Creep Test*

This is an engineering test conducted to determine the time-dependent deformation of a material while under an applied load that was below its yield strength.

Creep phenomena occur with damage which may progress to failure; this is a critical factor in the long-term performance and reliability of materials such as polymer matrix composites which are often exposed to this type of stress in Civil Engineering and their applications.

Creep data for general design and research use were usually obtained under conditions of constant uniaxial loading and constant temperature up to a point of maximum creep point.

The results of all the experimental methods applied in this research work are presented and discussed in chapters 4 and 5.

E. Composite Density

- *Linear Mass Density,* $\bar{\lambda}_m$

This is the ratio of total mass of fibre to the total length of the fibre. Mathematically, this is given as:

$$\text{Linear mass density, } \bar{\lambda}_m = \frac{Total\ Mass}{Total\ Length} \quad (3)$$

- *Dry Bulk Density,* ρ_b

This is the ratio of total mass of fibre to total volume of the solution. Mathematically, this is given as:

$$\text{Dry bulk density, } \rho_b = \frac{mass\ of\ solid\ (fibre)}{Total\ Volume\ of\ the\ solution} \quad (4)$$

CHAPTER FOUR
RESULT AND ANALYSIS

A. Evaluation of the Sample's Densities

After the laboratory experiments, the sample's linear mass and dry bulk densities were calculated as follows using equations (3) and (4).

- *From Table (3.21), We have for Pre-Treatment:*

$$(A_i).\text{Linear mass density before treatment} = \frac{4.1(g)}{100(mm)} = 0.041\text{g/mm}$$

$$(A_{ii}).\text{ Linear mass density after treatment} = \frac{4.2(g)}{100(mm)} = 0.042\text{g/mm}$$

- *From Table (3.22), We have for Treatment:*

$$(B_i).\text{Linear mass density before treatment} = \frac{4.2(g)}{100(mm)} = 0.042\text{g/mm}$$

$$(B_{ii}).\text{Linear mass density after treatment} = \frac{4.2(g)}{100(mm)} = 0.042\text{g/mm}$$

- *From Table (3.21), We have for Pre-Treatment:*

$$(C_i).\text{Dry bulk density before treatment} = \frac{4.1(g)}{100(cm^3)} = 0.041\text{g/cm}^3$$

$$(C_{ii}).\text{Dry bulk density after treatment} = \frac{4.2(g)}{100(cm^3)} = 0.042\text{g/cm}^3$$

- *From Table (3.22), We have for Treatment:*

$$(D_i).\text{Dry bulk density before treatment} = \frac{4.1(g)}{100(cm^3)} = 0.041\text{g/cm}^3$$

$$(D_{ii}).\text{Dry bulk density after treatment} = \frac{4.2(g)}{100(cm^3)} = 0.042\text{g/cm}^3$$

B. Evaluation of the Sample's Areas, Stresses, Strains, Young Moduli of Elasticity, and Tensile Stresses

During the preparation of the experiments, the samples were tagged F_1 to F_9 and data generated based on that order. After the pre-treatment and treatment, the treated fibre was taken to the lab for analysis.

- *Based on the Data Generated from the Laboratory Analysis, a Program was Written using MatLab Software for the Evaluation of:*

- The sample Areas, A
- The Tensile stresses induced, σ
- The strain on the samples, ε
- The sample young moduli of elasticities, E and
- The tensile strength of the fibre (maximum σ).

- *Below is the program written in MatLab for the evaluation of the above properties of the fibre:*

```
% Calculation of values for Forces applied on 1st fiber group
% ========================================================
% where,  p1 = Forces applied on fiber 1
%         e1 = extension of fiber for forces applied
%         s1 = strain of first fiber group
%         q1 = stress on first fiber group
%         y1 = young modulus of first fiber group
%         d1 = diameter of first fiber group
%         A1 = area of first fiber group
%         l = length of fiber
%         t1 = tensile stress of first group of fiber
```

```
p1 = [0.00000;4.725;11.025;15.75];
e1 = [0.00000;0.125;0.75;1.625];
d1 = 0.63;
A1 = (pi)* (d1/2)^2;
l = 100;
q1 = p1./A1;
s1 = e1./l;
t1 = max(q1);
y1 = q1./e1
p11 = polyfit(s1,q1,1);
r1 = p11(1) .*s1 + p11(2);
figure
plot(s1,q1,'x');
hold on
plot(s1,r1,'-');
title('Stress against Strain graph for 1st group of Finger-root fiber');
xlabel('strain');
ylabel('stress(N/mm)');
h = text(min(xlim(gca)), max(ylim(gca)), ...
    sprintf('%fx + %f', p11(1), p11(2)),...
    'verticalalignment','top',...
    'horizontalalignment','left');
get(h)
slope = p11(1)
intercept = p11(2)
% [slope,intercept]
%  [p11(),p11(2),slope,inter]=getslopeintercept
% figure
% plot(s1, polyval(p11,s1),'k-');
% Calculation of values for Forces applied on 2nd fiber group
% ============================================================
% where,  p2 = Forces applied on fiber 2
%         e2 = extension of fiber for forces applied
%         s2 = strain of second fiber group
%         q2 = stress on second fiber group
%         y2 = young modulus of second fiber group
%         d2 = diameter of second fiber group
%         A2 = area of second fiber group
%         l = length of fiber
%         t2 = tensile stress of second group of fiber

p2 = [0.00000;1.5750;6.3000;14.1750];
e2 = [0.00000;0.1250;0.5000;0.8750];
d2 = 0.70;
A2 = (pi)* (d1/2)^2;
l = 100;
q2 = p2./A2;
s2 = e2./l;
t2 = max(q2);
y2 = q2./e2;
p12 = polyfit(s2,q2,1);
r2 = p12(1) .*s2 + p12(2);
figure
plot(s2,q2,'x');
hold on
plot(s2,r2,'-');
title('Stress against Strain graph for 2nd group of Finger-root fiber')
xlabel('strain');
ylabel('stress(N/mm)');
h = text(min(xlim(gca)), max(ylim(gca)), ...
    sprintf('%fx + %f', p12(1), p12(2)),...
    'verticalalignment','top',...
```

```
   'horizontalalignment','left');
get(h)
slope = p12(1)
intercept = p12(2)
% [slope,intercept]
% Calculation of values for Forces applied on 3rd fiber group
% ============================================================
% where,  p3 = Forces applied on fiber 3
%         e3 = extension of fiber for forces applied
%         s3 = strain of third fiber group
%         q3 = stress on third fiber group
%         y3 = young modulus of third fiber group
%         d3 = diameter of third fiber group
%         A3 = area of first third group
%         l = length of fiber
%         t3 = tensile stress of third group of fiber

p3 = [0.00000;6.3000;14.1750;21.7350];
e3 = [0.00000;0.2500;0.8750;1.625];
d3 = 0.56;
A3 = (pi)* (d3/2)^2;
l = 100;
q3 = p3./A3;
s3 = e3./l;
t3 = max(q3);
y3 = q3./e3;
p13 = polyfit(s3,q3,1);
r3 = p13(1) .*s3 + p13(2);
figure
plot(s3,q3,'x')
hold on
plot(s3,r3,'-')
title('Stress against Strain graph for 3rd group of Finger-root fiber')
xlabel('strain');
ylabel('stress(N/mm)');
h = text(min(xlim(gca)), max(ylim(gca)), ...
   sprintf('%fx + %f', p13(1), p13(2)),...
   'verticalalignment','top',...
   'horizontalalignment','left');
get(h)
slope = p13(1)
intercept = p13(2)
% [slope,intercept]
% Calculation of values for Forces applied on 4th fiber group
% ============================================================
% where,  p4 = Forces applied on fiber 4
%         e4 = extension of fiber for forces applied
%         s4 = strain of third fiber group
%         q4 = stress on third fiber group
%         y4 = young modulus of third fiber group
%         d4 = diameter of third fiber group
%         A4 = area of first third group
%         l = length of fiber
%         t4 = tensile stress of third group of fiber

p4 = [0.00000;4.7250;9.1350;14.1750;20.4750];
e4 = [0.00000;0.6250;0.7500;1.3750;2.2500];
d4 = 0.58;
A4 = (pi)* (d4/2)^2;
l = 100;
q4 = p4./A4
s4 = e4./l
t4 = max(q4);
```

```
y4 = q4./e4
p14 = polyfit(s4,q4,1);
r4 = p14(1) .*s4 + p14(2);
figure
plot(s4,q4,'x')
hold on
plot(s4,r4,'-')
title('Stress against Strain graph for 4th group of Finger-root fiber')
xlabel('strain');
ylabel('stress(N/mm)');
h = text(min(xlim(gca)), max(ylim(gca)), ...
   sprintf('%fx + %f', p14(1), p14(2)),...
   'verticalalignment','top',...
   'horizontalalignment','left');
get(h)
slope = p14(1)
intercept = p14(2)
% [slope,intercept]
   % Calculation of values for Forces applied on 5th fiber group
% ============================================================
% where,  p5 = Forces applied on fiber 5
%        e5 = extension of fiber for forces applied
%        s5 = strain of third fiber group
%        q5 = stress on third fiber group
%        y5 = young modulus of third fiber group
%        d5 = diameter of third fiber group
%        A5 = area of first third group
%        l = length of fiber
%        t5 = tensile stress of third group of fiber

p5 = [0.00000;7.245;15.435;20.4750;26.1450];
e5 = [0.00000;0.5000;0.8750;1.3750;2.1250];
d5 = 0.63;
A5 = (pi)* (d5/2)^2;
l = 100;
q5 = p5./A5;
s5 = e5./l;
t5 = max(q5);
y5 = q5./e5;
p15 = polyfit(s5,q5,1);
r5 = p15(1) .*s5 + p15(2);
figure
plot(s5,q5,'x')
hold on
plot(s5,r5,'-')
title('Stress against Strain graph for 5th group of Finger-root fiber')
xlabel('strain');
ylabel('stress(N/mm)');
h = text(min(xlim(gca)), max(ylim(gca)), ...
   sprintf('%fx + %f', p15(1), p15(2)),...
   'verticalalignment','top',...
   'horizontalalignment','left');
get(h)
slope = p15(1)
intercept = p15(2)
% [slope,intercept]
% Calculation of values for Forces applied on 6th fiber group
% ============================================================
% where,  p6 = Forces applied on fiber 6
%        e6 = extension of fiber for forces applied
%        s6 = strain of third fiber group
%        q6 = stress on third fiber group
%        y6 = young modulus of third fiber group
```

```
%       d6 = diameter of third fiber group
%       A6 = area of first third group
%       l = length of fiber
%       t6 = tensile stress of third group of fiber

p6 = [0.00000;4.725;11.025;17.3250;20.4750];
e6 = [0.00000;0.125;0.3750;0.8750;1.8750];
d6 = 0.60;
A6 = (pi)* (d6/2)^2;
l = 100;
q6 = p6./A6;
s6 = e6./l
t6 = max(q6);
y6 = q6./e6;
p16 = polyfit(s6,q6,1);
r6 = p16(1) .*s6 + p16(2);
figure
plot(s6,q6,'x')
hold on
plot(s6,r6,'-')
title('Stress against Strain graph for 6th group of Finger-root fiber')
xlabel('strain');
ylabel('stress(N/mm)');
h = text(min(xlim(gca)), max(ylim(gca)), ...
   sprintf('%fx + %f', p16(1), p16(2)),...
   'verticalalignment','top',...
   'horizontalalignment','left');
get(h)
slope = p16(1)
intercept = p16(2)
% [slope,intercept]
% Calculation of values for Forces applied on 7th fiber group
% ============================================================
% where,  p7 = Forces applied on fiber 7
%       e7 = extension of fiber for forces applied
%       s7 = strain of third fiber group
%       q7 = stress on third fiber group
%       y7 = young modulus of third fiber group
%       d7 = diameter of third fiber group
%       A7 = area of first third group
%       l = length of fiber
%       t7 = tensile stress of third group of fiber

p7 = [0.00000;4.7250;9.4500;13.5400];
e7 = [0.00000;0.3750;0.7500;0.8750];
d7 = 0.58;
A7 = (pi)* (d7/2)^2;
l = 100;
q7 = p7./A7;
s7 = e7./l;
t7 = max(q7);
y7 = q7./e7
p17 = polyfit(s7,q7,1);
r7 = p17(1) .*s7 + p17(2)
figure
plot(s7,q7,'x')
hold on
plot(s7,r7,'-')
title('Stress against Strain graph for 7th group of Finger-root fiber')
xlabel('strain');
ylabel('stress(N/mm)');
h = text(min(xlim(gca)), max(ylim(gca)), ...
   sprintf('%fx + %f', p17(1), p17(2)),...
```

```
   'verticalalignment','top',...
   'horizontalalignment','left');
get(h)
slope = p17(1)
intercept = p17(2)
% [slope,intercept]
% Calculation of values for Forces applied on 8th fiber group
% ========================================================
% where,  p8 = Forces applied on fiber 8
%         e8 = extension of fiber for forces applied
%         s8 = strain of third fiber group
%         q8 = stress on third fiber group
%         y8 = young modulus of third fiber group
%         d8 = diameter of third fiber group
%         A8 = area of first third group
%         l = length of fiber
%         t8 = tensile stress of third group of fiber

p8 = [0.00000;6.3000;14.1750;17.3250];
e8 = [0.00000;0.5000;1.0000;1.8750];
d8 = 0.65;
A8 = (pi)* (d8/2)^2;
l = 100;
q8 = p8./A8;
s8 = e8./l;
t8 = max(q8);
y8 = q8./e8
p18 = polyfit(s8,q8,1);
r8 = p18(1) .*s8 + p18(2)
figure
plot(s8,q8,'x')
hold on
plot(s8,r8,'-')
title('Stress against Strain graph for 8th group of Finger-root fiber')
xlabel('strain');
ylabel('stress(N/mm)');
h = text(min(xlim(gca)), max(ylim(gca)), ...
   sprintf('%fx + %f', p18(1), p18(2)),...
   'verticalalignment','top',...
   'horizontalalignment','left');
get(h)
slope = p18(1)
intercept = p18(2)
% [slope,intercept]
% Calculation of values for Forces applied on 9th fiber group
% ========================================================
% where,  p9 = Forces applied on fiber 9
%         e9 = extension of fiber for forces applied
%         s9 = strain of third fiber group
%         q9 = stress on third fiber group
%         y9 = young modulus of third fiber group
%         d9 = diameter of third fiber group
%         A9 = area of first third group
%         l = length of fiber
%         t9 = tensile stress of third group of fiber

p9 = [0.00000;4.725;9.4500;12.6000];
e9 = [0.00000;0.3750;0.8750;1.6250];
d9 = 0.60;
A9 = (pi)* (d9/2)^2;
l = 100;
q9 = p9./A9;
s9 = e9./l;
```

```
t9 = max(q9);
y9 = q9./e9;
p19 = polyfit(s9,q9,1);
r9 = p19(1) .*s9 + p19(2)
figure
plot(s9,q9,'x')
hold on
plot(s9,r9,'-')
title('Stress against Strain graph for 9th group of Finger-root fiber')
xlabel('strain');
ylabel('stress(N/mm)');
h = text(min(xlim(gca)), max(ylim(gca)), ...
    sprintf('%fx + %f', p19(1), p19(2)),...
    'verticalalignment','top',...
    'horizontalalignment','left');
get(h)
slope = p19(1)
intercept = p19(2)
[slope,intercept]

% Calculation of values for Forces applied on untreated fiber group
% ============================================================
% where,  p9 = Forces applied on untreated fiber
%         eu = extension of fiber for forces applied
%         su = strain of third fiber group
%         qu = stress on third fiber group
%         yu = young modulus of third fiber group
%         du = diameter of third fiber group
%         Au = area of first third group
%         l = length of fiber
%         tu = tensile stress of third group of fiber

pu = [0.00000;3.1400;6.2900;11.0250;15.7500;22.0400];
eu = [0.00000;0.2500;1.1250;2.2500;3.6250;4.2500];
du = 0.60;
Au = (pi)* (du/2)^2;
l = 100;
qu = pu./Au;
su = eu./l;
tu = max(qu);
y9 = qu./eu;
p1u = polyfit(su,qu,1);
ru = p1u(1) .*su + p1u(2)
figure
plot(su,qu,'x')
hold on
plot(su,ru,'-')
title('Stress against Strain graph for 9th group of Finger-root fiber')
xlabel('strain');
ylabel('stress(N/mm)');
h = text(min(xlim(gca)), max(ylim(gca)), ...
    sprintf('%fx + %f', p1u(1), p1u(2)),...
    'verticalalignment','top',...
    'horizontalalignment','left');
get(h)
slope = p1u(1)
intercept = p1u(2)
[slope,intercept]

% [t1;t2;t3;t4;t5;t6;t7;t8;t9]
x = nctttt(:,1)
y = nctttt(:,4)
z = nctttt(:,5)
```

```
xi = linspace(min(x),max(x),20)
yi = linspace(min(y),max(y),20)
[XI YI]=meshgrid(xi,yi);
ZI = griddata(x,y,z,XI,YI);
figure
surf(XI,YI,ZI)
xlabel('concentration')
ylabel('time')
zlabel('tensile strength')
axis tight
box on
rotate3d

x1 = [s1;s2;s3;s4;s5;s6;s7;s8;s9]
y1 = [q1;q2;q3;q4;q5;q6;q7;q8;q9]
% f(x1) = y1
% x1i = linspac(min(x1), max(x1))
% y1i = linspac(min(yi),max(y2))
p = polyfit(x1,y1,1);
figure
plot(x1,y1,'bs')
r = p(1) .* x1 + p(2)
plot(x1, y1, 'x');
hold on;
plot(x1, r, '-');
title('Stress against Strain Graph')
xlabel('Strain')
ylabel('Stress')
hold off;
[t1 t2 t3 t4 t5 t6 t7 t8 t9]
```

CHAPTER FIVE
DISCUSSION AND CONCLUSION

A. Deduction of Creep Rate Quadratic Model

For P-value to be significant at 95% confidence interval, it must have a value of 0.05 or less i.e. P-value ≤ 0.05.

R^2/Adj R^2 gives the model accuracy.

For T-statistics to be significant, its value has to be between 2 to -2.

The general quadratic model for the MATLAB program used for the creep analysis is of the form:

$$Y_{CR} = a_0+a_1X_1+a_2X_2+a_3X_3+a_4X_4+a_5X_5 \quad (**)$$

Where a_0 = the constant terms,

$a_1 \ldots a_5$ = the model coefficients,

X_1 = the produced fibre length,

X_2 = the fibre volume fraction in the general quadratic model above.

The model that predicts the behavior of the creep rate is gotten from (table AX) using the T-statistics column given as:

$$Y_{CR} = a_0+a_2X_2 +a_4X_1^2+a_5X_5^2$$

Simply put that T-statistics values judges variables based on their values in the coefficients in the model equation.

Judging from the F-statistics table, it shows that the model is adequate since its P-value is close to that of the analysis of variance table.

Regression squared values, R^2-values shows that the model can only explain (70-71)% variability in the data, with the assistance of the R^2-values in the explanation of the model variabilities. Hence, the deduced model is (70-71)% accurate at 95% confidence interval.

Fibre volume fractions, the square of the fibre length and the square of the fibre volume fraction chosen significantly changed the strength property (i.e., the creep rate studied).

B. Conclusion

FRP composites are two-phased materials created by combining multiple constituent materials. Industries continually seek innovative materials to reduce costs and increase profit margins.

Natural fibers offer distinct advantages over conventional reinforcing fibers like glass and carbon, particularly in terms of cost and energy efficiency. These fibers are renewable resources that can be cultivated and processed within a short timeframe, providing an unlimited supply compared to the limited availability of traditional glass and carbon fibers used in advanced composites.

Natural fibers are eco-friendly, low-density, recyclable, and cost-effective materials. Their excellent tensile properties make them viable alternatives to conventional fibers for reinforcing plastic materials. According to analysis results, the treated fiber demonstrated a tensile strength of 79.6 N/mm², with a maximum creep rate of 2.0870×10^{-4} sec^{-1}.

C. Recommendation

This research has crystallized the advantages inherent in fibre reinforced polymer composite as a good replacement for steel and other conventional composites in the construction industry.

Being a low-density material, its use in building structures for instance, will result in structures with reduced self-weight as against the high building self-weight experienced in reinforced concrete and steel structures.

REFERENCES

[1]. Humphreys, Matthew (2003) The Use of Polymer Composites in Construction. In Yang, Jay (Ed.) Proceedings of the CIB 2003 Int'l conference on Smart and Sustainable Built Environment. Queensland University of Technology, Australia, Queensland, Brisbane, pp. 1-9.

[2]. Aref, A. J. and Parsons, I. D. (1996). "Design and Analysis Procedures for a Novel Fiber Reinforced Plastic Bridge Deck", Advanced Composite Materials in Bridges and Structures, CSCE, Montreal, Quebec, Canada, pp. 743-750.

[3]. Bank, L.C. and Gentry, T. R., (2000). "Composite Materials for Roadside Safety Structures", Proceedings of ACUN-II International Composites Conference, University of New South Wales, Australia

[4]. Barbero, E., GangaRao, H.V.S. (1991). "Structural Applications of Composites in Infrastructure", SAMPE Journal, Vol 27, No 6, SAMPE, USA.

[5]. Barbero, E. J., Fu, S. H. and Raftoyiannis, I. (1991). "Ultimate Bending Strength of Composite Beams", Journal of Materials in Civil Engineering, Vol.3, No.4, November, pp. 292-306.

[6]. Ballinger, C. A. (1990). "Structural FRP composites-Civil Engineering's Material of the Future?", Civil Engineering, ASCE, 60(7), pp. 63-65.

[7]. Bank, L. C., (1989). "Properties of Pultruded Fiber Reinforced Plastic Structural Members", Transportation Research Record 1223, Transportation Research Board, Washington D.C., pp. 117-124.

[8]. Bledzki A K, and Gassan J. (1999). Prog. Polym. Sci. 24 221

[9]. Carse, A., (1997). "The Asset Management of a Long Bridge Structure Affected by Alkali-Silica Reaction", Proceedings of Concrete '97 Conference, Concrete Institute of Australia, Adelaide chakrapan tuakta (2004), "use of fiber reinforced polymer composite in bridge structures"

[10]. Conrad Kathrine, (2008). Correlation between the distribution of lignin and pectin and distribution of sorbed metal ions (lead and zinc) on coir (Cocos nucifera L.), Bioresource Technology 99:8476–8484

[11]. Davalos, J. F., and Qiao, P. (1997). "Analytical and Experimental Study of Lateral and Distortional Buckling of FRP Wide-Flange Beams", Journal of Composites for Construction, Vol. 1, No. 4, pp. 150-159.

[12]. Dufresne A, Caville J and Vignon M 1997 J. Appl. Polym. Sci. 64 1185

[13]. Fisher, S., Roman, I., Harel, H., Marom, G., and Wagner, H. D. (1981). "Simultaneous Determination of Shear and Young's Moduli in Composites", Journal of Testing and Evaluation, Vol.9, No.5, September, pp. 303-307.

[14]. Erhard, Gunter (2006). Designing with Plastics. Trans. Martin Thompson. Munich Hanser Publishers. Available November 2014: http://en.wikipedia.org/wiki/Fibre-reinforced_plastic.

[15]. Gowripalan N., (1999). "Fibre reinforced Polymer (FRP) Applications for Prestressed Concrete Bridges", Proceedings of ACUN 1 Conference Composites: Innovations and Structural Applications, UNSW, Australia

[16]. Gowripolan, N., 2000, "Design Considerations for Prestressed Concrete Beams with Fibre Reinforced Polymer (FRP) Tendons", Fibre Composites: Who Needs Them?,

[17]. A Workshop for Civil and Structural Engineers, University of Southern Queensland, Australia

[18]. Hale, J. M., (1997)."Strength Reduction of GRP Composites Exposed to High Temperature Marine Environments", Proceedings of ICCM11 International Conference on Composite Materials, Australian Composites Structures Society, Australia

[19]. Hollaway, L. (2002). "The Development and the Future of Advanced Polymer Composites in the Civil Infrastructure", Proceedings of the International Conference on Advanced Composites in Construction, University of Southampton

[20]. Humphreys M. F. (2002). The use of polymer composites in construction ISIS Canada, 1998). The University of Manitoba,Canada ISIS Annual Report 1997/1998.

[21]. Karbhari, V.M., Seible, F., Heigemier, G. A. and Zhao, L. (1997). "Fiber Reinforced Composite Decks for Infrastructure Renewal - Results and Issues", Proceedings of International Composites Expo, Session 3-C, pp. 1-6.

[22]. Karbhari, V. M. (1999). "Structural Characterization of Fiber-Reinforced Composite Short- and Medium-Span Bridge Systems", Developments In Design Standards, CRC-ACS, Australia

[23]. Karbhari, V. M., Zhao, L., (2000). "The Use of Composites for Twenty-First Century Civil Infrastructure", Fibre Composites: Who Needs Them?, A Workshop for Civil and Structural Engineers, University of Southern Queensland, Australia

[24]. Ko, K. (1997). "Fibre Architecture Based Design of Ductile Composite Rebar for Concrete Structures", Proceedings of ICCM-11: International Conference on Composite Materials, Australian Composites Structures Society, Australia.

[25]. Mohanty AK, Drzal LT, Misra M. (2002). Engineered natural .ber reinforced polypropylene composites: in.uence of surface modi-.cations and novel powder impregnation processing. J Adhes Sci Technol 16(8):999–1015.

[26]. Nagraj, V. and Gangarao, H. V. S. (1993). " Characterization of GFRP Pultruded Box Beams Under Static and Fatigue Loads", SAMPE Quarterly (Journal of Advanced Materials), Vol.24, No.4, pp. 3-9.

[27]. Oehlers, D. J. (2000). "Development of Design Rules for Retrofitting by Adhesive Bonding or Bolting Either FRP or Steel Plates to RC beams in Bridges and Buildings. ACUN2, UNSW, Australia

[28]. Panthapulakkal S, Zereshkian A and Sain M 2006 Bioresource Technol. 97 265

[29]. Prakash Kumar, K. Chandrashekhara and Antonio Nanni,(2001)."Testing and Evaluation of Components for a Composite bridge Deck," Journal of Reinforced Plastic s and Composites.

[30]. Prakash tudu (2009). Processing and characterization of natural fiber reinforced polymer composites.

[31]. Ravi Jain, Luke lee (2012). Fiber Reinforced Polymer (FRP) Composites for Infrastructure Applications. Focusing on Innovation, Technology Implementation and Sustainability. Springer

[32]. Singha, A, S., vijay kumar thakur. (2007). Mechanical properties of natural fibre reinforced polymer composites
[33]. Sain M M and Kokta B V (1994) Polym.–Plast. Technol. Eng. 33 89
[34]. Singha A S and Thakur Vijay K. (2007) Int. J. Plast. Technol. 11 835
[35]. Sotiropoulos, S. N., Gangarao, H. V. S., and Allison, R. W. (1994). "Structural Efficiency of Pultruded FRP Bolted and Adhesive Connections", Proceedings of 49th Annual Conference, Composite Institute, The Society of Plastics Industry Inc., Cincinnati, Ohio, SPI/Composite Institute, New York, N.Y.
[36]. Weaver, A., (1999). "Composites: Worldwide Markets and Opportunities", Materials Today
[37]. Zureick, A. H., Shih, B., and Munley, E. (1995). "Fiber-Reinforced Polymeric Bridge Decks", Structural Engineering Review, Vol.7, No.3, pp. 257-266.
[38]. Verma et al. 2013. "Coir Fibre Reinforcement and Application in Polymer Composites: A Review." https://studylib.net/doc/18673928/coir-fibre-reinforcement-and-application-in-polymer-compo...
[39]. *K. G. Satyanarayana et al. 1990."Natural Fibre Polymer Composites"* https://www.scribd.com/document/419347690/Natural-Fibre-polymer-Composites
[40]. Wikipedia. 2010. "Fiber-reinforced composite." https://en.wikipedia.org/wiki/Fiber-reinforced_composite
[41]. Kumar , A (2014) "*A study on mechanical behaviour of hair fiber reinforced epoxy composites." http://ethesis.nitrkl.ac.in/5532/*
[42]. Garg, Arun, "Natural fiber reinforced soy-based composites" (2002). *Masters Theses*. 2298. https://scholarsmine.mst.edu/masters_theses/2298
[43]. https://www.mst.edu/search/?q=fiber+reinforced+natural+composites

APPENDIX

Table 1 The Physical Properties of Pre-Treated and Treated Finger Root Fiber Material

Property	Pre-treatment ((NaOH) Treatment)		Treatment (($NaOCl_2$) treatment)	
	Before Treatment	After Treatment	Before Treatment	After Treatment
Length, L (mm)	100	100	100	100
Linear mass density, $\bar{\lambda}_m$ (g/mm)	0.041	0.042	0.041	0.042
Dry bulk density, ρ_b (g/cm^3)	0.041	0.042	0.041	0.042

Table 2 Sodium Hydroxide (NaOH) Pre-Treatment

Symbol	Weight before Treatment (g)	Weight after Treatment (g)
F_1	0.5000	0.6000
F_2	0.0000	0.0000
F_3	0.0000	0.0000
F_4	0.6000	0.6000
F_5	0.6000	0.6000
F_6	0.6000	0.6000
F_7	0.6000	0.6000
F_8	0.6000	0.6000
F_9	0.6000	0.6000
Total	4.1000	4.2000

Table 3 Sodium Chlorite ($NaOCl_2$) Treatment

Symbol	$NaOCl_2$ Concentration (Weight %)	Weight before Treatment (g)	Weight after Treatment (g)	Time (mains)
F_1	2	0.6000	0.6000	10
F_2	2	0.0000	0.0000	30
F_3	2	0.0000	0.0000	50
F_4	6	0.6000	0.6000	10
F_5	6	0.6000	0.6000	30
F_6	6	0.6000	0.6000	50
F_7	10	0.6000	0.6000	10
F_8	10	0.6000	0.6000	30
F_9	10	0.6000	0.6000	50
Total		4.2000	4.2000	

Table 4 The Physical Properties of Pre-Treated and Treated Finger Root Fibre Material

Properties	Pre-treatment ((NaOH) Treatment)		Treatment (($NaOCl_2$))	
	Before Treatment	After Treatment	Before Treatment	After Treatment
L	100mm	100mm	100mm	100mm
$\bar{\lambda}_m$	0.041g/mm	0.042g/mm	0.042g/mm	0.042g/mm
ρ_b	0.041g/mm	0.042g/mm	0.041g/mm	0.042g/mm

Table 5 Treated Finger Root Fiber, Surface Response Methodology Data Analysis

Varables	CO-Efficient	Se	T-statistics	P-values	F-statistics
Constants	-1.0250e-06	8.1828e-05	-0.0125	0.9908	SSe=4.3351e-09
Fiber (X_1) Length	4.3292e-06	4.3464e-06	0.9960	0.3926	Dfe=3
Fiber Volume Fraction (X_2)	9.3592e-06	4.3464e-06	2.1533	0.1203	Dfr=5
X_1*X_2	1.1750e-08	4.7517e-08	0.2473	0.8206	SSr=1.0488e-08
X^2_1	-7.2500e-08	6.7199e-08	-1.0789	0.3597	F=1.4516
X^2_2	-1.6250e-07	6.7199e-08	-2.4182	0.0943	Pval=0.4033
	R^2=0.7075	AdjR^2=0.2201		0.9908	

Table 6 Untreated Finger Root Fibre Analysis [F]

FORCE P(N)	EXTENSION (mm)	Stress (N/mm^2)	Strain	Young Modulus (N/mm^2)	Tensile Strength (N/mm^2)	Diameter (mm)	Area (mm^2)
0.0000	0.0000	0.0000	0.0000				
3.1400	0.2500	11.1055	0.0025				
6.2900	1.1250	22.2463	0.0113				
11.0250	2.2500	38.9930	0.0225	1632.7257	77.9506	0.6000	0.2828
15.7500	3.6250	55.7042	0.0362				
22.0400	4.2500	77.9506	0.0425				

Table 7 Treated Finger Root Fibre Analysis [F_1]

Sample No	Applied Forces (N)	Extension (mm)	Stress (N/mm^2)	Strain	Young Modulus (N/mm^2)	Tensile Strength (N/mm^2)	Diameter (mm)	Area (mm^2)
F_1	0.0000	0.0000	0.0000	0.0000		50.5254	0.6300	0.3117
	4.7250	0.1250	15.1576	0.0013				
	11.0250	0.7500	35.3678	0.0075	2859.9271			
	15.7500	1.6250	50.5254	0.0163				

Table 8 Treated Finger Root Fibre Analysis [F_2]

Sample No	Applied Forces (N)	Extension (mm)	Stress (N/mm^2)	Strain	Young Modulus (N/mm^2)	Tensile Strength (N/mm^2)	Diameter (mm)	Area (mm^2)
F_2	0.0000	0.0000	0.0000	0.0000		36.8330	0.7000	0.3848
	1.5750	0.1250	4.0926	0.0013	5119.90			
	6.3000	0.5000	16.3702	0.0050				
	14.1750	0.8750	36.8330	0.0088				

Table 9 Treated Finger Root Fibre Analysis [F_3]

Sample No	Applied Forces (N)	Extension (mm)	Stress (N/mm^2)	Strain	Young Modulus (N/mm^2)	Tensile Strength (N/mm^2)	Diameter (mm)	Area (mm^2)
F_3	0.0000	0.0000	0.0000	0.0000		88.2457	0.5600	0.2463
	6.3000	0.2500	25.5785	0.0025	5216.9955			
	14.1750	0.8750	57.5516	0.0088				
	21.7350	1.6250	88.2457	0.0163				

Table 10 Treated Finger Root Fibre Analysis [F_4]

Sample No	Applied Forces (N)	Extension (mm)	Stress (N/mm^2)	Strain	Young Modulus (N/mm^2)	Tensile Strength (N/mm^2)	Diameter (mm)	Area (mm^2)
F_4	0.0000	0.0000	0.0000	0.000		77.4958	0.5800	0.2642
	4.7250	0.6250	17.8836	0.0063	3497.2453			
	9.1350	0.7500	34.5750	0.0075				
	14.1750	1.3750	53.6509	0.0138				
	20.4750	2.2500	77.4958	0.0225				

Table 11 Treated Finger Root Fibre Analysis [F_5]

Sample No	Applied Forces (N)	Extension (mm)	Stress (N/mm^2)	Strain	Young Modulus (N/mm^2)	Tensile Strength (N/mm^2)	Diameter (mm)	Area (mm^2)
F_5	0.0000	0.0000	0.0000	0.0000		83.8721	0.6300	0.3117
	7.2450	0.5000	23.2417	0.0050				
	15.4350	0.8750	49.5149	0.0088	3999.4327			
	20.4750	1.3750	65.6830	0.0138				
	26.1450	2.1250	83.8721	0.0213				

Table 12 Treated Finger Root Fibre Analysis [F_6]

Sample No	Applied Forces (N)	Extension (mm)	Stress (N/mm^2)	Strain	Young Modulus (N/mm^2)	Tensile Strength (N/mm^2)	Diameter (mm)	Area (mm^2)
F_6	0.0000	0.0000	0.0000	0.0000		72.4155	0.6000	0.2827
	4.7250	0.1250	16.7113	0.0013				
	11.0250	0.3750	38.9930	0.0037	3569.8624			
	17.3250	0.8750	61.2747	0.0088				
	20.4750	1.8750	72.4155	0.0187				

Table 13 Treated Finger Root Fibre Analysis [F_7]

Sample No	Applied Forces (N)	Extension (mm)	Stress (N/mm^2)	Strain	Young Modulus (N/mm^2)	Tensile Strength (N/mm^2)	Diameter (mm)	Area (mm^2)
F_7	0.0000	0.0000	0.0000	0.0000		51.2475	0.5800	0.2642
	4.7250	0.3750	17.8836	0.0037	5530.4923			
	9.4500	0.7500	35.7673	0.0075				
	13.5400	0.8750	51.2475	0.0088				

Table 14 Treated Finger Root Fibre Analysis [F_8]

Sample No	Applied Forces (N)	Extension (mm)	Stress (N/mm^2)	Strain	Young Modulus (N/mm^2)	Tensile Strength (N/mm^2)	Diameter (mm)	Area (mm^2)
F_8	0.0000	0.0000	0.0000	0.0000	2814.9704	52.2104	0.6500	0.3318
	6.3000	0.5000	18.9856	0.0050				
	14.1750	1.0000	42.7176	0.0100				
	17.3250	1.8750	52.2104	0.0187				

Table 15 Treated Finger Root Fibre Analysis [F_9]

Sample No	Applied Forces (N)	Extension (mm)	Stress (N/mm^2)	Strain	Young Modulus (N/mm^2)	Tensile Strength (N/mm^2)	Diameter (mm)	Area (mm^2)
F_9	0.0000	0.0000	0.0000	0.0000		44.5634	0.6000	0.2827
	4.7250	0.3750	16.7113	0.0037	2692.6160			
	9.4500	0.8750	33.4225	0.0088				
	12.6000	1.6250	44.5634	0.0163				

Table 16 Finger Root Composite Creep Analysis Data [30% 50mm]

Applied Force (N)	Time (sec)	Extension (mm)	Strain (ε)	Width (mm)	Length (mm)	Thickness (mm)
0.0000	0.0000	0.0000	0.0000			
8.2000	3.7100	0.0250	0.0003			
39.2000	7.1800	0.0750	0.0008	20.0000	100.0000	3.2000
60.9000	10.2600	0.2500	0.0025			
64.0200	14.6400	0.2000	0.0020			

Table 17 Finger Root Composite Creep Analysis Data [30% 30mm]

Applied Force (N)	Time (sec)	Extension (mm)	Strain (ε)	Width (mm)	Length (mm)	Thickness (mm)
0.0000	0.0000	0.0000	0.0000			
19.6000	3.4900	0.0500	0.0005			
37.5800	6.8100	0.1500	0.0015	20.0000	100.0000	3.2000
45.0200	9.6600	0.2375	0.0024			

Table 18 Finger Root Composite Creep Analysis Data [30% 10mm]

Applied Force (N)	Time (sec)	Extension (mm)	Strain (ε)	Width (mm)	Length (mm)	Thickness (mm)
0.0000	0.0000	0.0000	0.0000			
8.2000	4.5800	0.0250	0.0003			
23.7000	8.3800	0.1000	0.0010	20.0000	100.0000	3.2000
39.2000	13.2200	0.1875	0.0019			

Table 19 Finger Root Composite Creep Analysis Data [50% 50mm]

Applied Force (N)	Time (sec)	Extension (mm)	Strain (ε)	Width (mm)	Length (mm)	Thickness (mm)
0.0000	0.0000	0.0000	0.0000			
57.8000	3.5000	0.0500	0.0005			
119.8000	8.0400	0.1125	0.0011	20.0000	100.0000	3.2000
138.7000	10.5100	0.1375	0.0014			

Table 20 Finger Root Composite Creep Analysis Data [50% 30mm]

Applied Force (N)	Time (sec)	Extension (mm)	Strain (ε)	Width (mm)	Length (mm)	Thickness (mm)
0.0000	0.0000	0.0000	0.0000			
51.6000	4.4700	0.0500	0.0005			
76.4000	6.9100	0.0600	0.0006	20.0000	100.0000	3.2000
82.6000	9.9800	0.1250	0.0013			

Table 21 Finger Root Composite Creep Analysis Data [50% 10mm]

Applied Force (N)	Time (sec)	Extension (mm)	Strain (ε)	Width (mm)	Length (mm)	Thickness (mm)
0.0000	0.0000	0.0000	0.0000			
70.2000	5.6800	0.0625	0.0006			
110.5000	8.9400	0.0875	0.0009	20.0000	100.0000	3.2000
144.6000	12.8000	0.1500	0.0015			

Table 22 Finger Root Composite Creep Analysis Data [10% 50mm]

Applied Force (N)	Time (sec)	Extension (mm)	Strain (ε)	Width (mm)	Length (mm)	Thickness (mm)
0.0000	0.0000	0.0000	0.0000			
54.7000	4.3600	0.0250	0.0003			
82.6000	6.6000	0.0875	0.0009	20.0000	100.0000	3.2000

Table 23 Finger Root Composite Creep Analysis Data [10% 30mm]

Applied Force (N)	Time (sec)	Extension (mm)	Strain (ε)	Width (mm)	Length (mm)	Thickness (mm)
0.0000	0.0000	0.0000	0.0000			
45.4000	5.0900	0.0500	0.0005			
70.2000	7.5100	0.0750	0.0008	20.0000	100.0000	3.2000
102.2000	11.4900	0.1375	0.0014			

Table 24 Finger Root Composite Creep Analysis Data [10% 10mm]

Applied Force (N)	Time (sec)	Extension (mm)	Strain (ε)	Width (mm)	Length (mm)	Thickness (mm)
0.0000	0.0000	0.0000	0.0000			
20.6000	2.9500	0.0375	0.0004			
33.0000	5.2600	0.0500	0.0005	20.0000	100.0000	3.2000
45.4000	7.2600	0.1000	0.0010			

Table 25 Composite Minimum Creep Rate Data Analysis

FIBER LENGTH (mm) X_1	FIBER VOLUME FRACTION (%) X_2	MINIMUM CREEP RATE (sce^{-1})
10.0000	10.0000	0.0001273
10.0000	30.0000	0.0001472
10.0000	50.0000	0.0001147
30.0000	10.0000	0.000121
30.0000	30.0000	0.0002523
30.0000	50.0000	0.0001228
50.0000	10.0000	0.0001271
50.0000	30.0000	0.0001686
50.0000	50.0000	0.0001333

Table 26 Analysis of Variance

Source	Sum Sq.	d.f.	Mean Sq.	F	Prob>F
X1	1.94601e-009	2	9.73003e-010	0.88	0.4823
X2	8.45353e-009	2	4.22676e-009	3.82	0.118
Error	4.42347e-009	4	1.10587e-009		
Total	1.4823e-008	8			

Table 27 Natural Plant Finger Root Fibre Processing Cost Estimate

S/N	Materials	Price (#)
1	**Sourcing** i. Local Finger root Plant ii. Chemicals needed (NaOH and $NaOCl_2$) iii. Apparatus Required	
2	**Extraction of Local Natural Plant Finger root Fibre**	
3	**Sample Preparation for:** i. Treatment ii. Modifications	
4	**Local Finger Root Treatment** i. NaOH Solution ii. $NaOCl_2$ Solution	
5	**Properties Characterized** **A. Strength Properties Test** i. Tensile Test of Fibre ii. Fibre Young Modulus Evaluation iii. Fibre Areas iv. Fibre Diameters v. Fibre Linear Density Evaluation vi. Fibre Bulk Density Evaluation	

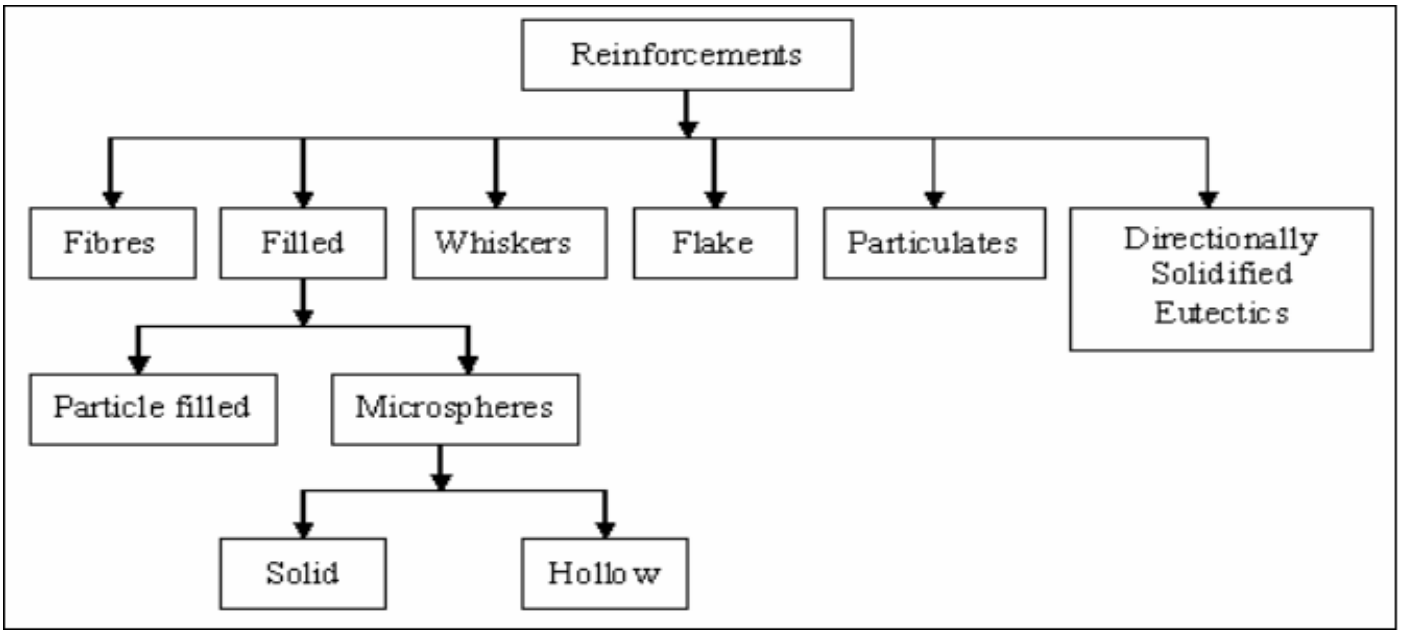

Fig 1 Types of Reinforcements

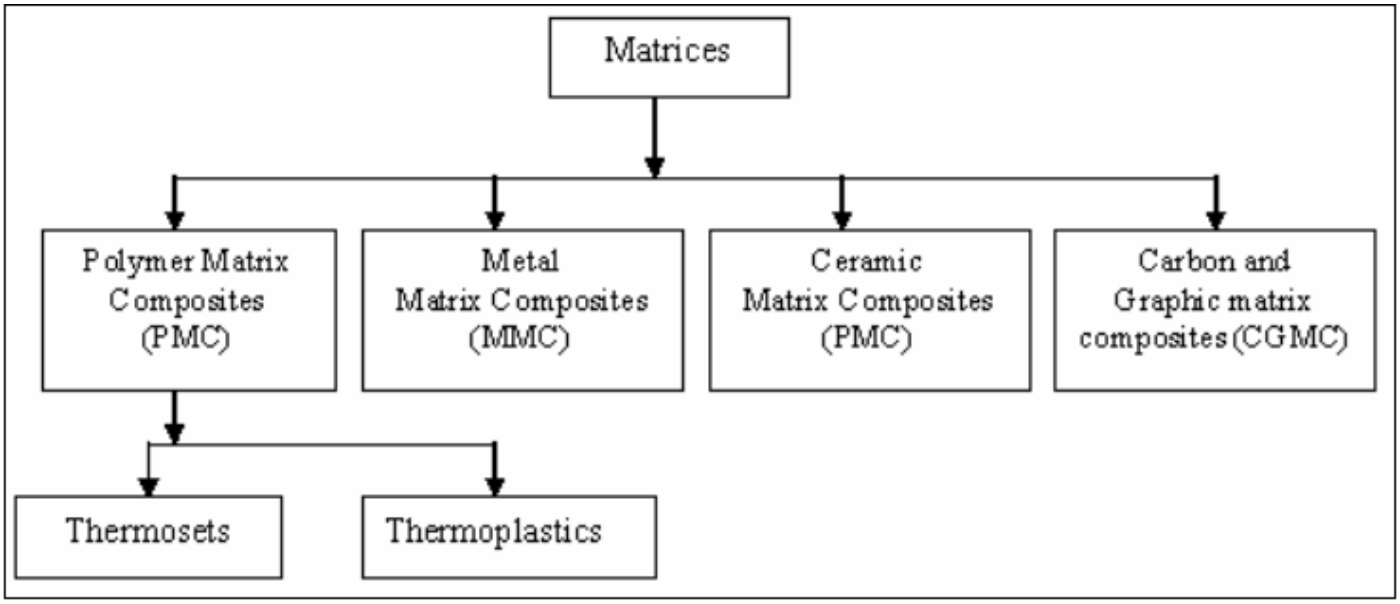

Fig 2 Classification of Matrix Materials

Fig 3 Finger Root Plant Stem Fibre

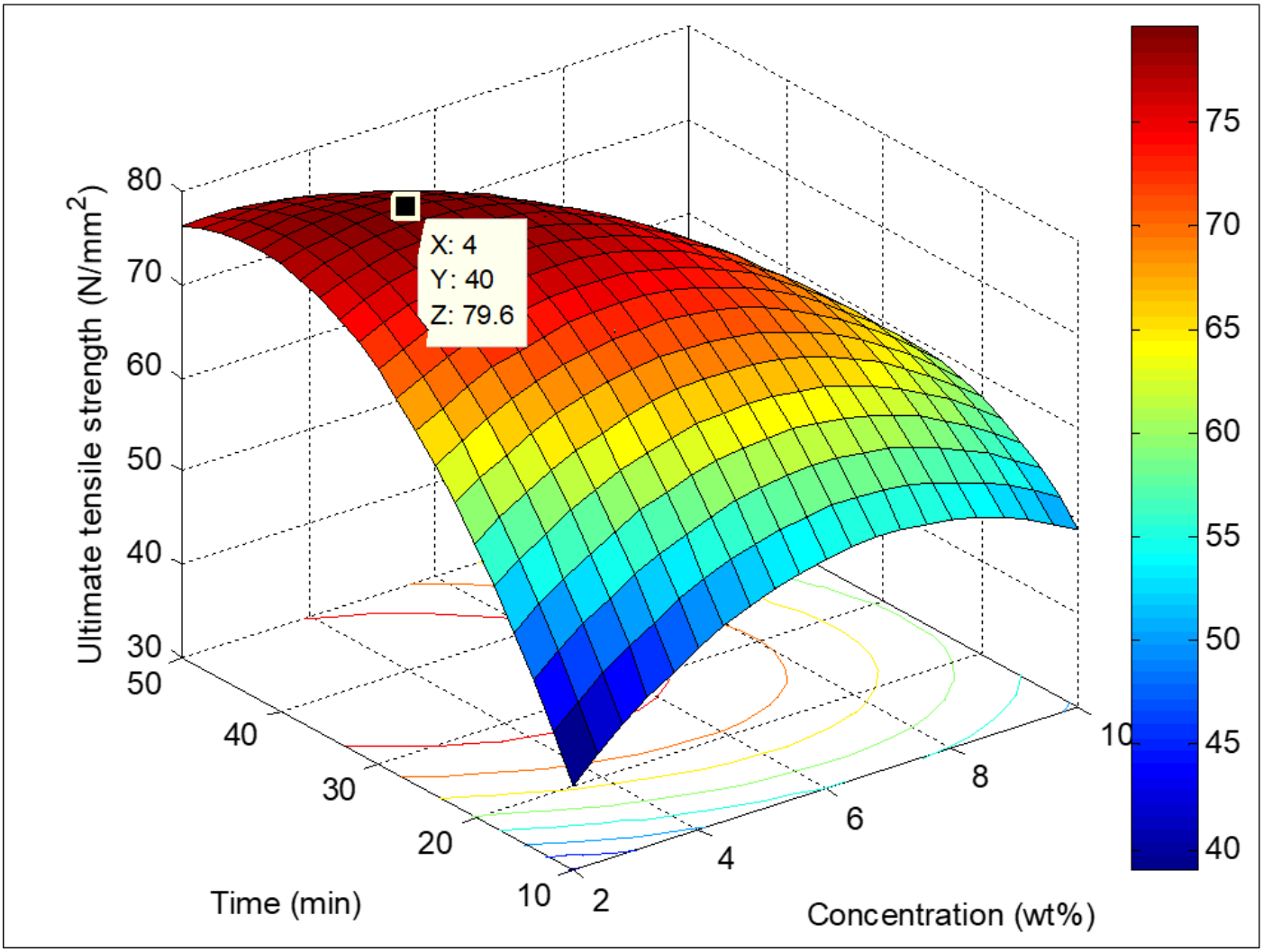

Fig 4 Surface Plot for the Ultimate Tensile Strength of the Treated Fibre

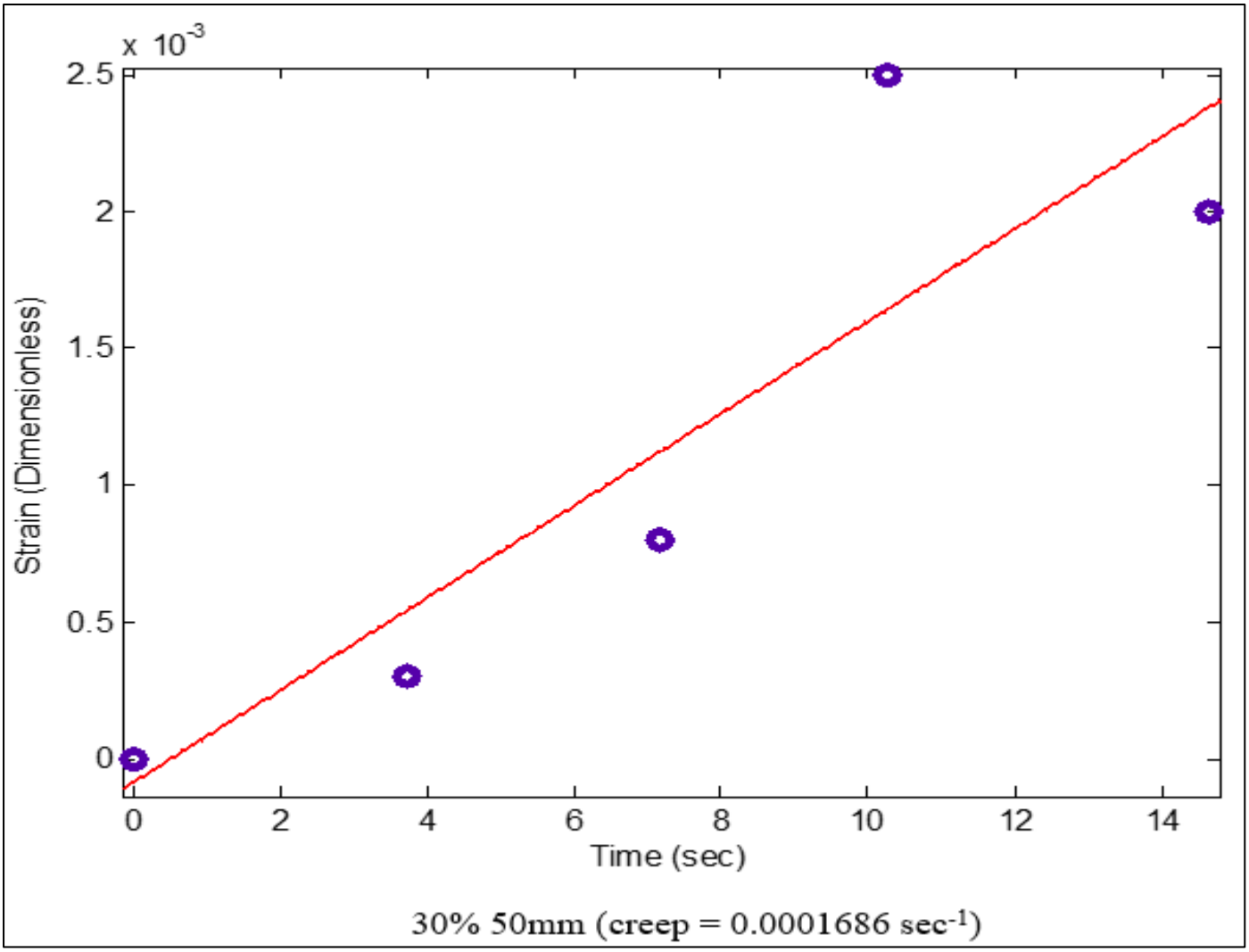

Fig 5 Creep Rate for 30% Fibre Volume Fraction and 50mm Fibre Length

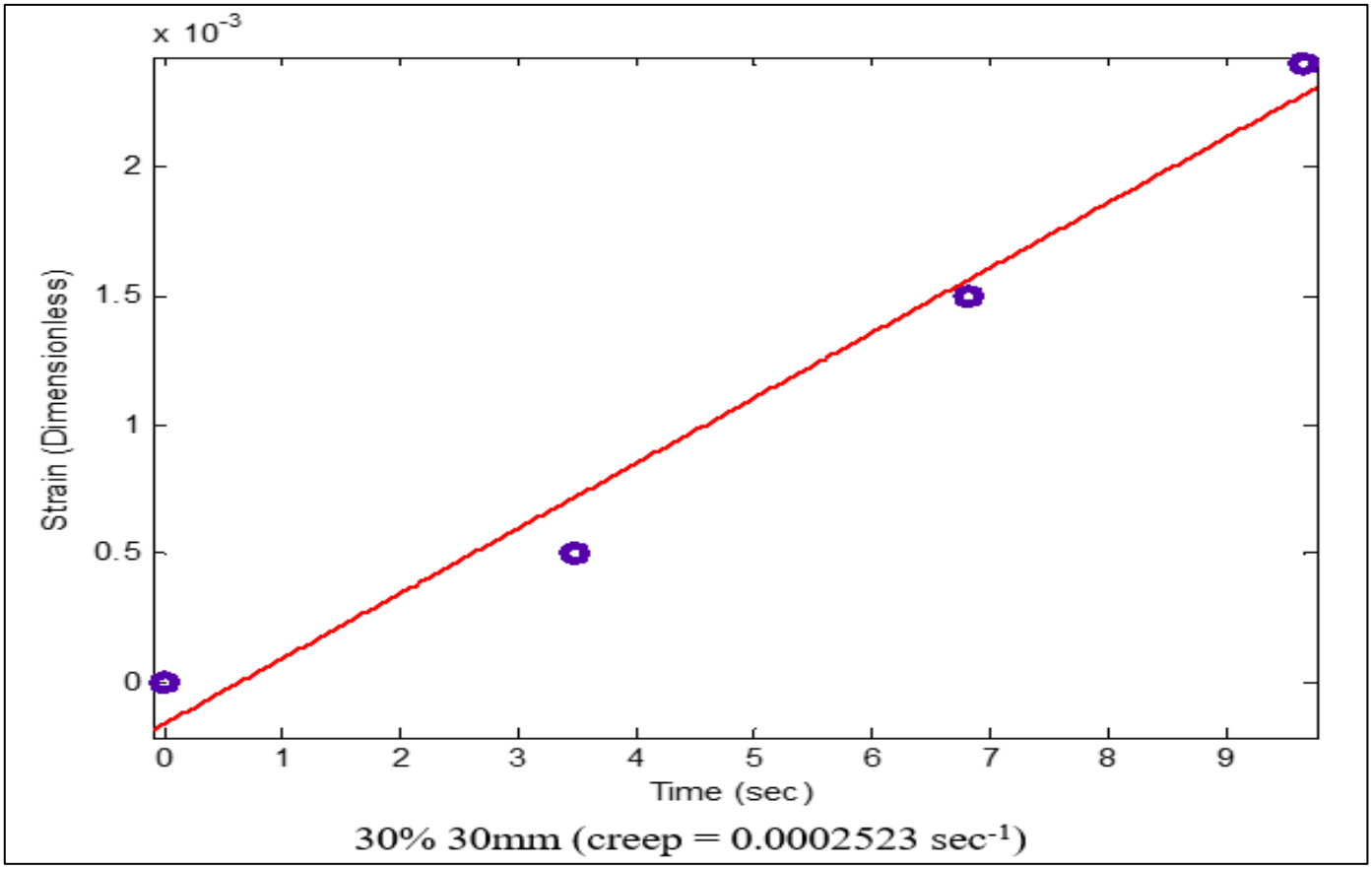

Fig 6 Creep Rate for 30% Fibre Volume Fraction and 30mm Fibre Length

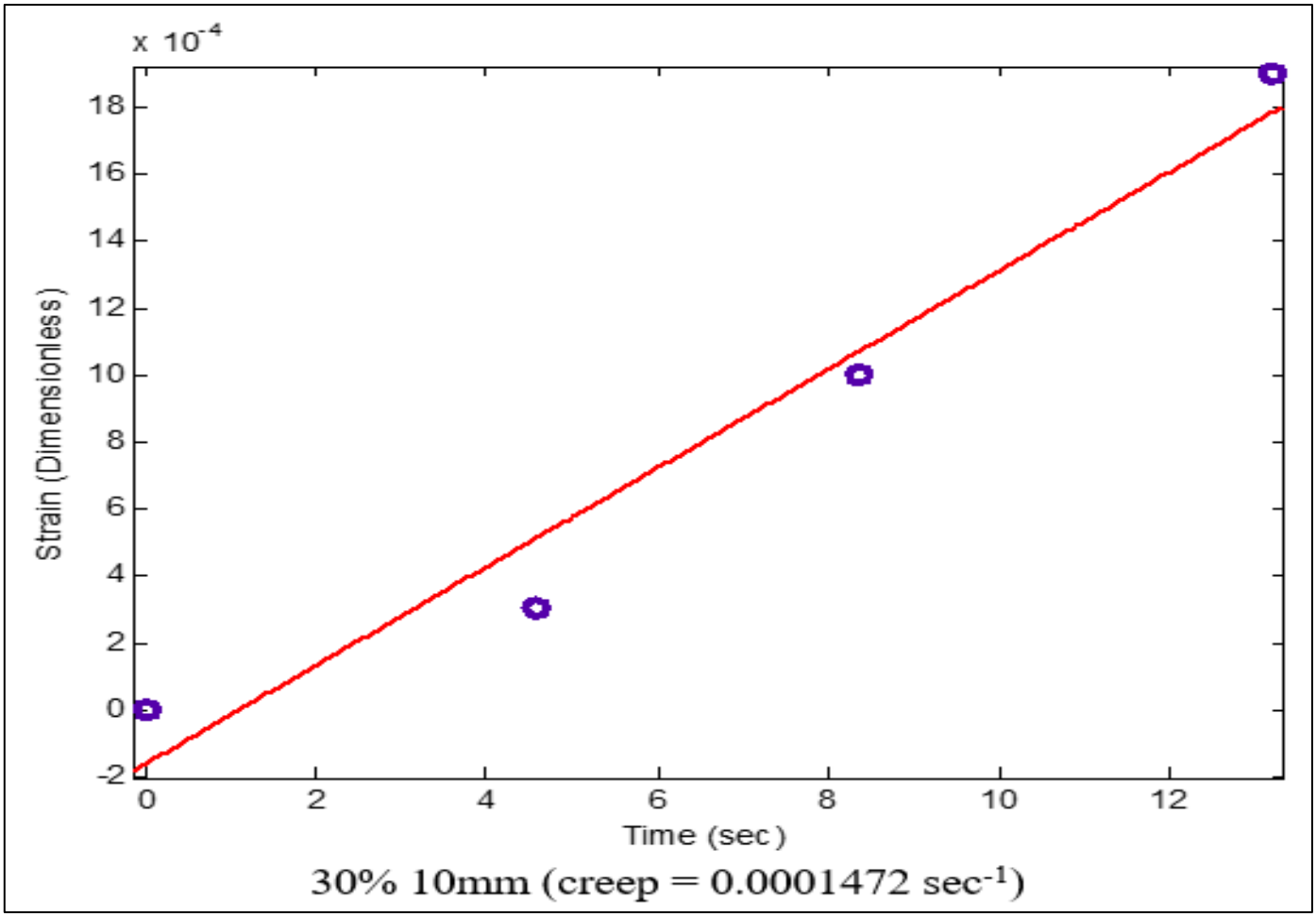

Fig 7 Creep Rate for 30% Fibre Volume Fraction and 10mm Fibre Length

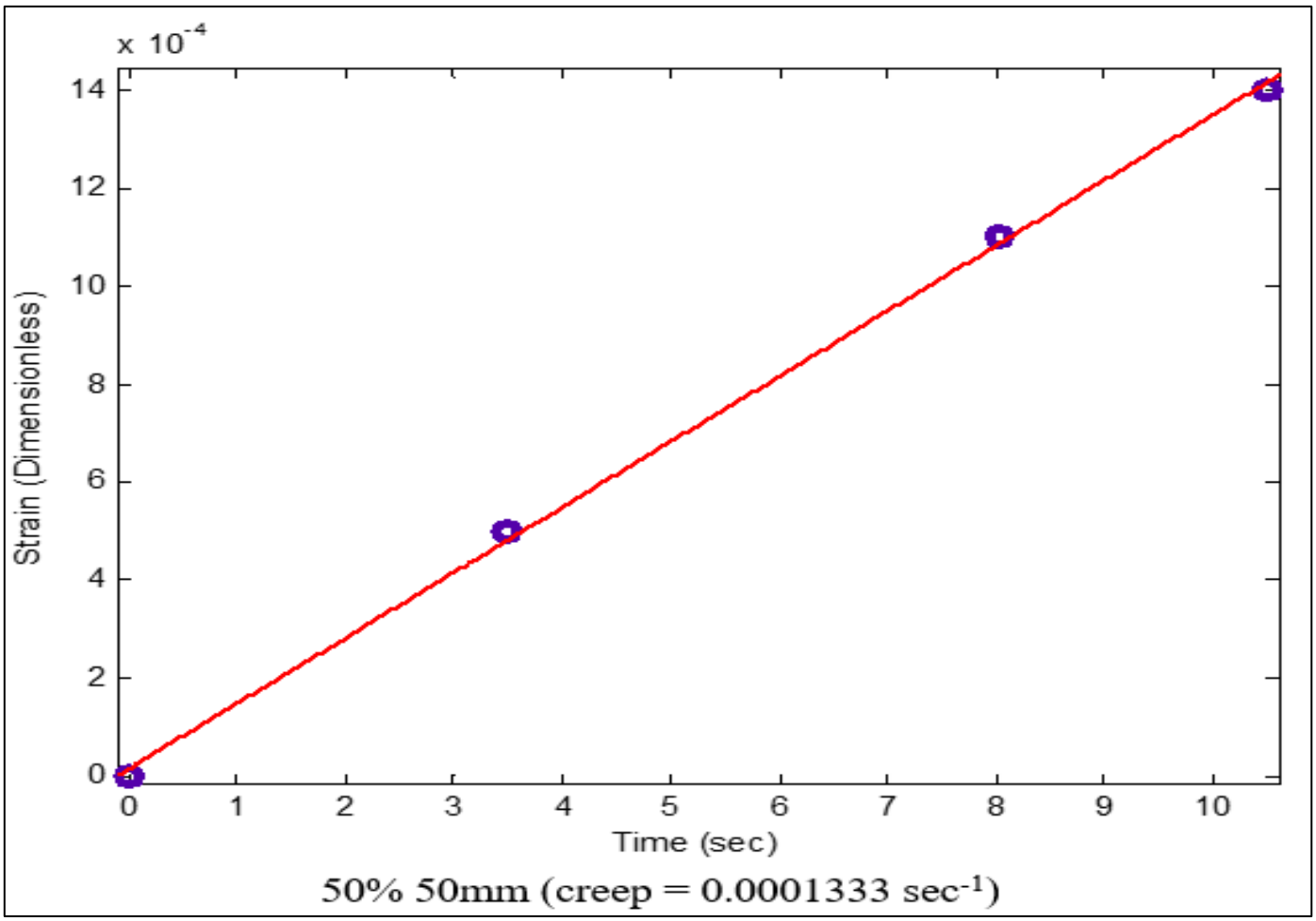

Fig 8 Creep Rate for 50% Fibre Volume Fraction and 50mm Fibre Length

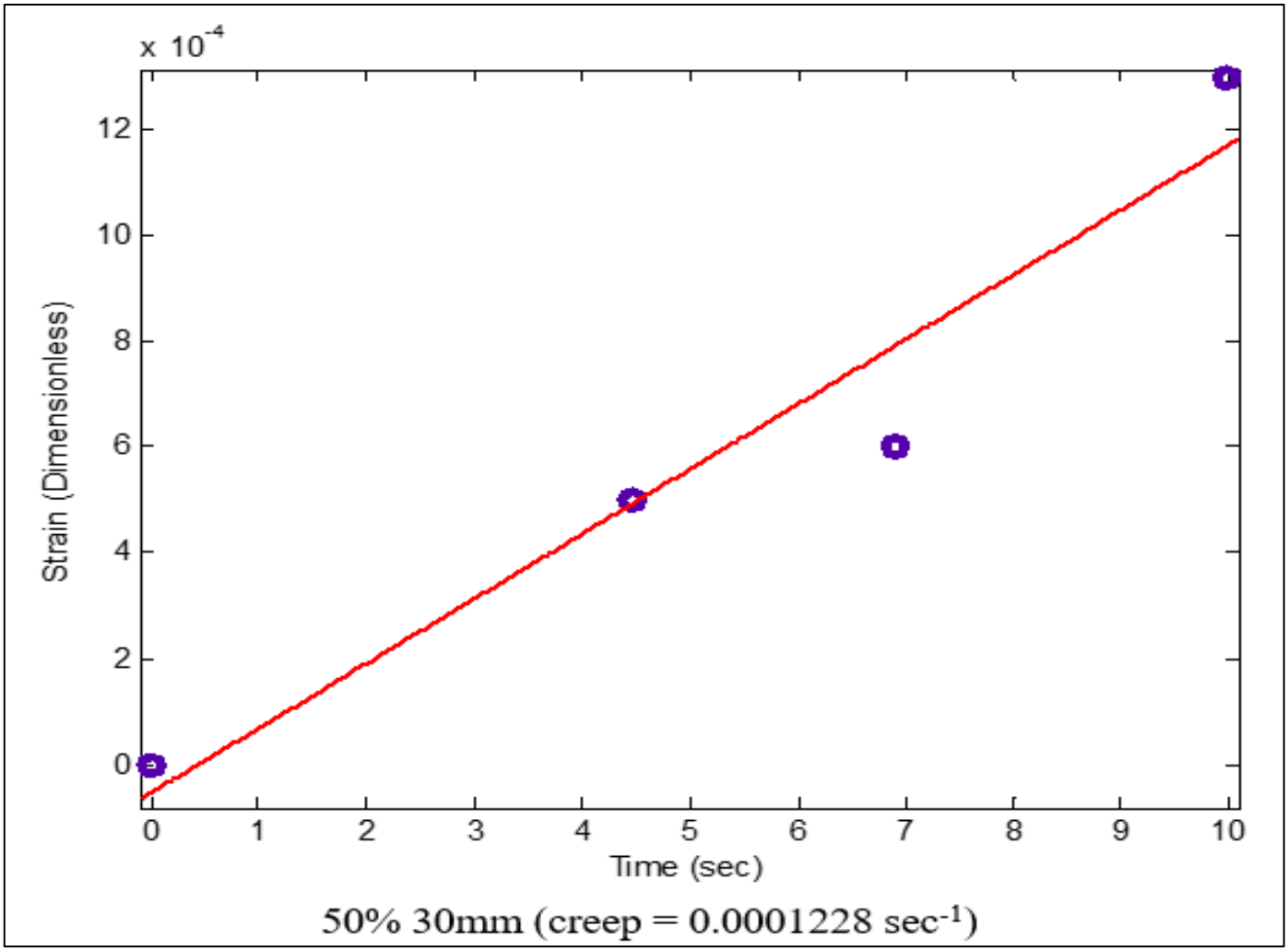

Fig 9 Creep Rate for 50% Fibre Volume Fraction and 30mm Fibre Length

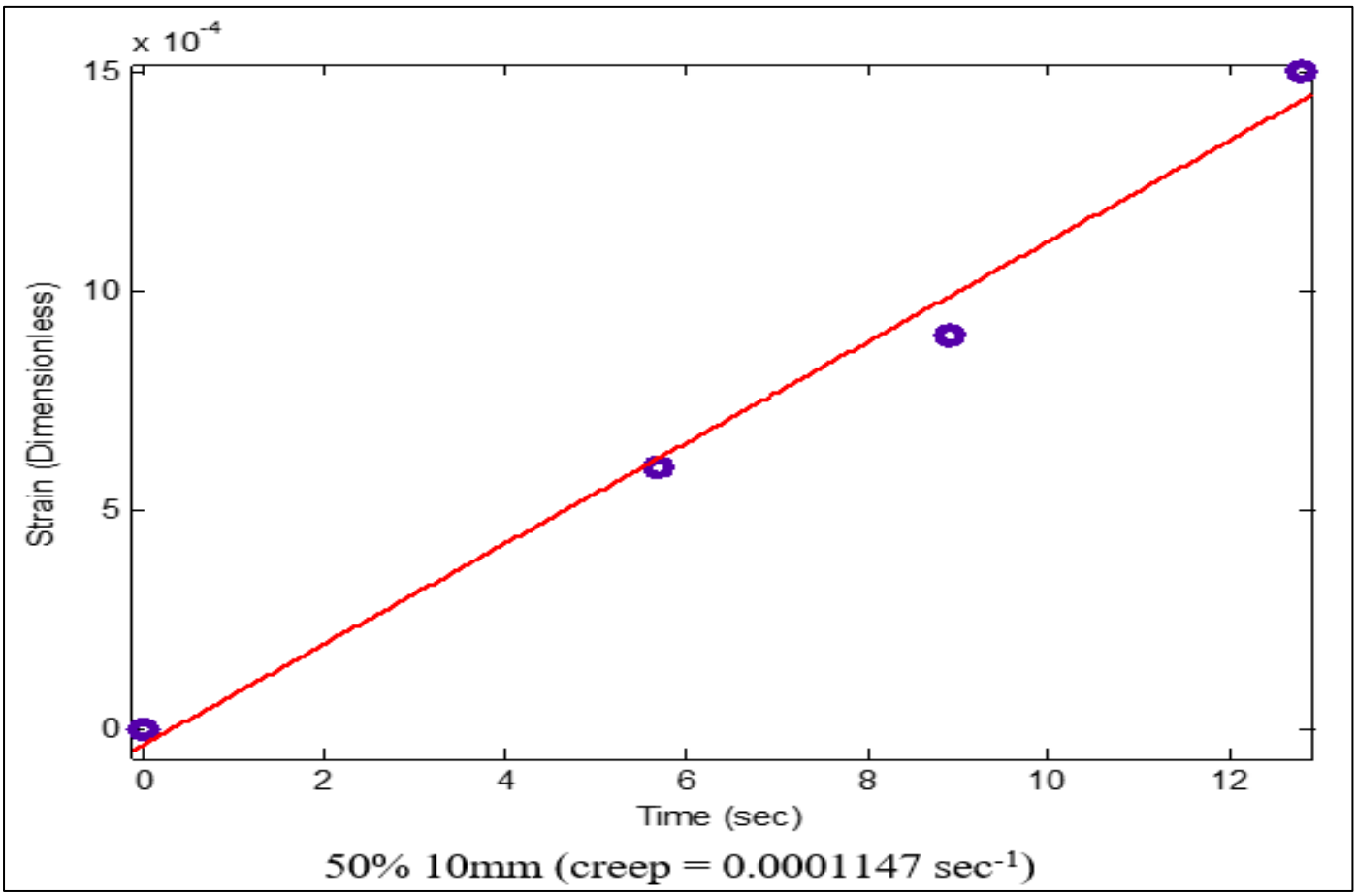

Fig 10 Creep Rate for 50% Fibre Volume Fraction and 10mm Fibre Length

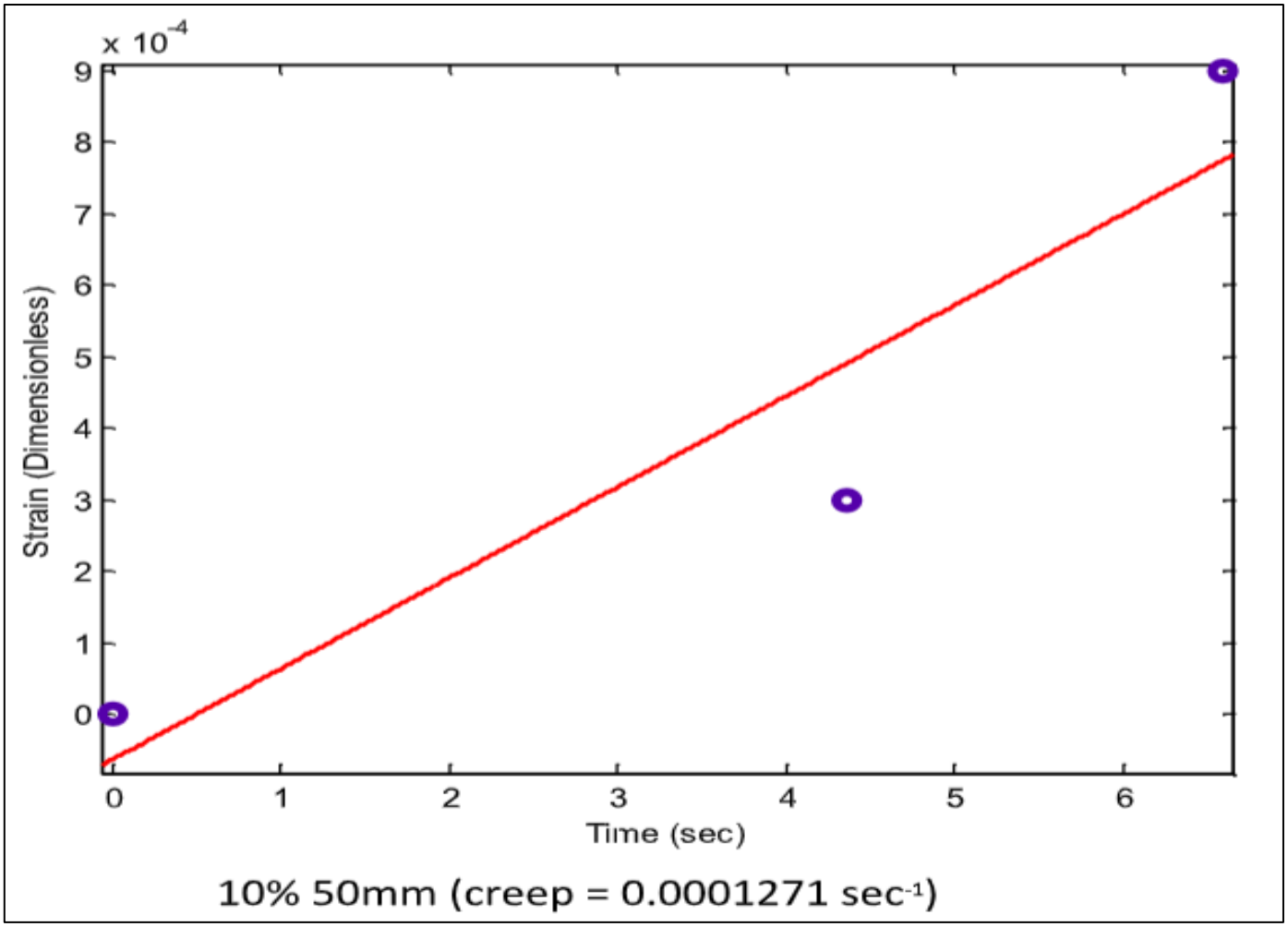

Fig 11 Creep Rate for 10% Fibre Volume Fraction and 50mm Fibre Length

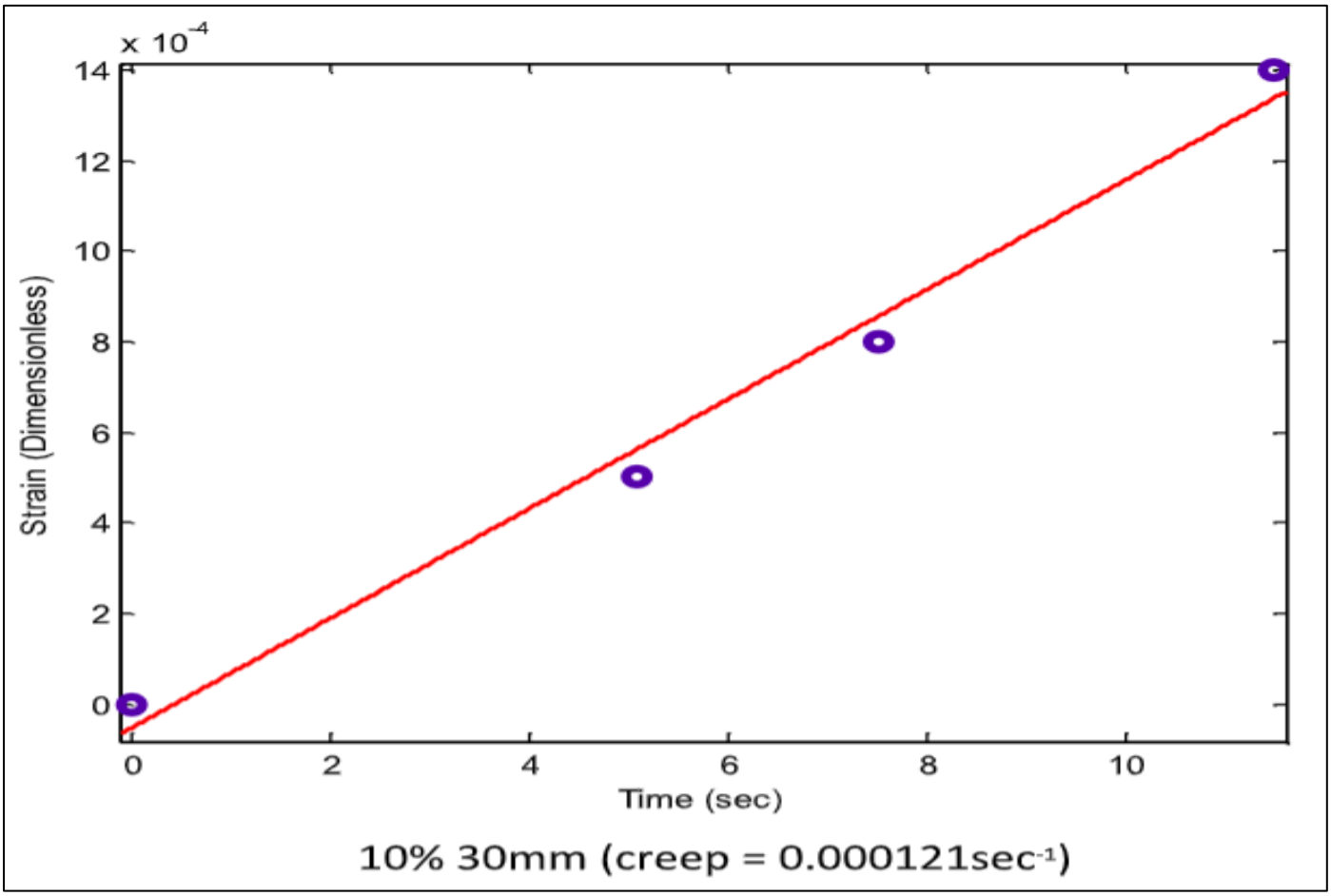

Fig 12 Creep Rate for 10% Fibre Volume Fraction and 30mm Fibre Length

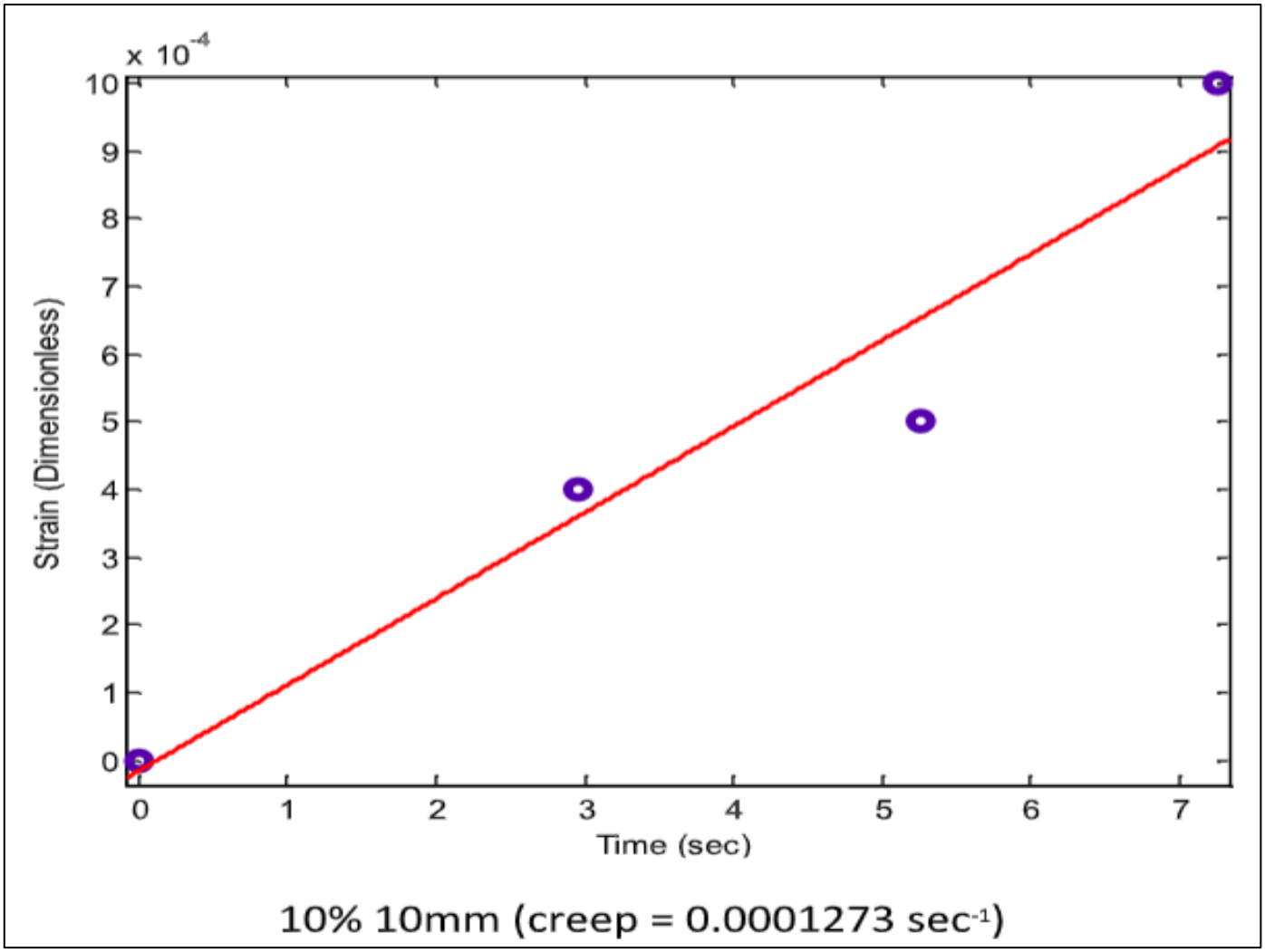

Fig 13 Creep Rate for 10% Fibre Volume Fraction and 10mm Fibre Length

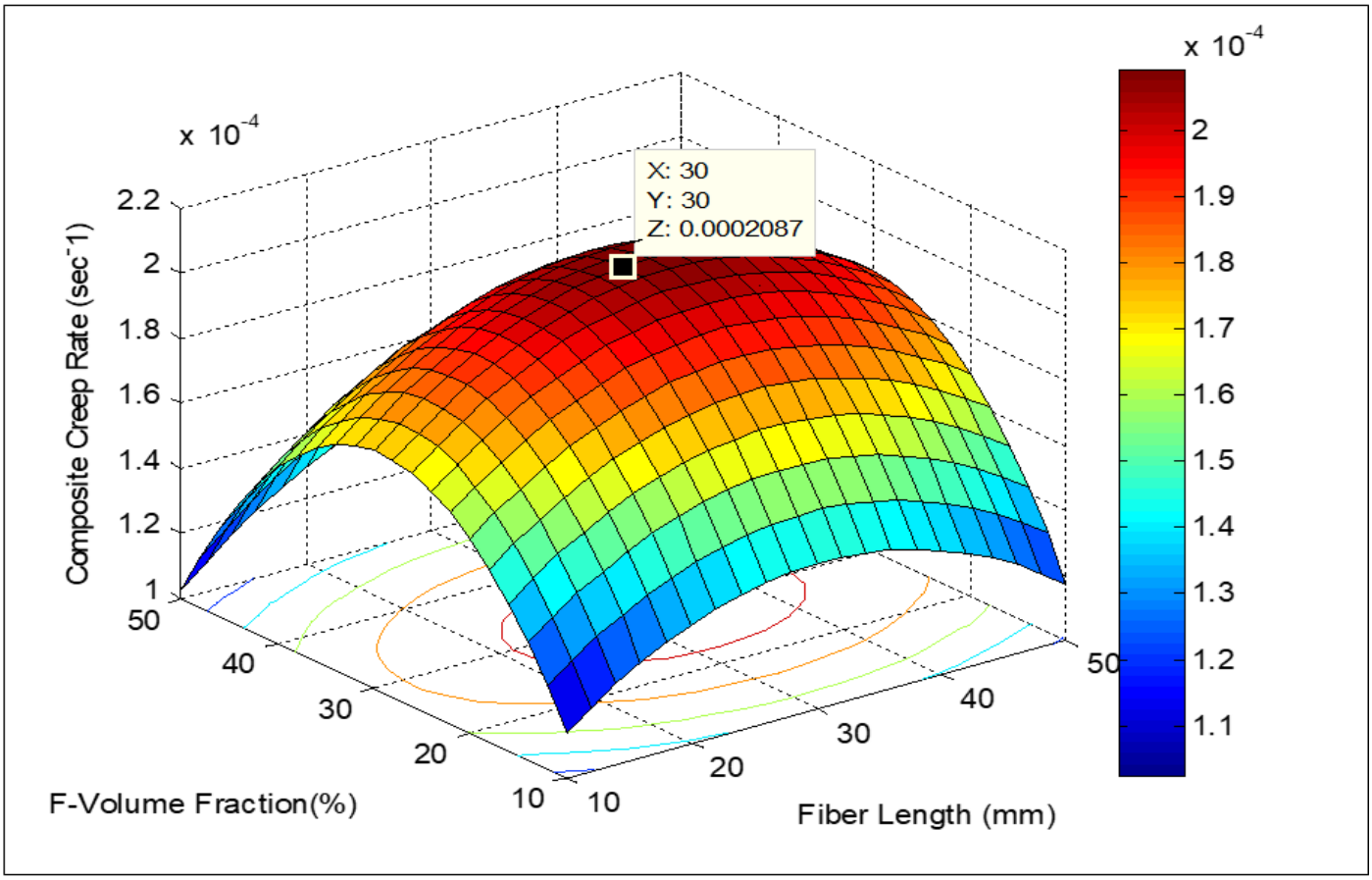

Fig 14 Surface Plot for Maximum Creep for Fibre Volume Fraction of 30% and Fibre Length of 30mm