DETERMINATION OF OPTIMUM FIBER CONTENT FOR FIBER REINFORCED MICRO CONCRETE

By

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A thesis submitted to the Department of Civil Engineering, Bangladesh University of Engineering and Technology, Dhaka, in partial fulfillment of the degree of Master of Science in Civil & Structural Engineering.

DEPARTMENT OF CIVIL ENGINEERING
BANGLADESH UNIVERSITY OF ENGINEERING AND TECHNOLOGY

28 May, 2016

The thesis titled "DETERMINATION OF OPTIMUM FIBER CONTENT FOR FIBER REINFORCED MICRO CONCRETE", submitted by Md. Belal Hossen, Student number- 0413042356F and session April/2013 has been accepted as satisfactory in partial fulfillment of the requirement for the degree of Master of Science (Civil & Structural Engineering) on 28 May, 2016.

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ABSTRACT

Fiber Reinforced Concrete is one of the most promising construction techniques and repairing materials of modern times. Polyester and steel fibers are, by far, the front runner in the field of reinforcing fibers. A very recent investigation on the properties of locally available Galvanized Iron wire (GI wire) which is basically mild steel wire with a thin coating of Zinc has discovered that it has the potential to be a viable low-cost alternative of commercially available steel fibers. Besides that, polyester fiber has been used as popular reinforcing material from long ago. On the other hand, Micro concrete technology is a new trend where the size of coarse aggregate is reduced significantly without compromising the strength of concrete. Here along with strength, workability is ensured using chemical admixture (Super plasticizer).Now a days it is mainly used for retrofitting purposes for its various inherent characteristics. Therefore, a research has been conducted to study the performance of locally available GI wire fiber reinforced Micro concrete (GWRMC) and Polyester fiber reinforced Micro concrete (PFRMC) and also make comparison to find the suitable option for our country. This paper presents the findings of several basic characteristics of GWRMC and PFRMC primarily related to strength, ductility and durability. The prime focus of the study was on the effect of fiber content on the foregoing properties of Micro concrete. Consequently, within the scope of the work, fiber dosage was varied within low range (1 to 2.5% by weight for GWRMC and 0.1 to 0.5% by volume for PFRMC) while the concrete mix-design and fiber properties were kept unchanged. A wide variety of tests including compressive and splitting tensile strength, modulus of elasticity and water absorption test (Sorptivity) were performed on suitable test specimens. It was observed for polyester fiber compressive strength increases upto 43 percent and splitting tensile strengths increases upto 30 percent with respect to control. Again for steel fiber compressive strength increases upto 47 percent and splitting tensile strengths increases upto 25 percent with respect to control. Durability test i.e. Sorptivity revealed that water absorption rate of Micro concrete is significantly lower than normal concrete. Furthermore, cost analysis and comparison of both types of fiber shows that the use of GI wire fiber instead of polyester fiber is little bit economical and convenient from the perspectives of Bangladesh.

ACKNOWLEDGEMENT

The author wish to express his deepest gratitude and sincere appreciation to Dr. Raquib Ahsan, Professor, Department of Civil Engineering, BUET for his constant guidance, invaluable suggestions, motivation in difficult times and affectionate encouragement, which were extremely helpful in accomplishing this study.

The author also takes the opportunity to pay his heartfelt thanks to all the staff members of Concrete Laboratory and Strength of Materials Laboratory for their consistent support and painstaking contributions to the research and experimental work.

The author also likes to thank Rowshon Jadid, Md. Abdullah al Sarfin, Md. Rafiqul Islam for their consistent support and motivation at different stages of this research work.

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NOTATIONS

FRMC- Fiber Reinforced Micro concrete

PFRMC- Polyester Fiber Reinforced Micro concrete

GWRMC- Galvanized iron Wire Reinforced Micro concrete

GI wire- Galvanized Iron Wire

GWRC- Galvanized iron Wire Reinforced Concrete

MoE- Modulus of Elasticity

SFRC- Steel Fiber Reinforced Concrete

Si –Initial absorption rate, mm/sec$^{1/2}$

Ss–Secondary absorption rate, mm/sec$^{1/2}$

Vf – Volume fraction of fiber

w/c ratio- Water to Cement ratio

ρ_b- Balanced reinforcement ratio

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CHAPTER 1
INTRODUCTION

1.1 General

At present Micro concrete is most widely used construction and repair material throughout the world. Therefore, it has always been very important from the civil engineering perspective and there has been a constant urge for improving the performance of Micro concrete. The greatest limitation of this concrete being lack of ductile and improving this aspect of concrete is a prime concern for civil engineers. In this pursuit for better ductility in Micro concrete, considerable amount of studies are being carried out by incorporating various types of fibers (steel fiber, glass fiber, fiber polymer, natural fiber, nano-fiber etc.) within concrete. Concrete with these fibers, generally known as FRMC (Fiber Reinforced Micro concrete), is one of the most promising new construction materials due to its improved ductility and better performance against flexure.

In the field of FRMC, polyester fibers and steel fibers are, by far, the front runner as a suitable reinforcing material; since incorporation of these fibers in concrete improve mechanical properties such as tensile strength, ductility, toughness, fatigue life, impact resistance etc. has been established in a number of researches. But additional cost for fibers has always been an issue to ponder. In this concern, fibers from GI (Galvanized Iron) wire can provide a viable low cost substitute for steel fibers, especially for Bangladesh since steel fiber for use in FRC is not available in local market and importing from the cheapest of sources proves quite expensive. Moreover, GI wire is locally produced and is available at a relatively low price. On the other hand though we have to import polyester fiber from neighboring countries, as it is not locally produced, its price is reasonable as a construction material. So it was also considered low cost reinforcing materials for this subcontinent. In this research Micro concrete was reinforced with Polyester fibers and Galvanized Iron steel fibers and thus the improvement of different properties of Micro concrete observed. At last optimum fiber content for both types of fiber was determined and their performances also compared so that we may find out the better option as reinforcing material for Micro concrete from the perspective of our country.

1.2 Background and Present State of the Problem

As a matter of recent development, very little background knowledge about fiber reinforced Micro concrete (FRMC) is available at present. Many researchers have made their researches to improve different property of concrete as requirement by adding fibers but the results of these researches are not available in general. The study is regarded as one of the pristine attempts to incorporate GI wire fiber and polyester fiber as reinforcing material in FRMC. Therefore, the research followed the guidelines and specifications available in the literature concerning steel and polyester fiber reinforced concrete. Considering this study as a stepping stone, the present research attempts to move the current state of affairs forward and to lay the groundwork for future research in this field.

1.3 Objectives and Possible Outcome

The objectives of this research are

1. To observe the workability of Micro concrete with different content of Polyester fiber and Steel fiber.
2. To observe the change of tensile strength of Micro concrete with different content of Polyester fiber and Steel fiber.
3. To observe the compressive strength of Micro concrete with different content of Polyester fiber and Steel fiber.
4. To observe the Modulus of Elasticity of Micro concrete with different content of fiber Polyester fiber and steel fiber.
5. To observe the Water Absorption of Micro concrete with different content of Polyester fiber and steel fiber.

Possible Outcome

1. Optimum content of Polyester fiber at which Micro concrete would hold sufficient tensile strength without deteriorating other properties like slump, compressive strength, durability etc. will be determined.

2. Optimum content of steel fiber at which Micro concrete would hold sufficient tensile strength without deteriorating other properties like slump, compressive strength, durability etc. will be determined.

1.4 Scope of the Study

The main focus of the study is on strength, ductility and durability of PFRMC. Three basic strength properties, namely compressive strength, split-cylinder tensile strength and modulus of elasticity have been determined for FRMC with Galvanized Iron wire and Polyester fiber. These two types of Micro concrete are termed as Galvanized Wire Reinforced Micro concrete (GWRMC) and Polyester Fiber Reinforced Micro concrete (PFRMC). For both types of concrete workability has been assessed by slump test. Durability of concrete has been verified through and water absorption capacity (Sorptivity) tests. For both types of concrete coarse aggregate was 5 mm downgraded crushed stone and fine aggregate was natural sylhet sand. To ensure workability of concrete super-plasticizer (Master gelenium) was used as admixture. Due to a wide range of tests, mix-design of the concrete was kept the same with only variation being fiber content. Low volume fraction of fiber was deployed for the GWRMC i.e. 1% to 2.5% on weight basis and for the PFRMC i.e. 0.1% to 0.5% on volume basis. Fiber content up to 6% by weight is not uncommon for SFRC; but for initial study, low fractions were preferred to judge the suitability of GI wire fiber as a substitute of steel fiber in FRMC.

1.5 Organization of the Thesis

The thesis paper has been organized into total six chapters. Apart from introductory chapter, the remainder of the thesis has been divided into five chapters.

Chapter Two: This chapter discusses the history and common features of fiber reinforced concrete, types of fiber used in concrete, development of Micro concrete and improving different properties of Micro concrete using fibers.

Chapter Three: Various types of materials such as cement, coarse aggregate, fine aggregate, GI wire, polyester fiber etc. were used for the preparation of test specimens. Properties and relevant information about the materials are provided in Chapter 3.

Chapter Four: Mix-design principles, schedule of experimentation, methodology of experiments and their significance etc. are indispensable elements of a thesis if experiment is the basis of the thesis. Chapter 4 contains all these information with appropriate illustrations and also explanations for the choice of experiments

Chapter Five: Chapter 5 covers the most significant part of the thesis- results of the experiments and their analysis. This chapter presents the findings from the experimental results and provides explanation for the behavior observed.

Chapter Six: Chapter 6 summarizes the overall research work and presents the conclusions and recommendations. Appendix A shows table for raw data of Modulus of Elasticity tests for PFRMC and GWRMC, Appendix B contains graphical presentations of Modulus of Elasticity for PFRMC and GWRMC, Appendix C contains raw data of sorptivity test for PFRMC and GWRMC and Appendix D shows graphical presentation of water absorption test for PFRMC and GWRMC.

CHAPTER 2
LITERATURE REVIEW

2.1 Introduction

Fiber reinforcement of building materials has been used for hundreds of years for the purpose of construction. In early period, straw was used as additives in clay which made bricks stronger against failure. With the passage of time, numerous better performing materials were established and used for construction. Cement is one of the revolutionary materials in construction sector. But there has always been an incessant urge for further improvement and addition of fiber in cement matrix to change and enhance material characteristics is establishing itself over the past few decades.

Fiber material is being used with the intention to reinforce brittle matrices to enhance their mechanical properties. Concrete is a well-known brittle material which is strong in compression and weak in tension. Fibers increase the flexural strength by diminishing and arresting development of cracks in concrete and improve toughness by furnishing energy dissipating mechanisms. Fibers influence many other properties including shear and compressive strength. The strength and toughness of fiber reinforced concrete is affected by many parameters e.g. properties of the fiber, the matrix, the fiber-matrix interface, size, geometry and volume/weight fraction of fibers.

A good number of researches are found in the recent concrete history on Fiber Reinforced Concrete (FRC). However, no literature is available on use of GI wire as well as polyester fiber as repairing material in Micro concrete. Therefore, researches on steel and polymer fiber reinforced concrete would provide the necessary guideline for the present research on fiber reinforced Micro concrete. This chapter focuses on the previous works on Fiber reinforced concrete which will be the basis for using polyester and GI wire fiber in Micro concrete.

2.2 Fiber Reinforced Concrete

2.2.1 General

Fiber reinforced concrete (FRC) is a concrete mix containing water, cement, aggregate and discontinuous fibers of various shapes and sizes. According to (Bentur & Mindess, 2006), fibers have been used as reinforcement for a long time. Asbestos was the first material widely used in the beginning of the 20th century. Man-made fibers produced from steel, glass, synthetics, asbestos and natural fibers such as cellulose, sisal and jute are examples of materials that are being used in contemporary FRC. Unreinforced concrete is, as known, a brittle material with high compressive strength but low tensile strength. Therefore, concrete requires reinforcement. The most known method is to use ordinary continuous reinforcing bars in order to increase the load carrying capacity in the tensile and shear zones. Fibers that are short materials randomly spread in the concrete mix, are however discontinuous. They do not enhance the (tensile) strength remarkably, but due to their random distribution in the mix, they are very effective and useful when it comes to controlling cracks. As a result, the ductility of fiber reinforced members is increased. Fibers can also be used in thin and complex members where ordinary reinforcement cannot fit well.

2.2.2 History

The use of fibers to reinforce and enhance the properties of construction materials can be traced back at least 3500 years ago, when straw was used to reinforce sunbaked bricks in Mesopotamia,. Cement-bound products have been reinforced by various types of fibers since the beginning of the last century at least. Furthermore, steel and synthetic fibers have increasingly been used to improve the properties of concrete for the past 30 or 40 years. Steel fibers reinforced concrete (SFRC) was introduced commercially into the European market in the second half of the 1970's, as mentioned by (ccanz, 2009). At that time any standards or recommendations were unavailable and this was the foremost restriction for the wide recognition of this new technology. Initially, steel fibers were mostly used as a substitute for secondary reinforcement or for controlling cracks in less critical parts of a construction. At present, steel fibers are extensively used as an integral and unique reinforcing for industrial floor slabs, shotcrete and prefabricated concrete products. They are also being used and considered for structural purposes in reinforcement of slabs on piles, full replacement of the standard reinforcing cage for tunnel segments, concrete cellars, foundation slabs and shear reinforcement in prestressed elements. On the other hand Polyester Fiber Reinforced Concrete (PFRC) exhibited improved flexural and compressive strength, abrasion resistance, and reduced drying shrinkage over that of plain cement concrete (PCC). Not only that polyester fibers are alkali resistant, and PFRC can be used in the pavement quality concrete (PQC), and as over lays, with no adverse effect on concrete. The use of fibers can result in cement saving up to 10 percent, and in the presence of fly ash, the saving in cement can be up to 35 percent. Due to their non-biodegradability, the use of polyester fibers in cement concrete road works can also help in conservation of environment.

2.2.3 Effect of fibers in concrete

Fibers are usually used in concrete to control cracking due to plastic shrinkage and to drying shrinkage. They also reduce the permeability of concrete and thus reduce bleeding of water. Some types of fibers produce greater impact, abrasion, and shatter–resistance in concrete. Generally fibers do not increase the flexural strength of concrete, and so cannot replace moment–resisting or structural steel reinforcement. Indeed, some fibers actually reduce the strength of concrete.

The amount of fibers added to a concrete mix is expressed as a percentage of the total volume of the composite (concrete and fibers), termed "volume fraction" (V_f). V_f typically ranges from 0.1 to 3%. The aspect ratio (l/d) is calculated by dividing fiber length (l) by its diameter (d). Fibers with a non-circular cross section use an equivalent diameter for the calculation of aspect ratio. If the fiber's modulus of elasticity is higher than the matrix (concrete or mortar binder), they help to carry the load by increasing the tensile strength of the material. Increasing the aspect ratio of the fiber usually segments the flexural strength and toughness of the matrix. However, fibers that are too long tend to "ball" in the mix and create workability problems.

Some recent research indicated that using fibers in concrete has limited effect on the impact resistance of the materials. This finding is very important since traditionally, people think that ductility increases when concrete is reinforced with fibers. The results also indicated that the use of micro fibers offers better impact resistance to that of longer fibers.

2.3 Types of Fiber Used in Micro concrete

A wide variety of fibers have been used in concrete. For each application it needs to be determined which type of fiber is optimal in satisfying the concrete application. The different types of fibers used as concrete reinforcement are synthetic fibers and steel fibers. The different types of synthetic fibers used are Polypropylene, Nylon, Polythene, Polyester and Glass Fibers.

For architectural and decorative concrete products and for prevention of early age cracking, synthetic fibers may be used. Steel fibers are used for applications where properties of concrete in the hardened stage have to be modified, namely, post crack flexural strength, abrasion resistance, impact resistance and shatter resistance of concrete.

Fiber-reinforced concrete is concrete that uses fibers mixed in with the still liquid cement to reinforce the concrete structure. These fibers help make the concrete stronger and more resistant to temperature extremes. They also improve the concrete's water resistance. There are four types of fiber-reinforced concrete: steel fiber, glass fiber, synthetic fiber and natural fiber reinforced concrete.

2.3.1 Steel fiber-reinforced concrete

Steel fiber-reinforced concrete is basically a cheaper and easier to use. Steel fiber-reinforced concrete uses thin steel wires mixed in with the cement. This imparts the concrete with greater structural strength, reduces cracking and helps protect against extreme cold. Steel fiber is often used in conjunction with rebar or one of the other fiber types.

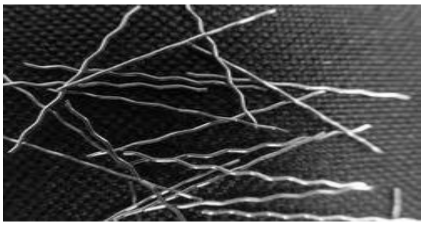

Figure 2.1: Steel fiber

2.3.2 Glass fiber reinforced concrete

Glass fiber-reinforced concrete uses fiber glass, much like found in fiber glass insulation, to reinforce the concrete. The glass fiber helps insulate the concrete in addition to making it stronger. Glass fiber also helps prevent the concrete from cracking over time due to mechanical or thermal stress. In addition, the glass fiber does not interfere with radio signals like the steel fiber reinforcement does.

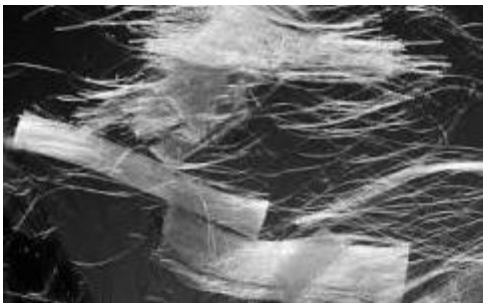

Figure 2.2: Glass fiber

2.3.3 Synthetic fiber reinforced concrete

Synthetic fiber-reinforced concrete uses plastic and nylon fibers to improve the concrete's strength. In addition, the synthetic fibers have a number of benefits over the other fibers. While they are not as strong as steel, they do help improve the cement pump-ability by keeping it from sticking in the pipes. The synthetic fibers do not expand in heat or contract in the cold which helps prevent cracking. Finally, synthetic fibers help keep the concrete from spalling during impacts or fires.

Figure 2.3: Synthetic fiber

2.3.4 Natural fiber reinforced concrete

Historically, fiber-reinforced concrete has used natural fibers, such as hay or hair. While these fibers enhance the strength of concrete they can also make it weaker if too much is used. In addition, if the natural fibers are rotting while being mixed, then the rot can continue even while in the concrete. This eventually leads to the concrete crumbling from the inside. So natural fibers are no longer used in construction.

In this research, mainly polyester fiber and steel fiber were used in Micro concrete to develop the property of concrete. In the following sections a brief description has been given specially on these two types of fibers.

2.4. Steel Fiber

Steel Fiber Reinforced Concrete (SFRC) utilizes steel fibers meeting one of the following four general types (ASTM A820/A820M, 2004). Based on shape, various types of steel fiber are shown in Figure 2.4.

a. Type I: Cold-drawn wire.

b. Type II: Cut sheet.

c. Type III: Melt-extracted.

d. Type IV: Other fibers.

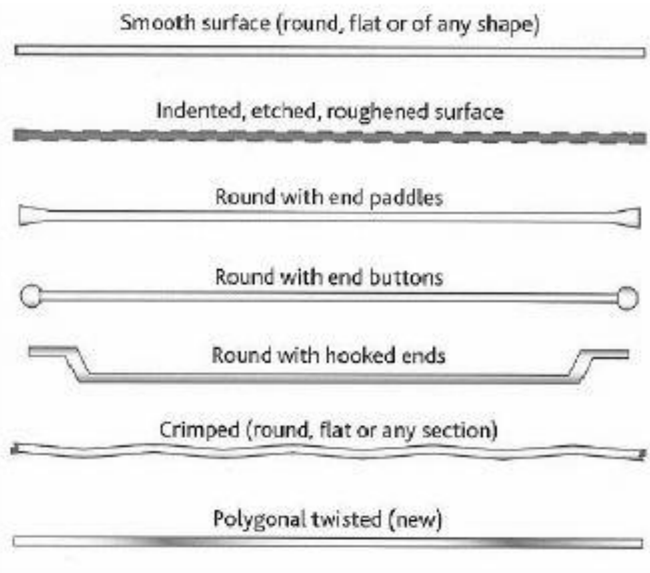

Figure 2.4: Various types of steel fiber used in Micro concrete

2.4.1 Specifications for steel fiber used in FRC

There are no specific specifications for steel fiber used in Micro concrete. For normal concrete three are some specifications stated in ACI and ASTM. The length of the steel fiber to be used in FRC generally varies between 0.5 in. (12.7 mm) to 2.5 in. (63.5 mm) and the most common fiber diameters are in the range of 0.017 in. (0.45 mm) to 0.04 in. (1.0 mm) (ACI Committee 544, 1993).In addition, the code stipulates that the aspect ratio should be between 30-100 with aspect ratio(λ) being the ratio of length(l) to diameter(d) or equivalent diameter(d_e). The specifications for aforementioned parameters of steel fibers in (ASTM A820/A820M, 2004) and (BS, 2006) conforms fully to the specifications of ACI 544.3R. Moreover, the standard steel fiber must have a minimum ultimate tensile strength of 50,000 psi (345 MPa) but fibers are available with strengths up to 2068 MPa (ACI Committee 544, 1993) Furthermore, standard fiber must satisfy bending requirements which provide a general indication of fiber ductility, as may be important in resisting breakage during handling and mixing operations, in accordance with (ASTM A820/A820M, 2004).

2.5 Types of Polyester Fiber

There are three classes of polyester used in polymer concrete mixtures. They are

- Class I resins; resist mild corrodents and non-oxidizing mineral acids.
- Class II resins; isophthalic type, are more resistant as compared to class I.
- Class III resins; are based on bisphenol-A and have the best overall resistance to corrosive solutions.

Increasing polymer content resulted in increasing flexural strength and flexural modulus while the compressive strength decreased. As a polymer fiber in this research Recron 3S modified polyester fiber was used.

2.5.1 Recron 3S modified polyester fiber

Recron 3S is a modified polyester fiber is generally used as secondary reinforcing material in concrete and soil to increase their performance. Recron 3S sample used in experiment was of 12mm length and manufactured by Reliance Industries Limited. Physical parameters of Recron 3S fiber as obtained from RIL Safety data sheet are given in Table 2.1. Use of Recron-3S as a reinforcing material is to increase the strength in various applications like cement based precast products, filtration fabrics etc. It also provides resistance to impact, abrasion and greatly improves the quality of construction during foundation, retaining wall design etc (Swine & Nayak, 2012). Currently Poly-propylene fiber is used to enhance the concrete strength properties, to reduce the shrinkage properties and to overcome chemical and biological degradation. During last few decades, much work has been done on strength deformation behavior of fiber reinforced concrete and it has been established beyond doubt that addition of fiber in concrete improves the overall engineering performance of concrete. Fiber reinforced concrete has been used in many countries in the recent past and further research is in progress for many hidden aspects of it. Material used to make fibers for reinforcement may be obtained from metal, nylon, polyester and other materials having widely varied physical properties (Foster & Attard, 2001).

Table 2.1: Physical parameters of Recron 3S fiber ((Physical and Chemical properties of Recron 3S Fibre, 2011)

Serial. No.	Parameter	Value
1	Appearance	Short cut staple fiber
2	Diameter	35 – 40 micron
3	Viscosity	Not applicable
4	Ignition temperature	> 450 ºC
5	Melting point	162-167 ºC
6	Flash point	> 329 ºC
7	Relative density	0.89-0.94 g/cm^3
8	Color	White

2.6 Micro concrete

Micro concrete is a ready mix cementitious based composition formulated for use in repairs of areas where the concrete is damaged & the area is restricted in movement, making the placement of conventional concrete difficult. This is a cementitious material, with additives, which impart controlled expansion characteristics in the plastic state with reduced water demand.

For the repair of damaged reinforced concrete elements like beams, columns, wall etc., where access is restricted, compaction is not possible and also for jacketing of RCC columns to increase its load bearing capacity.

It is designed for use in medium & large volume repairs typically ranging from 5mm to 50 mm thickness & deep. The product can be applied in sections generally ranging from 5mm to 50 mm thick although greater thicknesses may be achievable depending on the configuration of the repair location and the volume of exposed reinforcing steel & the final formulation offered. Description of different types of Micro concrete is given below.

2.6.1 Dr. Fixit Micro concrete

Dr. Fixit Micro concrete is a ready to use dry powder which requires only addition of clean water at site to produce a free flowing non shrink repair Micro concrete. It is composed of good quality cement, properly selected aggregates & additives. It is used & designed for repairing of damaged reinforced concrete elements like columns, beams & structure where the areas are restricted or not easily accessible for proper placement of concrete using vibrator. Dr. Fixit Micro concrete has excellent flowability, workability & proper particle size to reach small & congested reinforcement.

Specification

Dr. Fixit Micro concrete meets the requirement of (ASTM C109/ C109M, 1999) and (ASTM 307-03, 2012)

Areas of application

- Repair of damaged reinforced concrete elements like beams, columns, wall, etc. where access is restricted and compaction is not possible.
- For jacketing of RCC columns to increase load-taking capacity (strengthening of a vertical members)

Features & benefits

- Pumpable - Can be pumped or poured into restricted locations.
- Flowable - Flowable mortar hence does not require compaction.

- Shrinkage compensation – Controlled expansion system which compensates for shrinkage and settlement in the plastic state.
- Strength - Develops high initial and ultimate compressive strength.
- Moisture resistant - Offers excellent resistance to moisture ingress.
- Durability - Makes repaired sections highly durable & compatible to parent concrete. Thickness build up - Can be applied at 100 mm thickness at one stroke
- Early reinstatement - Rapid strength gain helps in early reinstatement & removal of shuttering.

2.6.2 Micro -concrete MC-500 (Free flowing Micro concrete)

Chemistik Micro concrete MC-500 Free Flowing Micro concrete is pre-packed factory made Micro concrete suitable for repairs to all kinds of concrete structures. It is developed and so formulated that can be used to reinstate large sections of concrete or recommended to be used where access is difficult or complex reinforcements do not allow the use of conventional materials or methods. It is based on Portland cement graded fillers and additives which control shrinkage and reduce water demand and facilitate quick and easy working with controlled quality.

Advantages

- No compaction required.
- Very low permeability.
- Chloride free.
- Excellent bond to concrete surfaces.
- Can be pumped.
- High early strength.
- Reduces shrinkage.
- Repairs upto 200 mm at one time.

Applications

This ready to use Micro concrete enhances quality of work with its consistent quality which completely eliminates human errors of onsite mixing. It can be used to repair large sections of damaged/spalled concrete, making good honeycombs in new concrete specially repairing of structural beams and columns. Repairing defects in Railway sleepers, RCC Hume pipes etc.

2.6.3 Cera Micro concrete

Cera Micro concrete is a ready to use product developed for meeting the specific requirement of repair and rehabilitation of concrete structures. The product is manufactured from graded aggregates, special cements and various chemicals to derive unique functional characteristics.

Advantages

- Excellent adhesion with parent concrete, positive grip with reinforcement
- High early and final strength
- Efficient restoration material
- Compensation for shrinkage and settlement in the plastic state
- High fluidity enables placing without Vibration
- Low permeability Ensures water tightness
- Easy to use
- Pre-packed system overcomes the batched weight variations

Uses

- Cera Micro concrete is compatible for use with different concrete grades and can be used for thin sections also.
- Cera Micro concrete is widely used in repairs where conventional concrete placing and vibrating is difficult due to congestion of reinforcement.
- Cera Micro concrete is an ideal material for structural strengthening of columns, beams etc. by encasement or jacketing.
- Cera Micro concrete can be used for repairing larger sections by mixing with 5-12mm aggregates in the proportion of 50 to 100% by weight of Micro concrete.

2.6.4 Rona bond flowable Micro concrete

Description

Ronabond flowable Micro concrete is a repair concrete used in place of hand applied mortars to repair and replace sections of concrete. Designed for pour and pump application the material is poured in to shuttering to reform concrete profiles. It is shrinkage compensated and provides high early and ultimate strengths. Flow is affected by temperature.

Uses

- Trowelled, poured or pumped
- Internal and external application
- Thick section repairs up to 300mm
- Suitable when hand applied repairs are not practical

Benefits

- Pre-packed for quality assurance and ease of mixing
- Shrinkage compensated
- Protects steel reinforcement
- Achieves extremely high compressive strength

2.7 Fiber Reinforced Micro concrete

Problems of early degradation, reduced service life and repair costs that overhead the price of structure itself, have resulted in development of new materials and technologies for repair of concrete structures. Recent results show that Fiber-Reinforced Micro concrete (FRMC), used as repair material, has very good properties concerning stability, serviceability and durability. For that reason there has been a growing interest in the use of FRMC for repair and rehabilitation of concrete structures. In many research testing of compressive strength, flexural strength, modulus of elasticity and toughness has been performed on concrete beams repaired with fiber-reinforced Micro concrete and cement mortar. Results of this research have proven that the use of high performance fiber-reinforced Micro concrete as repair material has both economic and technical advantages.

2.7.1 Durability and toughness of fiber reinforced Micro concrete

Durability of concrete has been and is still one of the main topics of research performed by scientists and professionals dealing with technology of concrete worldwide. Main reasons for early degradation of concrete structures are poor design, incompatible technology of construction and absence of monitoring and maintenance of structures during the service life. Problems of early degradation, reduced service life and increase repair costs that overhead the price of structure itself, have resulted in development of new materials and technologies for repair of concrete structures [(Shannag, Barakat, & Abdul-Kareem, 2002), (Skazlic, 2005), (Markovic, 2006)]. One of those materials is fiber-reinforced Micro concrete (FRMC), material with excellent mechanical properties and with durability properties better than those of normal concrete. Since this material can be embedded with the use of different concreting technologies (classical concreting, grouting, shotcreting) the idea of using FRMC as repair material seems very promising [((Lankard, 1985), (Gurrini, 2000), (Shannag, Barakat, & Abdul-Kareem, 2002)]. Results of testing bending behavior of four type specimens with different repair procedures are shown in Figures 2.5. In the diagraphs shown in Figures 2.6, area below the load versus displacement curve represents the ability of the specimen to absorb the energy produced during loading.

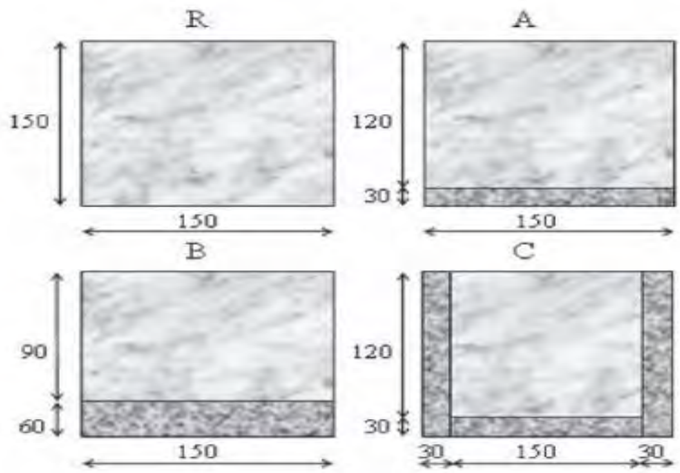

Figure 2.5: Different repair procedure with FRMC

R. Cross section of control concrete beam dimensions 150 × 150 mm without fiber reinforced.

A. Cross section of concrete beam dimensions 120 × 150 mm was reinforced in tensile zone with 30 × 150 mm layer of High Performance Fiber Reinforced Micro concrete (HPFRMC),

B. Cross section of concrete beam dimensions 90 × 150 mm was reinforced in tensile zone with 60 × 150 mm layer of HPFRMC,

C. Cross section of concrete beam dimensions 120 × 90 mm was reinforced on the sides and in tensile zone with 30 mm thick layer of HPFRMC.

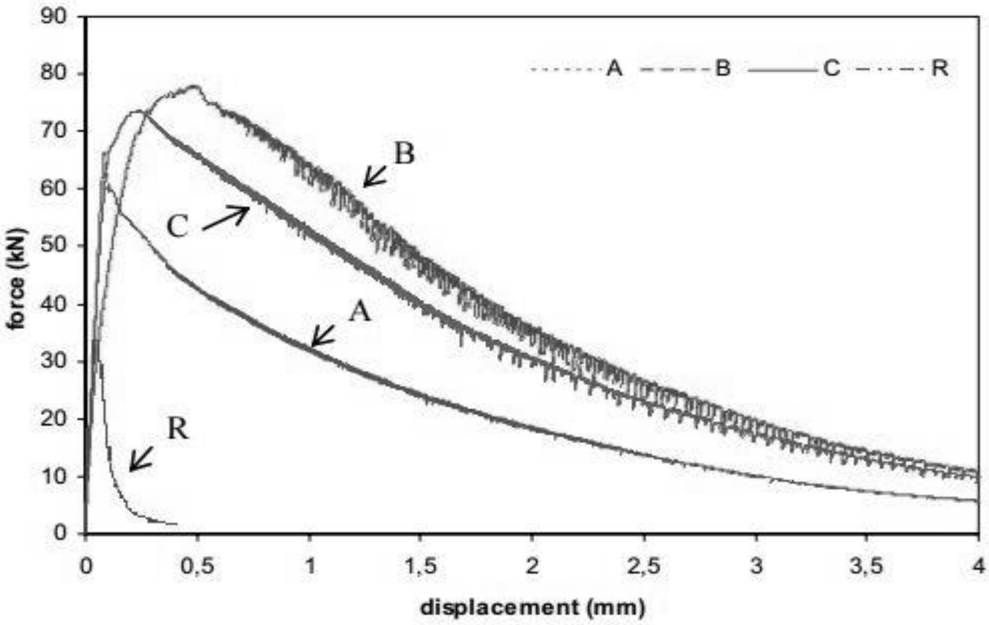

Figure 2.6 : Load versus displacement curve for different types of FRMC

From the results shown in Figure 2.6 it can be concluded that specimen B shows the best mechanical behavior under flexural load at 28 days, because it can absorb the maximum energy. From the diagram it also can be seen that compared to control concrete (R) that was strengthened with HPFRMC, all HPFRMC reinforced concretes showed an appreciable increase in flexural strength. Among all types of reinforcing, specimen HPFRMC B (that was reinforced with 60 mm thick fiber layer) showed the best behavior under flexural loading.

CHAPTER 3
MATERIALS

3.1 Introduction

Micro concrete is a stone like material obtained by permitting a carefully proportioned mixture of cement, sand and gravel or other aggregate, and water to harden in the forms of the shape and dimensions of the desired structure (Nilson, Darwin, & Dolan, 2003). The bulk of the material consists of fine and coarse aggregate. Cement and water interact chemically to bind the aggregate particles into solid mass. Even though aggregate typically accounts for 70% to 80% of the concrete volume, it is commonly thought of as inert filler having little effect on the finished concrete properties since cement is the material that has the adhesive and cohesive properties necessary to bond these inert aggregates into a solid mass of adequate strength and ductility. Yet, aggregate plays a substantial role in determining workability, strength, dimensional stability, and durability of the concrete and also have a significant effect on the cost of the concrete mixture. Therefore, properties of both cement and aggregates are of utmost importance in ensuring the desired performance of conventional concrete. But for fiber reinforced concrete, fiber is one of the most important elements and has a vital role to enhance the mechanical properties of the concrete. Efficiency of fiber reinforcement is dependent on the achievement of uniform distribution of fiber within the concrete, their interaction with the cement matrix and the ability of the concrete to be successfully cast or spread. Though, addition of fiber affects the workability of the concrete and also impedes the placement, the problem can be overcome with careful mixing and good workmanship and by using chemical admixture. Hence, selecting materials with the proper attributes is one of the prerequisites of achieving desired performance from concrete.

3.2 Cement

3.2.1 General

Cement is the binding material in concrete and thereby, the most important component of concrete. The main ingredient of cement is clinker which is manufactured by blending and grinding limestone, sand, clay and iron and heating to a temperature of 1450˚ C (2640˚ F) in a rotary kiln. The cement obtained from pulverizing clinker and gypsum is called Portland cement which is the most widely used cement all over the world. Portland cement is categorized as hydraulic cement since hydration of key ingredients of cement is the primary mechanism of strength development. About 90-95% of Portland cement is comprised of the four main cement minerals, which are Tricalcium Silicate (C_3S), Dicalcium Silicate (C_2S), Tricalcium Aluminate (C_3A), and Tetracalcium Aluminoferrite (C_4AF), with the remainder consisting of calcium sulfate, alkali sulfates, unreacted (free) CaO, MgO, and other minor constituents left over from the clinkering and grinding steps. The four cement minerals play different roles in the hydration process that converts the dry cement into hardened cement paste. The C_3S and the C_2S contribute virtually all of the beneficial properties by generating the main hydration product, C-S-H gel. However, the C_3S hydrates much more quickly than the C_2S and thus is responsible for the early strength development. The C_3A and C_4AF minerals also hydrate, but the products that are formed contribute little to the properties of the cement paste.

3.2.2 Classifications

Portland cement can be classified in various ways. In Bangladesh, based on the percentage of clinker, Portland cement is classified into two main categories: Ordinary Portland Cement (OPC) and Portland Composite Cement (PCC). Ordinary Portland cement and Portland Composite Cement are designated as CEM-I and CEM-II respectively. OPC consists 95-100% of clinker and 0-5% of gypsum. On the other hand, PCC contains about 65-80% clinker, 0-5% gypsum and 15-35% pozzolanic materials such as slag, fly ash, silica fume etc.

The ASTM has designated five types of Ordinary Portland Cement, designated Types I-V. Physically and chemically, these cement types differ primarily in their content of C3A and in their fineness. In terms of performance, they differ primarily in the rate of early hydration and in their ability to resist sulfate attack. The general characteristics of these types are listed in Table 3.1.

Table 3.1: Classification of OPC according to ASTM

	Classification	Characteristics	Applications
Type I	General purpose	Fairly high C_3S content for good early strength development	General construction (most buildings, bridges, pavements, precast units, etc)
Type II	Moderate sulfate resistance	Low C_3A content (<8%)	Structures exposed to soil or water containing sulfate ions
Type III	High early strength	Ground more finely, may have slightly more C_3S	Rapid construction, cold weather concreting
Type IV	Low heat of hydration (slow reacting)	Low content of C_3S (<50%) and C_3A	Massive structures such as dams. Now rare.
Type V	High sulfate resistance	Very low C_3A content (<5%)	Structures exposed to high levels of sulfate ions
White	White color	No C_4AF, low MgO	Decorative (otherwise has properties similar to Type I)

3.2.3 Selection

The objective of the present study is to investigate strength and ductility of GI wire fiber reinforced Micro concrete and Polyester fiber reinforced Micro concrete comparing the results with the performance of ordinary Micro concrete (without fiber). Therefore, cement properties are not of prime importance for the current research and any locally available cement would meet the requirements as long as all the specimens were prepared using the same cement. Consequently, the research was conducted using Basundhara Portland Composite Cement due to its availability.

3.3 Aggregates

3.3.1 General

Aggregates are inert granular materials such as sand, gravel, or crushed stone that is thought to serve as the filler within the concrete mix. But aggregates have a significant influence and play a key role in the properties of both fresh and hardened concrete. Changes in gradation, maximum size, unit weight, and moisture content in the aggregates can all cause alteration in the character and performance of the concrete mix. Hence, the importance of using the right type and quality of aggregates cannot be exaggerated. Generally, aggregates constitute 60% to 75% of the concrete volume (70% to 85% by mass) and are divided into two distinct categories- fine and coarse.

3.3.2 Fine Aggregate

In general, aggregate comprising of particles finer than 5 mm (0.2 in.) e.g. sand, crushed stone or crushed slag screenings etc. can be classified as fine aggregate. Fine aggregate is an essential constituent of aggregate since its primary function is to fill up the large voids between the particles of coarse aggregate and prevent honeycomb in the concrete matrix. For adequate consolidation of concrete, the desirable amount of air, water, cement, and fine aggregate (that is, the mortar fraction) should be about 50% to 65% by absolute volume (45% to 60% by mass) (Kosmatka, Kerkhoff, & Panarese, 2002). Rounded aggregate, such as gravel, requires slightly lower values, while crushed aggregate requires slightly higher values. Fine aggregate content is usually 35% to 45% by mass or volume of the total aggregate content (Kosmatka, Kerkhoff, & Panarese, 2002). It is imperative for the aggregate to be clean, inert, free of organic matter and deleterious substances, and relatively free of silt and clay.

Sylhet sand extracted from Surma river bed is utilized as fine aggregate in the concrete prepared for the study. Table 3.2 shows the gradation curve. Table 3.2 presents property test results.From the gradation curve it can be said that the fine aggregate was well graded sand.

Table 3.2: Fine aggregate (sylhet sand) properties according to (ASTM C29/29M, 1991)-97 and (ASTM C 136, 2001).

Basic Property	Condition	Shylet sand
Unit weight	Oven dry rodded unit weigth	1554.30 kg/m^3
Specific Gravity	Oven-dry bulk Sp. Gr.	2.709
Absorption capacity		2.67%
Fineness Modulus		2.92

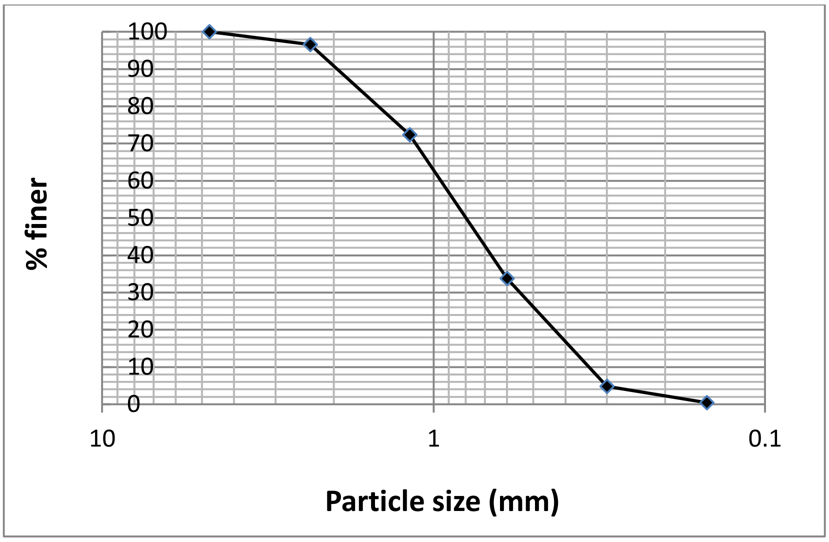

Figure 3.1: Gradation curve of fine aggregate (Sylhet sand)

3.3.3 Coarse Aggregate

In Micro concrete the size of coarse aggregate is kept smaller than usual size. As a result it can be pumped easily to the desired height. Not only that, it requires less compaction than conventional concrete and it is also easy to handle. The main advantage of using this aggregate is its capability of using in congested area where the spacing of reinforcement is kept smaller than usual spacing. Besides that, in retrofitting and renovation purposed it is also required to keep the coarse aggregate size smaller. In those cases Micro concrete with smaller particle size is ideal solution.

In this research 5mm downgraded crushed stone was used as coarse aggregate. As this ranges stone is not available or commonly used, so first of all ¾ inches downgraded crushed stone was collected. Then the stone was sieved through number four sieve to get the desired ranges stone. In this process, though the criteria of particle sizes fulfilled, but as the stone was found from sieving process, its gradation curve was not found well graded rather it was uniform graded. So it is suggested, if possible to use 5 mm downgraded crushed stone to get better performance. Table 3.3 shows the properties of coarse aggregate and Figure 3.2 represents grain size distribution of coarse aggregate.

Table 3.3: Properties of coarse aggregate.

Basic Property	Condition	Shylet sand
Unit weight	Oven dry rodded unit weigth	1584.9 kg/m^3
Specific Gravity	Oven-dry bulk Sp. Gr.	2.804
Absorption capacity		2.95%
Fineness Modulus		4.95

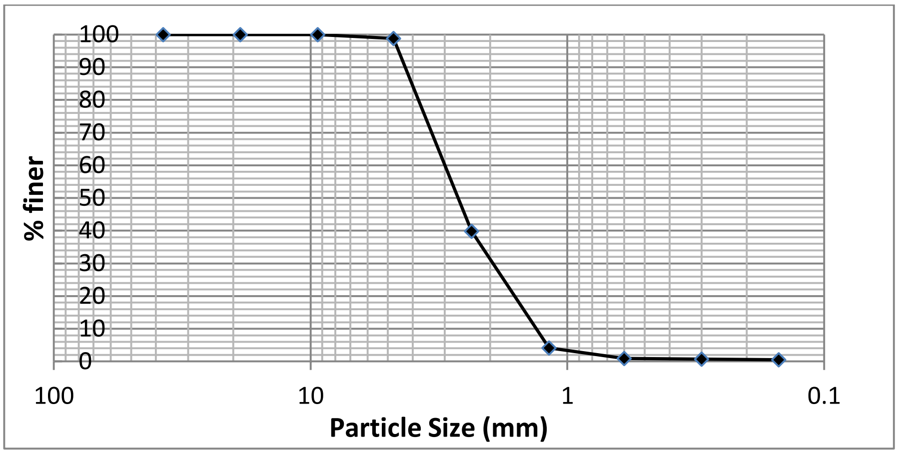

Figure 3.2: Gradation curve of coarse aggregate (crushed stone)

3.4 Galvanized Iron Wire Fiber

3.4.1 General

Galvanized Iron (GI) wire is a slender strain like piece of filament of relatively rigid or flexible metal coated with Zinc to protect corrosion. It usually has a circular section and the diameter varies from 0.37 mm to 5 mm. The commonly available GI wires are either mild carbon or high carbon steel wires, which are coated with Zinc which impart the base wire with superior properties i.e. high resistance to moisture and mechanical damage and have a very bright and smooth surface finish. The primary application of GI wire does not include being used as fiber in concrete, but it has the potential for a very effective fiber to be used in FRC, especially in conditions conducive to corrosion of steel in concrete. Where concrete is exposed to chloride, sulfate attack or carbonation, main reinforcement and fibers are expected to corrode and but Zinc coating in fiber can prove to be very convenient in inhibiting swift deterioration. Moreover, GI wire shows such filamentary nature that may allow the concrete to theoretically deform in a pseudo-ductile nature.

3.4.2 Classification

GI wire can be classified against two main features- wire material and coating technique. Materials used in GI wire do not vary a lot. The customary materials used in manufacturing are-

- Mild-carbon iron
- High-carbon iron
- Annealed carbon steel wire

Based on Zinc coating application technique i.e. galvanizing method, GI wire is divided into two categories-

I. Hot Dip G.I. wire
II. Electro-galvanized wire

3.4.3 Characteristics

Hot-dip galvanized wire offers excellent flexibility and softness. The zinc coating can vary from 100g/m^2 to 300g/m^2 (http://www.metalwiresupplier.com/, 2014).Common sizes available for this kind of wire range from 0.19 mm to 3.8 mm. Electro-galvanized wire has the characteristics of uniform, good corrosion resistant and firm zinc coating. Wire diameter ranging from 0.19 mm to 5.0 mm of this kind of GI wire is mostly used by general consumers. Zinc coating in electro-galvanization is much more controlled than hot-dipping and thereby, a thin unbroken layer of 10 g/m^2 to 25 g/m^2 is usually applied on the wire. Tensile strength of electro-galvanized wire depends on the material used in the wire and normally varies from 40 to 85 kg/mm^2 (55 to 120 ksi) (http://www.metalwiresupplier.com/, 2014).

3.4.4 Manufacturing information

There are a lot of manufacturers of GI wire around the country and world. In Bangladesh, leading companies are Gazi Wire, Moon Steel Limited, Razor Barbed Wire, Mushna Group of Industries etc. Along with locally produced wire, imported

GI wires are also available in the market. Most of the imported GI wires are from China and India.

Low carbon steel wires are normally used in producing hot dip GI wire. The manufacturing process includes wire drawing, acid washing, rust removing, annealing and coiling. Electro-galvanized iron wire is usually made with mild steel and the metal is hard drawn into wire before galvanizing and packaging processes i.e. winding, coiling, cutting and packing. GI wires are commercially available in the form of baling wire, big coil, small coil and spool wire or even pre-processed straight-cut and U wire.

3.4.5 General use and application

GI wire is rust-resistant and very versatile in applications. It is mainly used in-

a) Construction as binding wire for reinforcements
b) Gardening for binding flowers, tying fences etc.
c) Wire mesh making as weaving wire
d) Agricultural settings and orchards as baling wire
e) Packaging of products and other daily uses

3.4.6 Selection and processing

Fibers used in fiber reinforced concrete are required to conform to specifications stipulated in various codes and standards [(ACI Committee 544), (ACI Committee 544, 1993)]. Five general types of steel fibers are identified in (ASTM A820/A820M, 2004) based upon the product or process used as a source of the steel fiber material: Type I, cold-drawn wire; Type II, cut sheet; Type III, melt-extracted; Type IV, mill cut; Type V, modified cold-drawn wire. Fiber from GI (Galvanized Iron) wire falls in the category of Type V, modified cold-drawn wire. Therefore, for GI wire fiber, ASTM specifications for Type V are followed hereafter.

Performance of GI wire as concrete fiber was investigated (Karim, Mamun, & Rahman, 2013) and was found suitable in all possible aspects. All the samples satisfied the required mechanical properties, namely tensile and bending requirements, of steel fibers in FRC. According to the findings of the research, 0.64

mm diameter GI wire was chosen and suitable length for the GI wire fibers was taken to be 37.5 mm (1.5 in). The resulting aspect ratio of 58.59 falls within the limit of 30 to 100 as specified in (ACI Committee 544, 1993) or (ASTM A820/A820M, 2004). Therefore, 0.64 mm diameter GI wire was cut into 37.5mm. pieces to produce GI wire fiber which was used to prepare GWRC with an aim at assessing strength and ductility. Figure 3.3, 3.4, 3.5shows GI wire bundle and GI wire fiber ready-to-use as fiber in GWRC. The specific brand of the wire was '*Apple GI Wire*' which is produced in Narayanganj, Bangladesh. Tensile strength test was performed for a set of local GI wires with diameter of 1.5 mm. Stress-strain curves are plotted in Figure 3.6 -3.8.The properties of the GI wire indicate that iron used in this wire is mild steel. Properties of the GI wire are as follows-

Yield strength- 340 MPa (49ksi)
Ultimate strength- 500MPa (72.5ksi)
Elongation- 10%

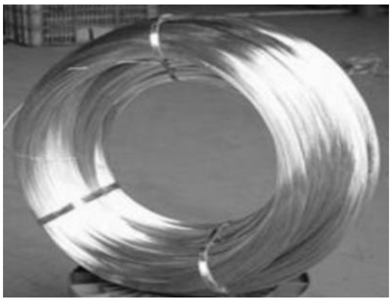

Figure 3.3: GI wire coil

Figure 3.4: GI wire fiber stack

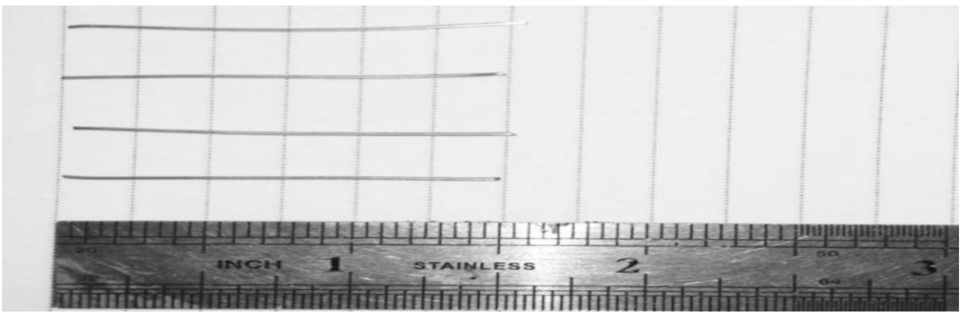

Figure 3.5: GI wire fiber

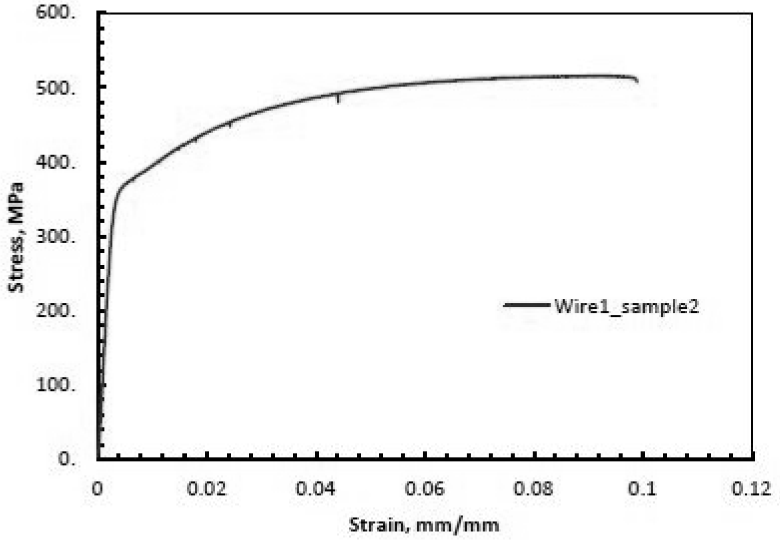

Figure 3.6: Stress-strain curve for wire1 sample 1

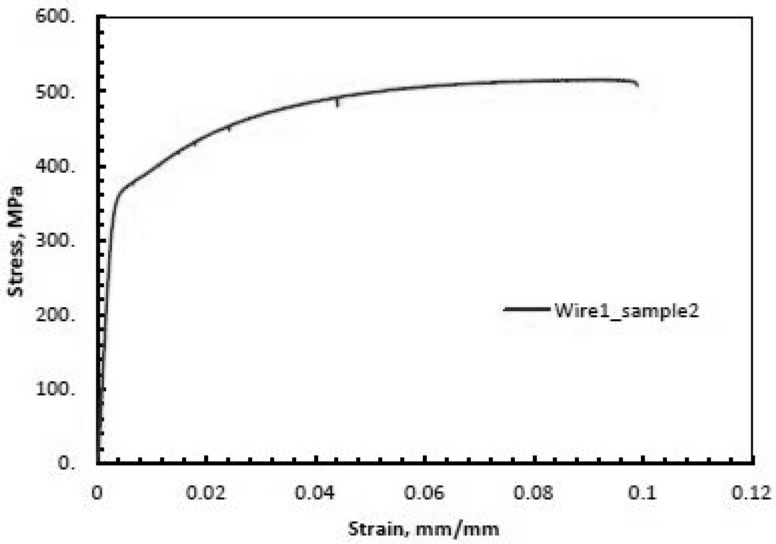

Figure 3.7: Stress-strain curve for wire1 sample 2

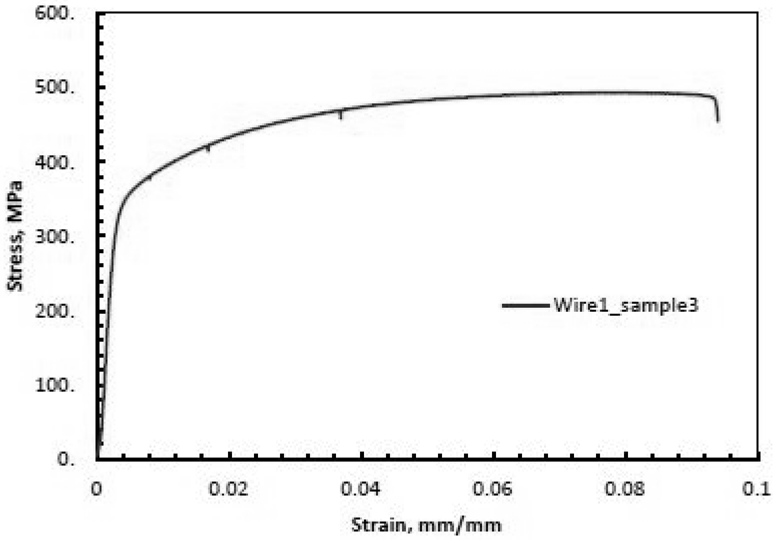

Figure 3.8: Stress-strain curve for wire1 sample 3

3.5 Polyester Fiber

Research and development work in Fiber Reinforced Concrete (FRC) composites began in India in the early 1970s. Fiber reinforced concrete was developed to overcome the problems associated with cement based materials such as low tensile strength, poor fracture toughness and brittleness of cementations composites. In the beginning, FRC was primarily used for pavements and industrial floors but now a day FRC composite is being used for a wide variety of applications including bridges, tunnel and canal linings, hydraulic structures, pipes, safety vaults and structural members.

There are so many type of polymer fiber available as secondary construction materials, The Recron-3S fiber is one of them, and The Reliance Industry Limited (RIL) has launched Recron-3S. Recron-3s polymer fiber for mixing concrete and mortar for improving certain properties of the concrete and mortar. Fibers have special triangular shape for better anchoring with other ingredient of the mix. Recron-3S fiber is available in 6mm and 12mm length.

3.5.1 General information about the fiber

A. General Details about Product:

1) Product Name: Recron-3s Polypropylene Short-cut Fiber

2) Company/ Undertaking Identification:

Manufacturer: Reliance Industries Ltd. (Polyester Sector)

3) Use of the Product:

Reliance Industry Limited (RIL) has launched Recron-3s fibers with the objective of improving the quality of plaster and concrete. Secondary reinforcement fiber for concrete, in wet laid non- woven, paper and Lead acid batteries.

B. Environmental Precautions:

In case of accidental spills, do not allow entering drains and water ways. The sample of Recron-3S is shown in Figure-

Figure 3.9: Recron-3S polymer modified fiber.

C. Merits and Demerits:

1) Merits:

– Control cracking: It helps in controlling micro shrinking cracks in plastic stage.

– Reduces water permeability: Test results have confirmed that the use of recron-3s reduces water

Permeability of the Pavement concrete.

– Reduces rebound loss: Use of recron-3s reduce the rebound loss of mortar and concretes as confirmed by user feedback.

– Increases flexibility: Due to its high modulus of elasticity, recron-3s has found to be helping in increasing the flexural strength of Pavement concrete.

– Alkali resistance: Results have shown that recron-3s has acceptable range of alkali resistance.

– Maintenance: there is no special maintenance required with the use of Recron-3s fiber.

– Environmental: Recron-3s is environmental friendly.

2) Demerits:

– With the use of this product some extra weight is added in concrete and this will increase specific gravity of concrete and self-weight of structure.

– Adding of this product in Pavement concrete will increase the cost, so it is more costly than ordinary concrete.

– Using of FRC required highly skilled worker to finish the task in proper way.

D. Application:

Recron-3s fiber can be used in concrete element such as RC and PC lintel, Beam, column, flooring and wall plastering, foundation, tanks, manhole cover and tiles plastering, Road and pavement, hollow block and precast, Railway slippers, swimming pools.

Experimental investigations on Recron- 3s fiber at CSIR (Central Building Research Institute Roorke) are given in the following table.

Table 3.4: Properties of Recron-3S fibers.

Properties	Recron 3S
Type	Polyester
Cross section	Modified triangular
Form	Monofilament (Micro)
Specefic gravity	1.36
Tensile strength (MPa)	578
Modulus of elasticity (MPa)	17240
Length (mm)	12 ± 1, 18 ± 1
Equivalent diameter (mm)	0.0375
Aspect ratio	320 and 480

3.6 Admixture

Over the course of time, the concrete industry has to cope with the day to day challenges and the use of mineral and chemical admixtures has been a magic wand for the same. To achieve the desired properties in a high quality concrete, these admixtures, particularly superplasticizers, are added to the cement. Superplasticizers are the high range water reducers used for the proper dispersion of the cement particles in a concrete suspension (Ramachandran, 1995). The addition of the superplasticizers can reduce the water-cement ratio of the concrete to the range of 0.25–0.30, without affecting its strength and workability. This also increases the durability of the concrete. Thus, we get a homogeneous workable concrete at low water cement ratios, which is less susceptible to bleeding and segregation. The addition of superplasticizers not only improves the rheological properties of the concrete but imparts it more compactness and strength in the hardened state. These days, due to the availability of different types of admixtures and cement in the market, there is flexibility in choosing the right composition of the concrete according to the desired parameters, keeping in mind the overall economy and environmental safety. Admixtures, especially new superplasticizers are being developed regularly, which dramatically change the properties of the concrete. But if there is incompatibility between the cement and the admixture, it may cause rapid loss of workability, excessive quickening/retardation of setting and low rates of strength gain, in addition to the economic loss.

3.6.1 Types of superplasticizers

Superplasticizers can be classified into following four groups:

a) Sulfonated melamine–formaldehyde condensates (SMF)

b) Sulfonated naphthalene-formaldehyde condensates (SNF)

c) Modified lignosulfonates (MLS)

d) Poly-carboxylate Derivatives (PCE based)

3.6.2 Dispersion–fluidification property of superplasticizers

Superplasticizers are the dispersants, having a polar hydrophilic group attached to a non-polar hydrophobic organic chain with some polar groups, which prevent the flocculation of fine particles of cement. The polar groups in the chain get adsorbed on the surface of the cement grains, and the hydrophobic end with the polar hydrophilic groups at the tip point outwards from the cement grain. The hydrophilic tip is able to reduce the surface tension of water, and the adsorbed polymer keeps the cement particles apart due to electrostatic repulsions. Thus the fluidic property of the concrete increases and the concrete is workable even at lower water–cement ratios (The Concrte Portal, 2013)

3.6.3 Master Gelenium

Master-Glenium ACI doesn't cause delay in the hydration process and improves early strength development.
The unique molecular structure of Master-Glenium ACE **covers less** of the surface of the cement grains to react with the water.

3.6.4 Properties of Master-Gelenium

1. The essential performance benefit of Master-Glenium ACE is fast strength development at early ages of hydration at low, ambient and heat curing temperatures. Increased productivity has a direct impact on cost efficiency.
2. The Master-Glenium ACE technology meets all the requirements of the precast industry, while simultaneously saving time and money.
3. The Master-Glenium ACE range optimizes the efficiency of the mix and reduces the production cycle, potentially doubling output.
4. The amount of energy required in the production cycle is decreased. External energy supplies can be eliminated, removing the need for heat curing. As a result, Master-Glenium ACE saves money and increases the durability of concrete by limiting any micro cracks that may result from heat curing (thermal shock, temperature gradient, etc.).
5. The flow and water reduction action of Master-Glenium ACE enables the robust and direct formulation of self-compacting concretes. They can be placed without vibration when combined with a compatible manufacturing process. This reduces the stress factor of vibration and noise for workers and nearby residents.

Figure 3.10: Superplasticizer (Master-Gelenium)

CHAPTER 4
EXPERIMENTAL PROGRAMME

4.1 Objectives

The primary aim of the experiments conducted under the current program is assessing the performance of fiber (Polyester and steel) reinforced Micro concrete. Performance, literally, refers to a very broad spectrum and it is imperative to narrow down the focus on the specific parameters that are intended to be inspected. Three salient features of concrete have been brought under scrutiny in the present study- workability, strength, and durability. Strength itself can attract an open interpretation, and therefore, it is decided that three basic properties that define strength i.e. modulus of elasticity, compressive and tensile strength are going to be considered in this regard. And finally, durability which is directly related to the pores in the concrete matrix is judged by permeability to water and chloride ions through these pores into concrete. To sum up, the goal of the experimental phase of the research is to perform the following experiments-

- Slump test of Micro concrete
- Compressive strength of cylindrical concrete specimens
- Splitting tensile strength of cylindrical concrete specimens
- Determination of Static Modulus of Elasticity of concrete in compression Measurement of Rate of Absorption of Water by concrete (Sorptivity test)

4.2 Experiment Scheme

The range of tests carried out was quite multidimensional and a carefully thought planning was required to accomplish the work in the stipulated time frame. The tests were conducted in three phases. The first phase was for the determination of slump which was done during the mixing and preparation of concrete for casting cylinders. In the second phase of the experiments, mechanical properties i.e. modulus of elasticity, compressive and tensile strength were determined for control specimens, PFRMC and GWRMC with various fiber contents. Samples were cured for 28 days for compressive strength, Splitting tensile strength and modulus of elasticity. Third phase of the tests featured with Sorptivity test. Sorptivity tests were performed for samples aged 42 days since durability tests are more reliable for concrete aged more. Therefore, the experimental design comprises of three phases-

- First phase- determination of slump for measuring workability.
- Second phase- determination of modulus of elasticity, compressive and splitting tensile strength
- Third phase- evaluation of durability through Sorptivity test.

4.3 Mix Design

Appropriate proportioning of constituent materials which is termed as 'mix-design' is the key to achieving desired results in concrete. The art of mix design is reliant on quite a lot of factors. For fiber reinforced Micro concrete, the factors to be considered are even more. Moreover, types of fibers are very diverse, so are their characteristics. Therefore, the mix proportion and performance of concrete varies with the use of different fibers. Albeit, there is no specific guideline for fiber reinforced Micro concrete; standards and codes such as (ACI Committee 544, 1993), (ASTM C1116/ C1116M, 2002) etc. are available for fiber reinforced concrete. According to the code, following are the factors that influence the mix proportioning procedure of fiber reinforced concrete the most-

1. Workability and consistency
2. Aspect ratio of the fibers, l/d
3. Volume fraction of fiber, V_f
4. Type of fibers-size, shape, strength, modulus of elasticity etc.
5. Balling of fibers
6. Ratio of fine to coarse aggregate etc.

In addition, the aim of the research is to explore the possibilities of using PFRMC and GWRMC in Bangladesh. As a result, established construction practices here in Bangladesh also played an important part in determining suitable mix-proportion. Generally, mix-design is specified on weight basis all over the world and measuring weight of the aggregate, cement and other materials is convenient if a suitable weighing facility is available. Large scale productions require huge weighing facilities which are appropriate for batching plants for ready-mix concrete; but for small construction sites, these facilities might incur undue overhead. Moreover, ready-mix concrete is relatively new in Bangladesh and just recently garnering popularity, but majority of construction works are still dependent on small scale mixing and casting method. Due to unavailability of proper weighing facilities, a customary mix-design based on volumetric ratio has been used for construction over the years and it is well established here in Bangladesh. Therefore, basic concrete mix-proportion for the current study is chosen based on a conventional volumetric ratio of the materials. According to this mix-design, ratio of cement to fine aggregate to coarse aggregate is adopted to be 1:1:1.5 and the w/c ratio was fixed to 0.31.Fiber content for polyester fiber reinforced micro concrete was varied from 0.1%- 0.5% (Hossain, T., 2015) by volume basis. On the hand for GI fiber reinforced micro concrete the fiber content was varied from 1% to 2.5% (Emon, M. A.B., 2014) by weight basis. Mix-design on weight basis corresponding to this criterion is tabulated in Table 4.1 and Table 4.2 for PFRMC and GWRMC. All other mix-design parameters are chosen from (Karim, Mamun, & Rahman, 2013) and (Ahsan, Hasan, & Ahmed, 2015). It should be noted that, due to required workability and control shrinkage super-plasticizing admixture (master-Gelenium) was used.

Table 4.1: Mix-design of micro concrete with polyester fiber.

Item	Polyester fiber reinforced Micro concrete
Cement, kg/m3	550.5
Water, kg/m3	171
Coarse Aggregate, kg/m3	963.5
Fine Aggregate, kg/m3	698.5
Water Cement Ratio	0.31
Super plasticizer/ kg cement	6 ml
Fiber content (Volume percent)	0.1%, 0.2%, 0.3%, 0.4% and 0.5%

Table 4.2: Mix-design of micro concrete with GI (Steel) fiber.

Item	Galvanized wire reinforced Micro concrete
Cement, kg/m3	550.5
Water, kg/m3	171
Coarse Aggregate, kg/m3	963.5
Fine Aggregate, kg/m3	698.5
Water Cement Ratio	0.31
Super plasticizer/ kg cement	6 ml
Fiber content (weight percent)	1.0%, 1.5%, 2.0% and 2.5%

4.4 Slump Test

4.4.1 General

This test method is intended to provide the user with a procedure to determine slump of plastic hydraulic-cement concretes according to (ASTM C143/143 M, 2010). This test method is considered applicable to plastic concrete having coarse aggregate up to 1.5 inch [37.5 mm] in size. If the coarse aggregate is larger than 1.5 inch [37.5 mm] in size, the test method is applicable when it is performed on the fraction of concrete passing a 1.5-inch [37.5-mm] sieve, with the larger aggregate being removed in accordance with the section titled “Additional Procedure for Large Maximum Size Aggregate Concrete”. This test method is not considered applicable to non-plastic and non-cohesive concrete.

4.4.2 Methodology and test setup

The test specimen shall be formed in a mold made of metal not readily attacked by the cement paste. The metal shall not be thinner than 0.060 in. [1.5 mm] and if formed by the spinning process, there shall be no point on the mold at which the thickness is less than 0.045 in. [1.15 mm].The mold shall be in the form of the lateral surface of the frustum of a cone with the base 8 in. [200 mm] in diameter, the top 4 in. [100 mm] in diameter, and the height 12 in. [300 mm].Individual diameters and heights shall be within 6 ⅛in. [3mm] of the prescribed dimensions. The base and the top shall be open and parallel to each other and at right angles to the axis of the cone. The mold shall be provided with foot pieces and handles. The mold shall be constructed without a seam. The interior of the mold shall be relatively smooth and free from projections. The mold shall be free from dents, deformation or adhered mortar. A mold which clamps to a nonabsorbent base plate is acceptable instead of the one illustrated provided the clamping arrangement is such that it can be fully released without movement of the mold and the base is large enough to contain all of the slumped concrete in an acceptable test.

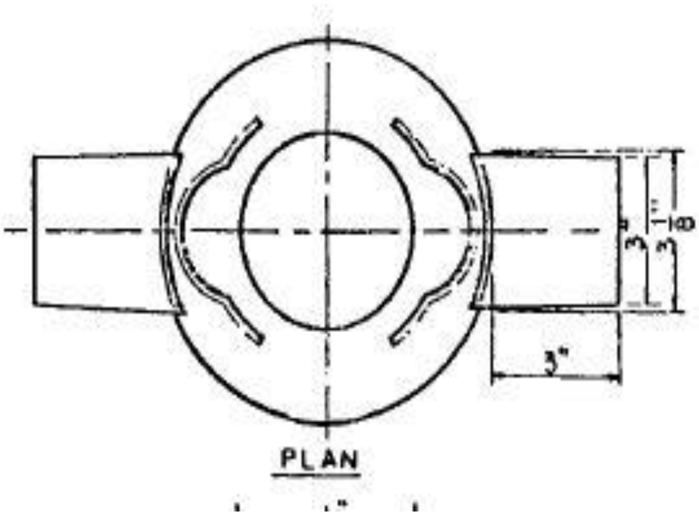

Figure 4.1: Plan of slump test apparatus

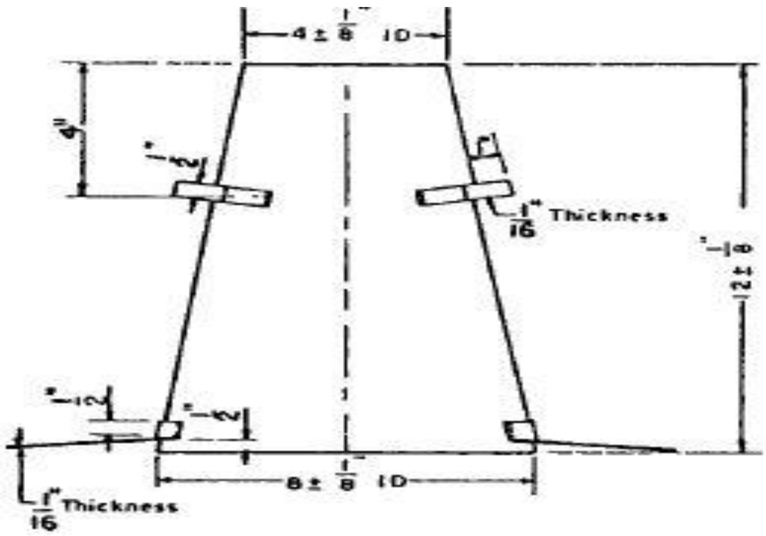

Figure 4.2: Dimensions of slump test apparatus

4.4.3 Significance of results

The result found from this test gives an indication about the workability of concrete during placing and casting. If the concrete don't have sufficient slump then it is tough to handle and desired performance can't be achieved. So a minimum slump is set limit for using concrete for different purposes.

4.5 Compressive Strength Test

4.5.1 General

Compressive strength of cylindrical concrete specimens; for example, molded cylinders and drilled cores; is determined according to (ASTM C39/ C39M, 2003) .Concrete should have a unit weight in excess of 50 lb/ft^3 [800 kg/m^3] for this test. This standard test is conducted by applying a compressive axial load to molded cylinders at a rate which is within a prescribed range until failure occurs. The compressive strength of the specimen is calculated by dividing the maximum load attained during the test by the cross-sectional area of the specimen.

As compressive strength is not a fundamental or intrinsic property of concrete made from given materials; care should be exercised in the interpretation of the strength. Obtained values are dependent on the size and shape of the specimen, batching, mixing procedures, the methods of sampling, molding, and fabrication and the age, temperature, and moisture conditions during curing.

4.5.2 Methodology and test setup

Compression tests of moist-cured specimens must be done as soon as practicable after removal from moist storage. Test specimens must be kept moist by any convenient method during the period between the removals from moist storage and testing. They need to be tested in the moist condition. All test specimens for a given test age should be broken within the permissible time tolerances prescribed in (ASTM C39/ C39M, 2003).

Bearing plates were placed at the top and bottom for even distribution of loads. Compressive load was applied by a hydraulically operated machine continuously and without shock. The load should be applied at a rate of movement (platen to crosshead measurement) corresponding to a loading rate on the specimen within the range of 0.15 to 0.35 MPa/s (20 to 50 psi/s) . So, the machine was set for a loading rate of 2500 N/s (560 lb/s) which falls within the stipulated range. Although, a higher rate of loading may be allowed during the application of the first half of the anticipated loading phase, the same rate was maintained from the start to the end of loading. The load is applied until the specimen fails, and the maximum load carried by the specimen during the test is recorded. The type of failure and the appearance of the concrete are generally noted. Test setup is shown in Figure 4.3.

Figure 4.3: Test setup for compression test of cylinders

4.5.3 Significance of results

The results obtained from this test method are used as a basis for quality control of concrete proportioning, mixing, and placing operations; determination of compliance with specifications; control for evaluating effectiveness of admixtures; and similar uses.

4.6 Test for Splitting Tensile Strength

4.6.1 General

The splitting tensile strength of cylindrical concrete specimens, such as molded cylinders and drilled cores, is determined by (ASTM C496/ C496M, 2011). According to the standard, a diametral compressive force is applied along the length of a cylindrical concrete specimen to conduct this test method at a rate that is within a prescribed range until failure occurs. Because of this loading, tensile stresses are induced on the plane containing the applied load and relatively high compressive stresses in the area immediately around the applied load. Tension failure rather than compressive one occurs because the areas of load application are in a state of tri-axial compression, thereby allowing them to withstand much higher compressive stresses than would be indicated by a uni-axial compressive strength test result.

The splitting tensile strength is obtained by dividing the maximum load sustained by the specimen by appropriate geometrical factors. The splitting tensile strength of the specimen is calculated as follows-

$$T = 2P/\pi ld \quad \text{……………………………………………………………………eq.4.1}$$

Where,

T = splitting tensile strength, MPa (psi),

P = maximum applied load indicated by the testing machine, N (lbf),

l = length, mm (in.) and

d = diameter, mm (in.)

4.6.2 Methodology and test setup

Size, molding, and curing requirements of the test specimens are conformed according to Practice (ASTM C192/C 192M, 2007). Between the removal from the curing environment and testing, moist-cured specimens are kept moist by suitable methods. Diametral lines are drawn on each end of the specimen using a suitable device that will ensure that they are in the same axial plane.

One of the plywood strips is centered along the center of the lower bearing block. The specimen is placed on the plywood strip and aligned so that the lines marked on the ends of the specimen are vertical and centered over the plywood strip. A second plywood strip is placed lengthwise on the cylinder, centered on the lines marked on the ends of the cylinder.

Assembly is positioned to ensure the following conditions:

- The projection of the plane of the two lines marked on the ends of the specimen intersects the center of the upper bearing plate, and
- The center of the specimen is directly beneath the center of thrust of the bearing block

The load has to be applied continuously without shock, at a constant rate within the range 0.7 to 1.4 MPa/min (100 to 200 psi/min) splitting tensile stress until failure of the specimen. For this research, the rate of loading was maintained at 500 N/s which falls within the instructed range of loading rate.

The maximum applied load was recorded, indicated by the testing machine at failure and splitting tensile strength was computed by the formula given in Equation 4.1. The test setup is shown in Figure 4.4.

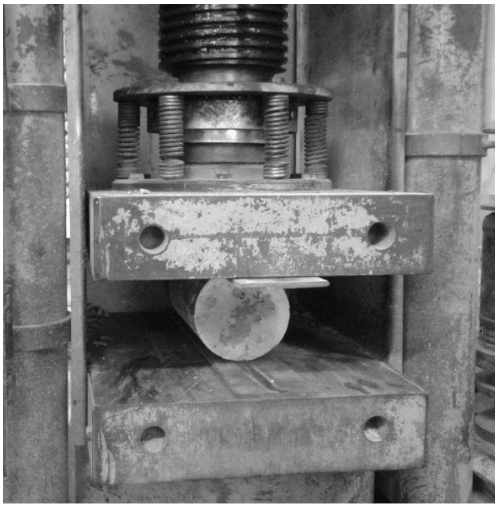

Figure 4.4: Test setup for splitting tensile strength of cylinders

4.6.3 Significance of result

Determination of splitting tensile strength is simple and usually greater than direct tensile strength and lower than flexural strength (modulus of rupture). For the evaluation of the shear resistance provided by concrete in reinforced lightweight aggregate concrete members and the determination of the development length of reinforcement; splitting tensile strength is used in the design of structural lightweight concrete members.

4.7 Test for Static Modulus of Elasticity

4.7.1 Concept

Young's modulus of elasticity of molded concrete cylinders and diamond-drilled concrete cores under longitudinal compressive stress are determined by (ASTM C469/ C469M, 2002). Stress versus strain curve is plotted with test data and Modulus of Elasticity is calculated to the nearest 344.74 MPa (50,000 psi) as follows:

$$E = (S_2 - S_1) / (e_2 - 0.000050) \qquad \text{eq. 4.2}$$

Where,

E = chord modulus of elasticity, psi,

S_2 = stress corresponding to 40 % of ultimate load,

S_1 = stress corresponding to a longitudinal strain, e_1 of 0.00005, psi, and

e_2 = longitudinal strain produced by stress S_2.

But in the laboratory test set up load can be applied up to 40 kips. So the ultimate load values were taken from the average of compressive strength test.

4.7.2 Methodology and test setup

Specimens are tested within 1 h after removal from the curing or storage room. Specimens, removed from a moist room for test, are kept moist by a wet cloth covering during the interval between removal and test. Specimens' ends are made perpendicular to the axis (± 0.5°) and plane (within 0.002 in.). Plainness is accomplished by capping, or by lapping, or by grinding if the specimen as cast does not meet the plainness requirements. Plainness is considered within tolerance when a 0.002 in. (0.05 mm) feeler gage does not pass between the specimen surface and a straight edge held against the surface. Repairing aggregate pop outs that occur at the ends of specimens is not prohibited, provided the total area of pop outs does not exceed 10 % of the specimen area and the repairs are made before capping or grinding is completed.

The specimen is placed, with the strain-measuring equipment attached, on the lower platen or bearing block of the testing machine. The axis of the specimen is carefully aligned with the center of thrust of the spherically-seated upper bearing block. The reading is noted down on the strain indicators.

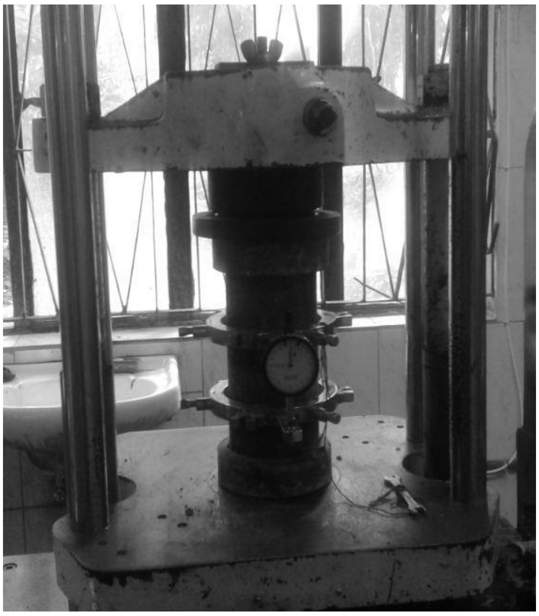

Figure 4.5: Test setup for Modulus of Elasticity

The load is applied continuously and without any sudden variations. Screw type testing machines are set so that the moving head travels at a rate of about 0.05 in. (1.25 mm)/min when the machine is running idle. In hydraulically operated machines, the load is applied at a constant rate within the range 35 ± 5 psi (241 ± 34 kPa)/s. Without interruption of loading, the applied load and longitudinal strain are recorded at the point when the longitudinal strain is 50 millionths and when the applied load is equal to 40 % of the ultimate load. Total longitudinal deformation divided by the effective gage length is defined as longitudinal strain. Readings are taken at two or more intermediate points without interruption of loading to determine a stress-strain curve. An instrument can be used that makes a continuous record for this purpose. Except the final loading, the load is reduced to zero at the same rate at which it was applied, immediately after reaching the maximum load. No automatic data logger was available and so, data was obtained by taking readings manually for the present study. The results are plotted with the longitudinal strain as the abscissa and the compressive stress as the ordinate when the intermediate readings are taken. The compressive stress is calculated by dividing the quotient of the testing machine load by the cross-sectional area of the specimen. Modulus of Elasticity is then determined by equation 4.2.

4.7.2 Significance of result

For sizing of reinforced and non-reinforced structural members, establishing the quantity of reinforcement, and computing stress for observed strains, modulus of elasticity value, applicable within the customary working stress range (0 to 40 % of ultimate concrete strength) is used. Obtained modulus of elasticity values may be less than moduli derived under rapid load application (dynamic or seismic rates, for example), and may be greater than values under slow load application or extended load duration in most cases, given other test conditions being the same.

4.8 Test for Rate of Absorption of Water

4.8.1 Concept

Penetrability of the pore system affects the performance of concrete greatly, especially where concrete is subjected to aggressive environments. Rate of ingress of water or other liquids through this porous system is largely controlled by absorption in unsaturated concrete due to capillary action. This phenomenon is termed as 'water sorptivity' (Hall, 1989) i.e. a test procedure for measuring rate of absorption (sorptivity) of water by concrete. The methodology was adopted by ASTM and it was introduced as a standard test; under the designation (ASTM C1585/ C1585 M, 2006); for determining the rate of absorption of water by hydraulic cement concrete by measuring the increase in the mass of a specimen resulting from absorption of water as a function of time when only one surface of the specimen is exposed to water. Dominated by capillary suction during initial contact with water; the exposed surface of the specimen remains immersed in water and water ingress of unsaturated concrete. Absorption is calculated by dividing the change in mass by the product of the cross-sectional area of the test specimen and the density of water. Temperature effect on the density of water is neglected and a value of 0.001 g/mm^3 is used for this test. The units of I is mm.

$$I = m_t/(ad) \qquad \text{eq. 4.4}$$

Where,
I = the absorption,
m_t= the change in specimen mass in grams, at the time t,
a = the exposed area of the specimen, in $mm^2$and
d = the density of the water in g/mm^3.

Slope of the line that is the best fit to I plotted against the square root of time ($s^{1/2}$) is defined as the initial rate of water absorption ($mm/s^{1/2}$). This slope can be obtained by using least-squares, linear regression analysis of the plot of I versus $time^{1/2}$. Regression analysis is done by using all the points from 1 min to 6 h, excluding points for times after the plot shows a clear change of slope. Data between 1 min and 6 h must follow a linear relationship and show a systematic curvature to determine the initial rate of absorption.

4.8.2 Methodology and Test setup

Conditioning of sample before the start of the absorption procedure is very important for this test. Samples were conditioned by processing them through suitable temperatures (50 ± 2°C for 3 days in desiccators), humidity and storage procedures (at 23 ± 2°C for 15 days in a sealable container)

Specimens were removed from the storage container and mass of the conditioned specimens were recorded to the nearest 0.01 g before sealing of side surfaces. Four diameters of the specimen were measured at the surface to be exposed to water. Diameters are measured to the nearest 0.1 mm and the average diameter is calculated to the nearest 0.1 mm. Side surface of each specimen was sealed with a suitable sealing material which was electrician's plastic tape in this case. The end of the specimen that is not exposed to water is supposed to be sealed by using a loosely attached plastic sheet.

The absorption procedure was conducted at 23 ± 2°C with tap water conditioned to the same temperature to determine water absorption as a function of time. Sealed specimen mass was measured to the nearest 0.01 g and it was recorded as the initial mass for water absorption calculations. At the bottom of the pan, support device was placed and then the pan was filled with tap water. The test setup is shown in Figure 4.6.

Figure 4.6: Test setup for rate of water absorption (sorptivity)

After starting the timing device, the test surface of the specimen was immediately placed into the water on the support device. Time and date of initial contact with water were recorded. According to the intervals listed in Table 4.4, mass is recorded after first contact with water. When a test specimen was removed from the pan, timing device was stopped when the contact time is less than 10 min, and any surface water was blotted off with a dampened paper towel for every mass determination.

Table 4. 3: Times and tolerances for the measurements schedule

Time	60 sec	5 min	10 min	20 min	30 min	60 min	Every hour up to 6 h	Once a day up to 3 days	Day 4 to 7 (3 readings 24 h apart)	Day 7 to 9 One reading
Tolerance	2 s	10 s	2 min	2 min	2 min	2 min	5 min	2 h	2 h	2 h

The mass is measured to the nearest 0.01 g within 15 seconds of removal from the water. The timing device is started again immediately after replacing the specimen in the water on the support device.

4.8.3 Significance of result

Water absorption of a concrete surface is largely dependent on many factors including:

(a) Concrete mixture proportions

(b) The presence of chemical admixtures and supplementary cementitious materials

(c) The composition and physical characteristics of the cementitious component and of the aggregates.

(d) The entrained air content

(e) The type and duration of curing

(f) The degree of hydration or age

(g) The presence of micro-cracks

(h) The presence of surface treatments such as sealers or form oil and

(i) Placement method including consolidation and finishing.

(j) Moisture condition of the concrete also strongly affects water absorption at the time of testing.

Determination of the susceptibility of an unsaturated concrete to the penetration of water is the prime function of this test method. Differences are visualized between the rate of absorption of concrete at the surface and the rate of absorption of a sample taken from the interior. Because of less curing; exterior surface becomes exposed to the most potentially adverse conditions. Using this test method, both the concrete surface and interior concrete water absorption rate can be measured. Absorption at different distances from the exposed surface can be evaluated by drilling a core horizontally and cutting it transversely at selected depths.

CHAPTER 5
RESULT AND DISCUSSION

In this chapter, test results from all the experiments and their analysis with proper explanations and illustrations will be presented.

5.1Slump

Slump gives an indication about the workability of concrete during placing and casting. The concrete without sufficient slump it tough to handle for different purposes and desired performance can't be achieved.

5.1.1 Results

It was found with the increases of Polyester fiber content the value of slump decreases. For 0.1% PFRMC the slump was found 6 inch, for 0.2% PFRMC it was found 5.5 inch, for 0.3% PFRMC it was found 5.25 inch. Again for 0.4% Polyester fiber content the slump drop down sharply to 1 inch and for 0.5 % concrete almost retains its shape and the slump was found only 0.5 inch. So it was found after 0.3% Polyester fiber content the amount of concrete slump reduces significantly. Albeit this property can be improved by using chemical admixture (Superplasticizer).

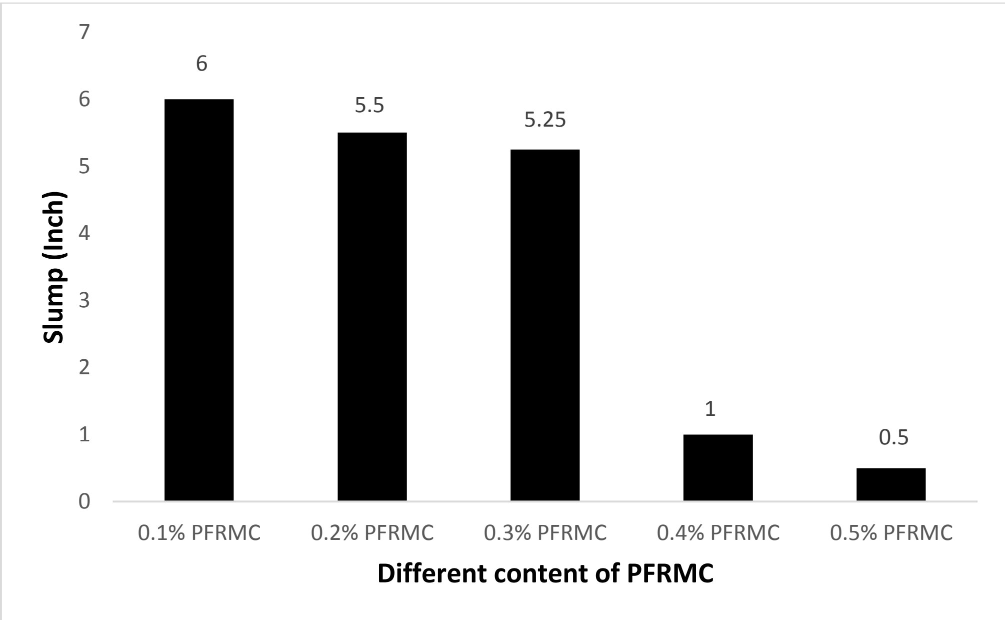

Figure 5.1: Decrease of slump with polyester fiber content

On the other for Galvanized wire reinforced steel fiber with the increase of fiber content the slump of Micro concrete also decreases but rate is comparatively low. For 1% GWRMC the slump was found six inch and when fiber content increases to 2.5% the slump was found 5 inch. So for steel fiber the decrease of slump is not so pronounced.

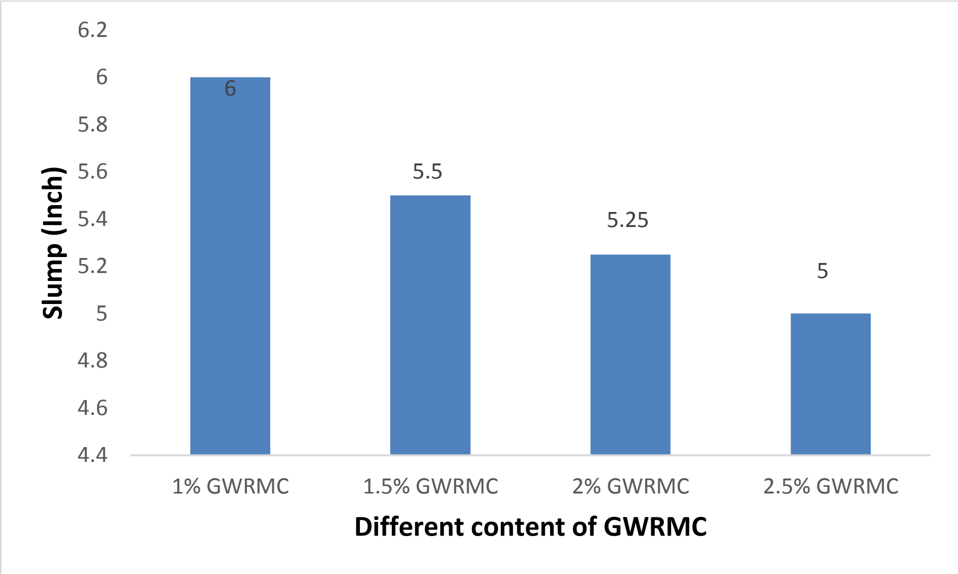

Figure 5.2: Decrease of slump with galvanized wire fiber content

5.2 Compressive Strength

Compressive strength is the most important property of concrete since the purpose that concrete is always supposed to serve is taking compressive stress. Compressive strength is the strong suit of concrete. Compressive strengths of GWRMC and PFRMC specimens were evaluated and the test results with analysis are presented in this section.

5.2.1 Results

Compressive strength was determined for control samples (samples without fiber) and four GWRMC mixes with Galvanized Ion wire fiber varying from 1 to 2.5 (weight basis) percent and five PFRMC mixes with polyester fiber varying from 0.1 percent to 0.5 percent(volume basis) in accordance with (ASTM C39/ C39M, 2003). The type of coarse aggregate was 5 mm downgraded crushed stone (stone chips). Properties of the aggregates and other materials have already been presented in Chapter 3.

Table 5.1: Calculation the compressive strength micro concrete for different content of polyester and GI fiber.

Type	compressive load (KN)	Actual load(KN)	Average Load(KN)	Average Load(lb)	Area(in2)	Compressive strength(psi)	Compressive strength (MPa)
control	263	254	233	52347.81	12.567	4165	28.73
	240	231					
	224	215					
0.1% polyster fiber	234	237	248	55717.84	12.567	4434	30.58
	240	243					
	260	263					
0.2% polyster Fiber	280	283	292	65603.26	12.567	5220	36.00
	314	317					
	274	277					
0.3% polyster Fiber	264	267	246	55268.5	12.567	4398	30.33
	210	212					
	256	259					
0.4% polyster fiber	318	321	334	75039.35	12.567	5971	41.18
	308	311					
	368	371					
0.5% polyster fiber	258	261	272	61109.89	12.567	4863	33.54
	260	263					
	288	291					
1% GI fiber	315	307	321	72118.65	12.567	5739	39.58
	338	330					
	333	325					
1.5% GI fiber	331	323	342	76836.7	12.567	6114	42.17
	362	355					
	356	349					
2% GI fiber	330	333	329	73916	12.567	5882	40.56
	328	331					
	320	323					
2.5% GIfiber	300	303	316	70995.31	12.567	5649	38.96
	328	331					
	310	313					

Characteristic compressive strength was determined with cylindrical concrete samples for 28 days of curing. The results of compressive strength tests are presented in the Table 5.1. This table shows the calculation of compressive strength of concrete cylinder for different content of polyester and steel fiber. Fig 5.3 and 5.4 shows the graphical representation for different content of polyester fiber and steel fiber respectively. Fig 5.5 and 5.6 graphically represents the increase of compressive strength with respect to control for different content of polyester and steel fiber respectively.

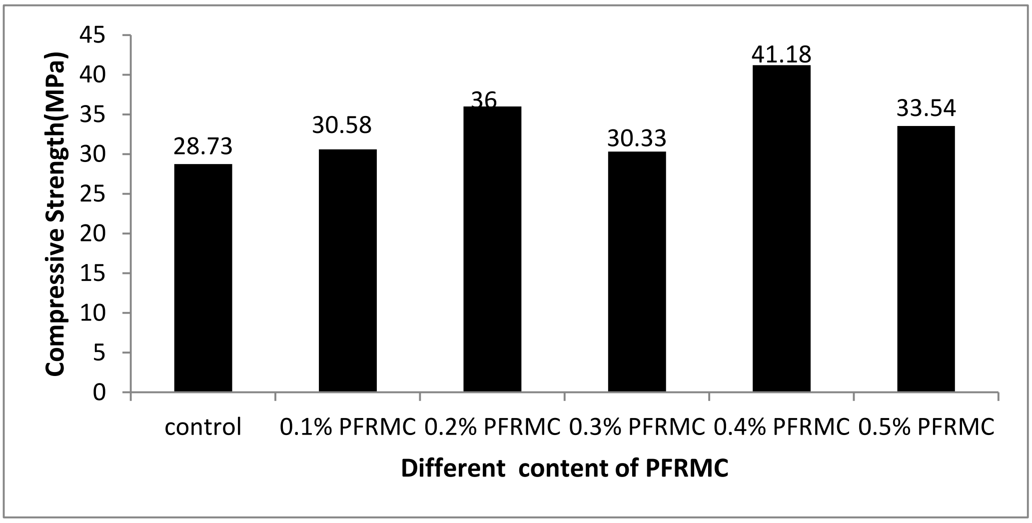

Figure 5.3:Compressive strength for different content of PFRMC

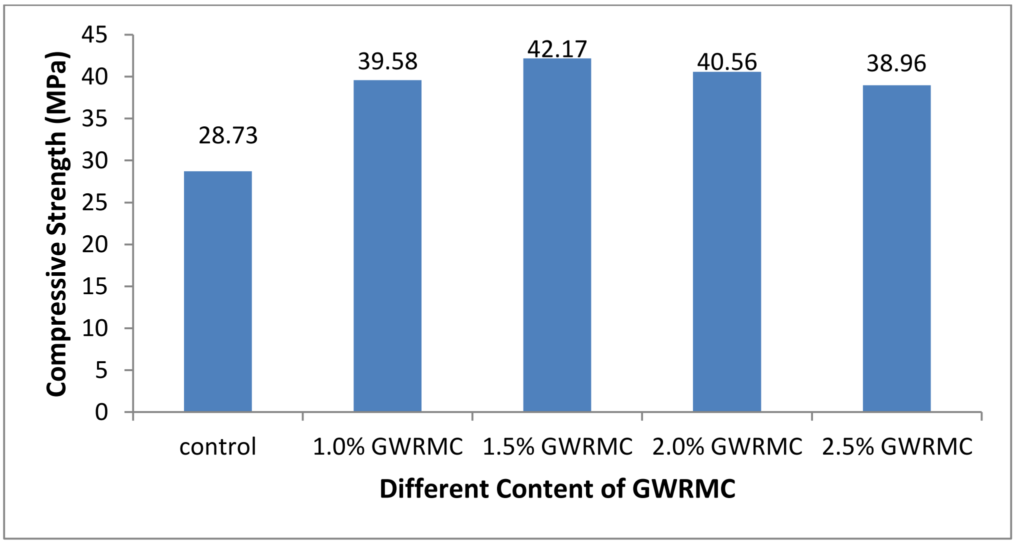

Figure 5.4: Compressive strength with different Content of GWRMC.

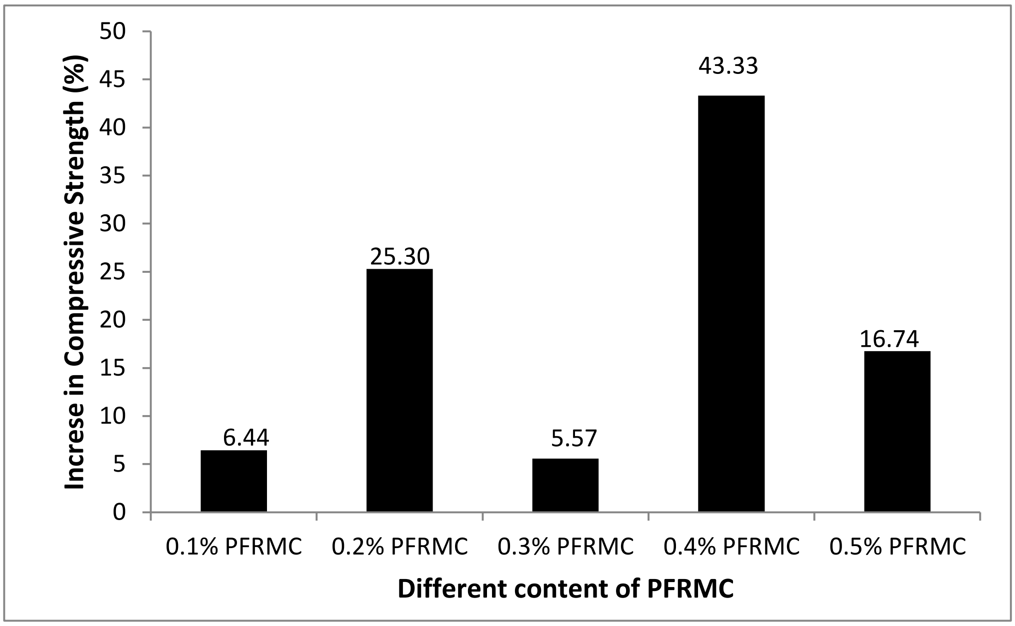

Figure 5.5: Increase of compressive strength for different content of PFRMC with respect to control

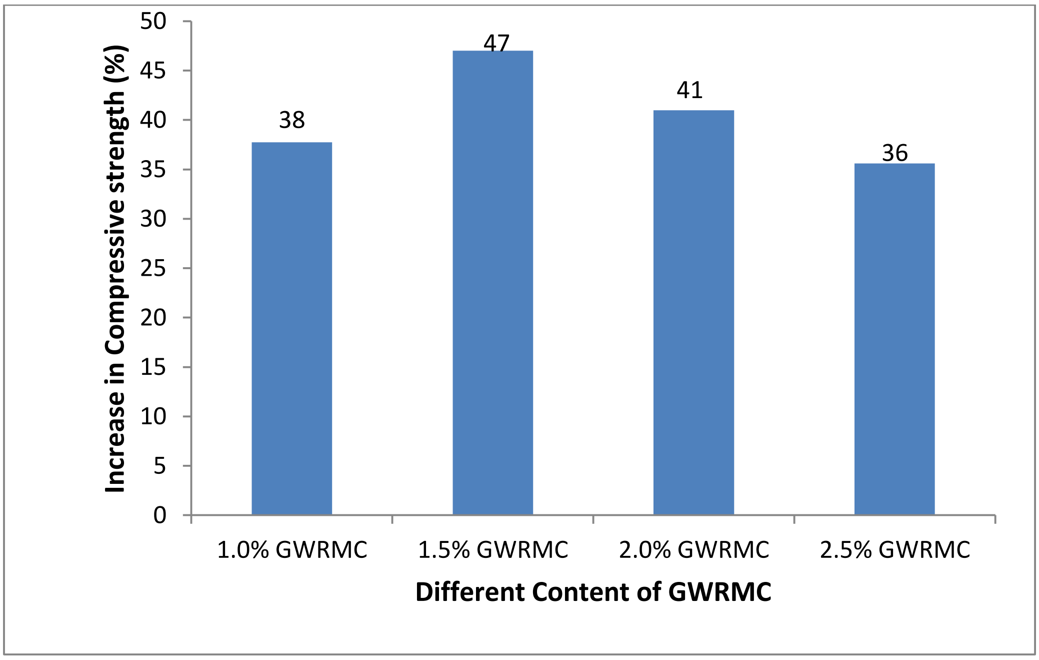

Figure 5.6: Increase of compressive strength for different content of GWRMC with respect to control.

5.2.2 Discussion

Concrete is a composite material and consequently, its strength depends on properties of all its constituent ingredients. Not only the materials, size and shape of the specimen, batching and mixing procedures; sampling, molding, fabrication methods; and the age, temperature, and moisture conditions during curing etc. or even the rate of loading influences the results of the compressive strength test. On top of all these, when fibers are added to the concrete matrix, the list of influencing factors even grows longer. Different characteristics of added fibers and their dosage come to play vital roles in inducing deviation, better or worse, in concrete's behavior and eventually the performance.

Fiber content and attributes do not have direct influence on compressive strength properties of fiber reinforced concrete; nonetheless, they can passively contribute to augmentation of compressive strength as observed from a lot of previous studies [(Bencardino, Rizzuti, Spadea, & Swamy, 2004), (Musmar, 2013), (Johnston, C. D., 1982)] with steel and polyester fibers in concrete. This phenomenon can be attributed to the confining effect of fibers that tend to hold the materials together and countering effect to the lateral tension. But the extent of these effects depend largely on preferential orientation of the fibers which is impracticable to control in such case of randomly distributed discrete fibers in concrete matrix. Consequently, contribution to static compressive strength due to randomly dispersed fibers cannot be predicted and foreseen. In Figure: 5.7 cylinders after failure can provide an idea of the confining effect of Polyester and GI wire fibers can impart into concrete matrix. Furthermore, fibers can significantly escalate the post-cracking ductility or, in other words, energy absorption of concrete (Bencardino, Rizzuti, Spadea, & Swamy, 2004).

Normal Micro concrete **PFRMC** **GWRMC**

Figure 5.7: failure pattern of different Micro concrete

Figures 5.3, 5.4 presented compressive strengths for 28 days for different content of Polyester and GI fiber respectively. From the graph it is seen that, addition of both types of fiber increases compressive strength of concrete. For Polyester fiber it was found for different content of fiber the increase of compressive strength don't follow a regular pattern. The maximum increase of compressive strength (43 percent with respect to control) was found at 0.4 percent Polyester fiber content. On the other hand for GI fiber the increase of compressive strength follows a regular pattern. There was a rising limb from 1 to 1.5 percent and then a falling limb from 1.5 to 2.5 percent. The maximum increase of compressive strength (47 percent with respect to control) was found at 1.5 percent of GI fiber content. However, from fig 5.3 and 5.4 it is substantiated that GI fiber is more effective for increasing compressive strength of Micro concrete compared to polyester fiber.

5.3 Tensile Strength

Split-cylinder tensile strength is the easiest method of determining tensile strength capacity of concrete. In order to understand the effect of Polyester fiber and GI wire fiber on tensile strength of Micro concrete, splitting cylinder test was performed on normal Micro concrete, PFRMC and GWRC. The test results are provided in this section and also the analysis of results.

5.3.1 Results

Splitting tensile strength of normal Micro concrete, PFRMC and GWRC was determined at 28 days according (ASTM C496/ C496M, 2011). The test provides an indication to tensile capacity of concrete. Table 5.2 shows the necessary calculation for determining tensile strength. Column charts in Figures 5.8, 5.9 present tensile strength results for Micro concrete with different content of PFRMC and GWRMC. Charts in Figures 5.10, 5.11 show the increase of tensile strength for different dosages of Polyester fiber and Galvanized iron wire fiber with respect to control.

Table 5.2: Calculation of tensile strength of micro concrete for different content of polyester and GI fiber.

Type	tensile load (KN)	Actual load (KN)	Average load (KN)	Average Load (lb)	Area(in2)	Tensile strength(psi)	Tensile strength(MPa)
control	86	87.742	95	21343.53	100.53	424	2.92
	92	93.778					
	100	101.826					
0.1% polyester	92	93.778	106	23814.88	100.53	474	3.26
	116	117.922					
	104	105.85					
0.2% polyester	110	111.886	123	27634.25	100.53	550	3.80
	134	136.03					
	118	119.934					
0.3% polyester	90	91.766	96	21568.2	100.53	430	2.96
	100	101.826					
	92	93.778					
0.4% polyester	102	103.838	110	24713.56	100.53	492	3.40
	90	91.766					
	132	134.018					
0.5% polyester	92	93.778	100	22466.87	100.53	446	3.08
	120	121.946					
	82	83.718					
1% steel fiber	130	132.006	111	24938.23	100.53	496	3.42
	84	85.73					
	112	113.898					
1.5% steel fiber	112	113.898	110	24713.56	100.53	492	3.40
	106	107.862					
	107	108.868					
2% steel fiber	100	101.826	119	26735.58	100.53	522	3.66
	130	132.006					
	120	121.946					
2.5% steel fiber	116	117.922	115	25836.9	100.53	514	3.54
	110	111.886					
	112	113.898					

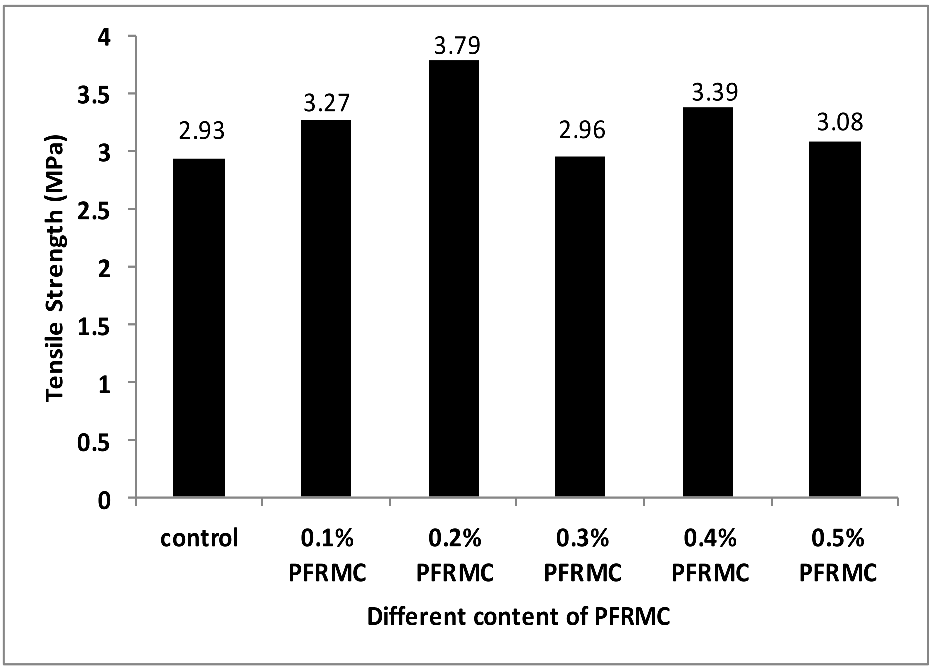

Figure 5.8: Tensile strength for different content of PFRMC

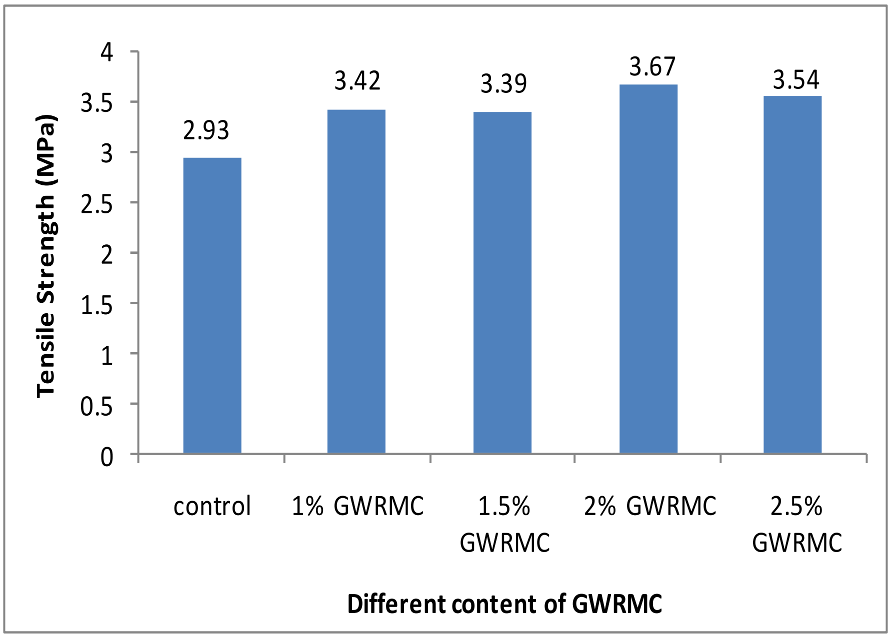

Figure 5.9 Tensile strength for different content of GWRMC

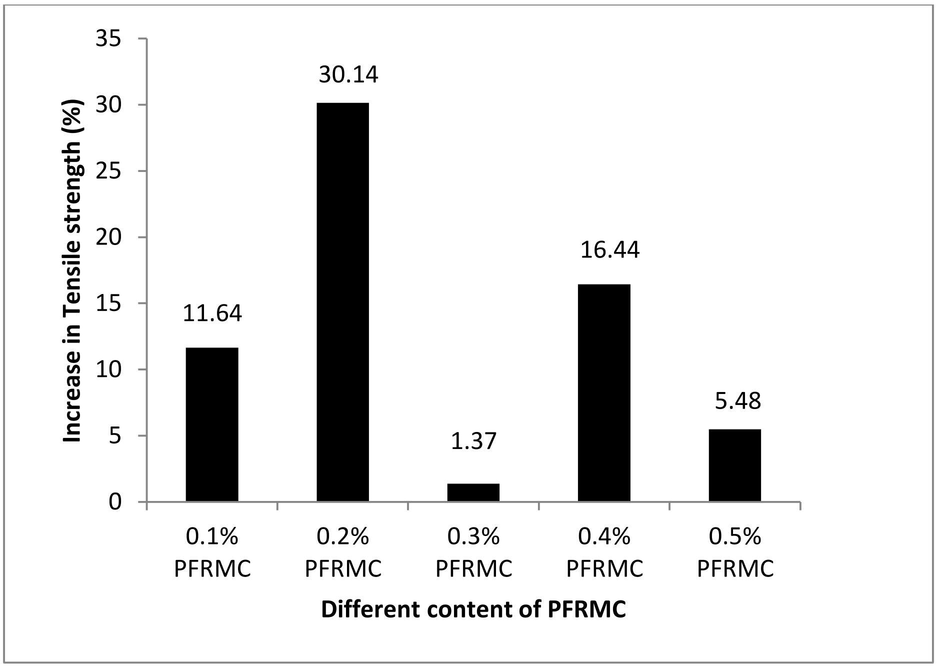

Figure 5.10 Increase in tensile strength of micro concrete for different content of PFRMC with respect to control

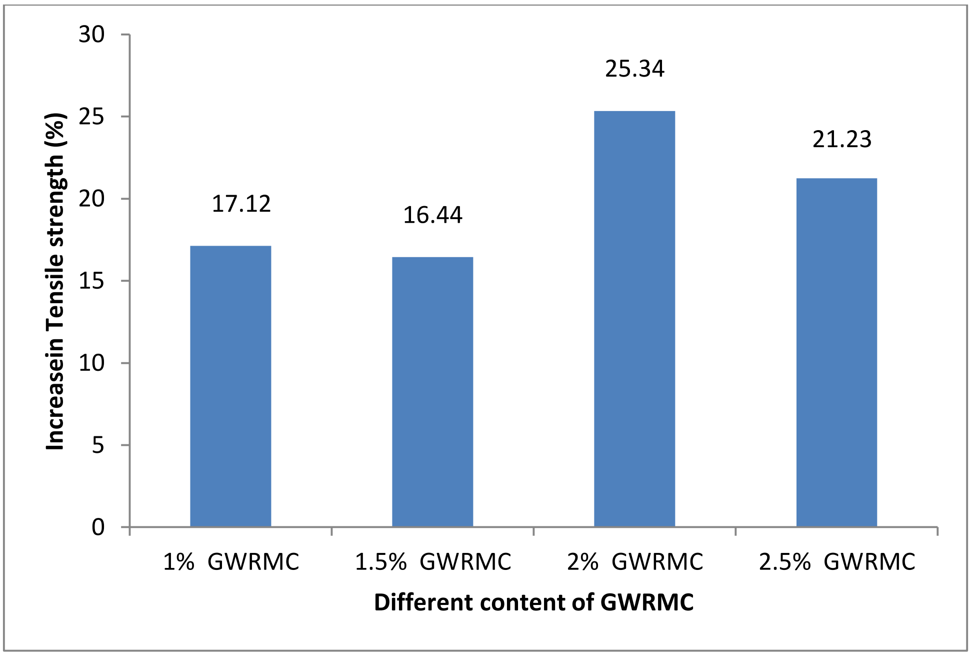

Figure 5.11 Increase in tensile strength of micro concrete for different content of GWRMC with respect to control

5.3.2 Discussion

The results are indicative of tensile strength of concrete. Values from splitting tensile strength tests are generally lower than direct tensile strength and higher than flexural strength i.e. Modulus of rupture (ASTM C496/ C496M, 2011). But this test is the simplest way of evaluating tensile capacity of concrete since it requires special arrangements for neither sample preparation nor testing the specimens.

Table 5.8 and 5.9 show tensile strengths from split-cylinder tests. According to Nilson et al. (Nilson, Darwin, & Dolan, 2003), approximate range of split cylinder strength of concrete is from $6\sqrt{f'c}$ to $8\sqrt{f'c}$. All the samples apparently have tensile strength within the range.

At present the tensile strength of concrete is also considered as an important property of concrete for different application. For example, for retrofitting measures of building joint's where sufficient shear reinforcement has not been provided the tensile strength of concrete may help to make it ductile.

From Figure 5.10, it was found for different content of PFRMC the maximum increase of tensile strength is 30.14 percent for 0.2 percent fiber content. At 0.2% fiber content the increase of compressive strength was 25.3 percent whereas the maximum increase of compressive strength was for 0.4 percent PFRMC. So maximum tensile strength and maximum compressive strength were not found at same fiber content. Beside that for PFRMC the increasing pattern was irregular. On the other hand from Figure 5.11 it was found for different content of GI fiber the maximum increase of tensile strength was found 25.34 percent for 2 percent of GI fiber content and at this content of GI fiber the increase of compressive strength was 41.18 percent which is close to maximum increase of compressive strength of 46.78 percent for 1.5 percent of GI fiber. From the graphs it was seen there was a rising limb from 1 percent to 2 percent of GWRMC and a falling limb from 2 percent to 2.5 percent of GWRMC.

5.4 Modulus of Elasticity

Modulus of Elasticity of a material is an important property to analyze load-deflection behavior. Modulus of elasticity of PFRMC specimens and GWRC specimens were determined as a part of the experimental work and this section presents and analysis the results of the tests.

5.4.1 Results

Modulus of Elasticity of concrete is determined according to (ASTM C496/ C496M, 2011). Due to heterogeneous nature of concrete, it can always show significant aberrations in results of Modulus of Elasticity test. The test was conducted to determine the effect of added Polyester fibers and GI fibers on this parameter.

Typical stress-strain curves for control sample, different content of Polyester fibers and different content of GI are shown in Figures 5.11 through 5.20. For each case one sample has been presented in this section and rests of the graphs are provided in Appendix A.

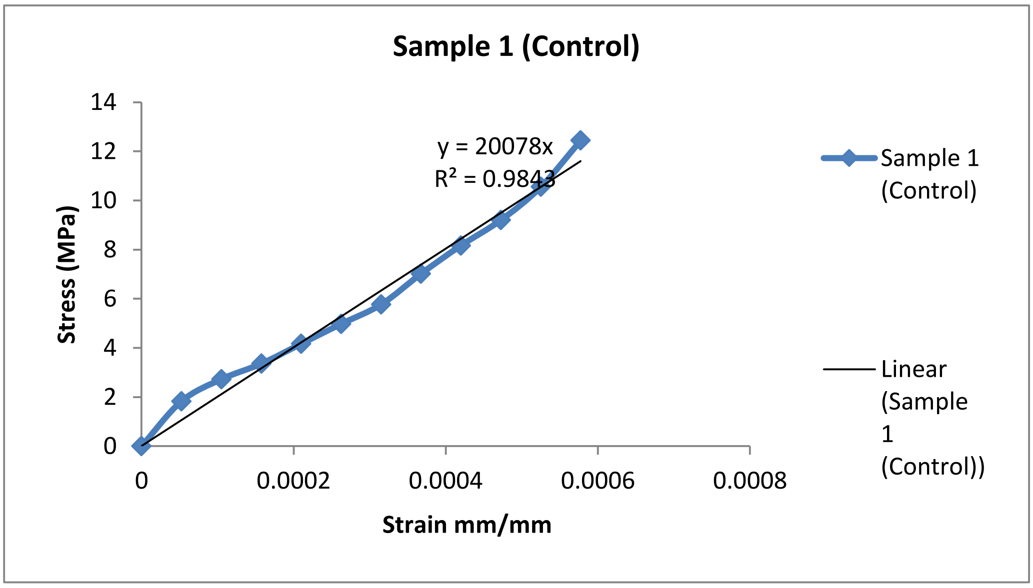

Figure 5.12: Stress-strain curve for control sample

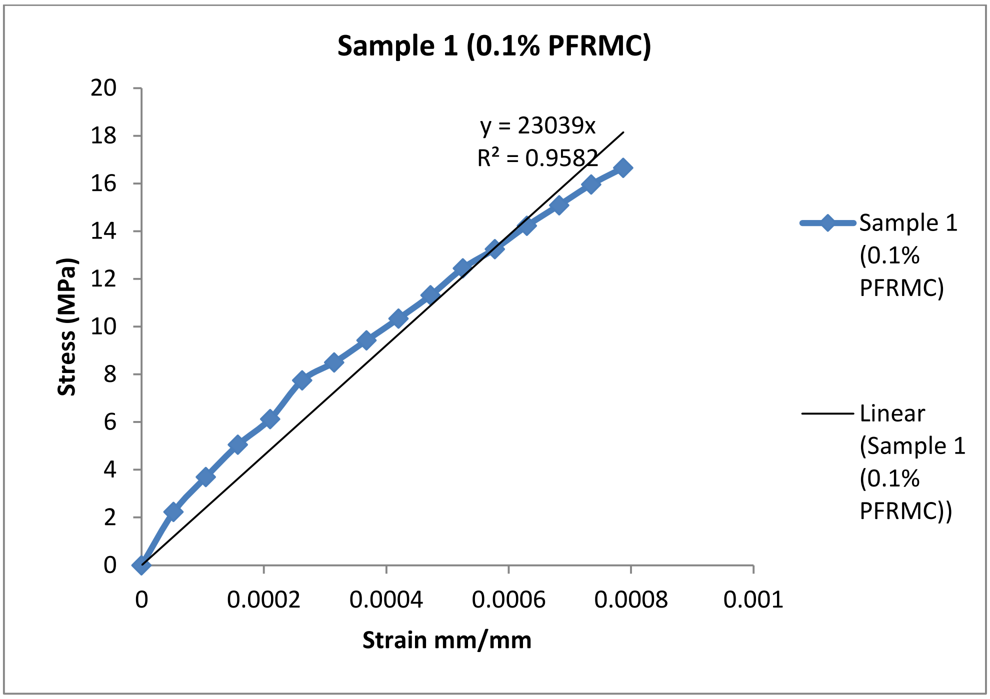

Figure 5.13: Stress-strain curve for sample with 0.1% PRFMC

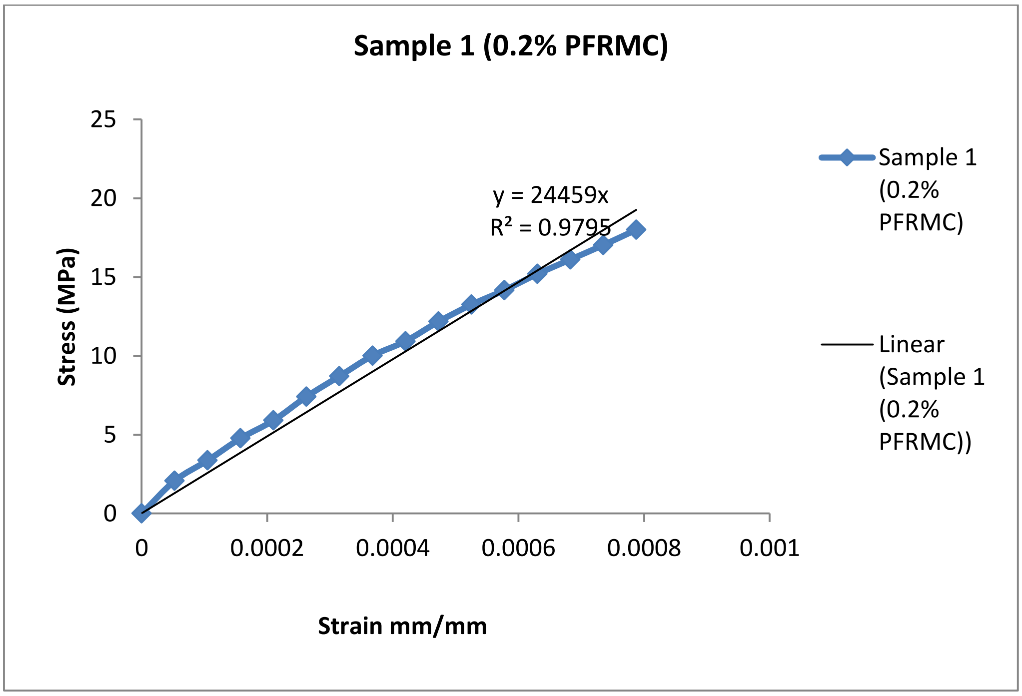

Figure 5.14: Stress-strain curve for sample with 0.2% PRFMC

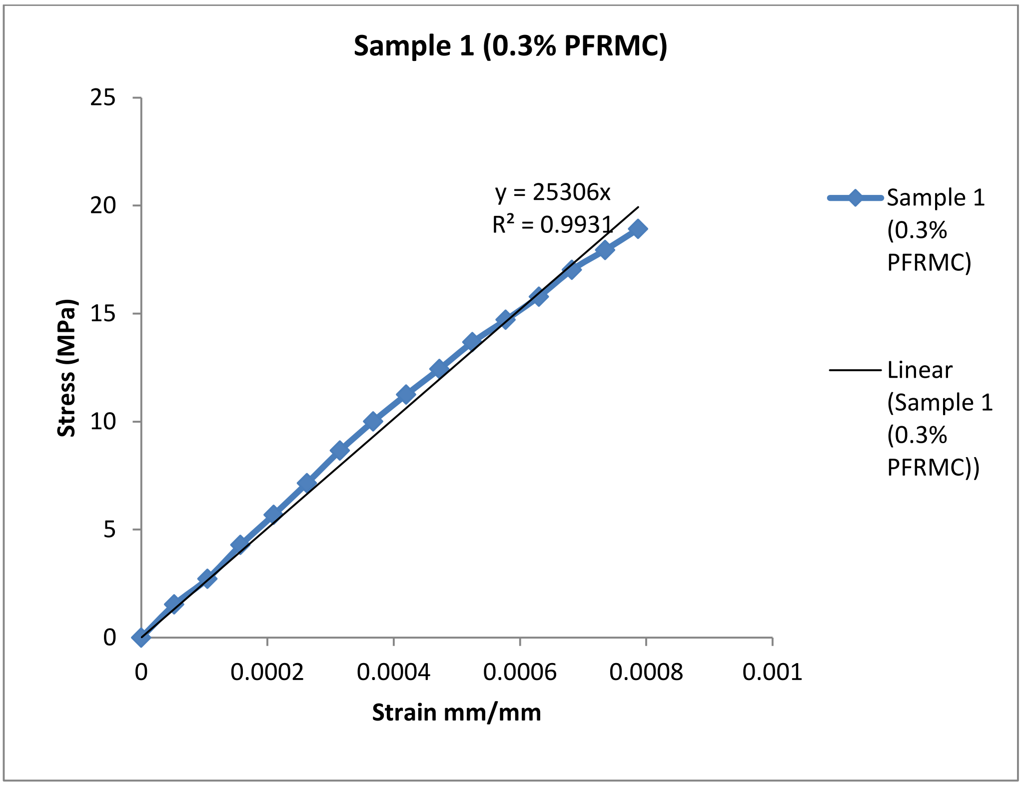

Figure 5.15: Stress-strain curve for sample with 0.3% PRFMC

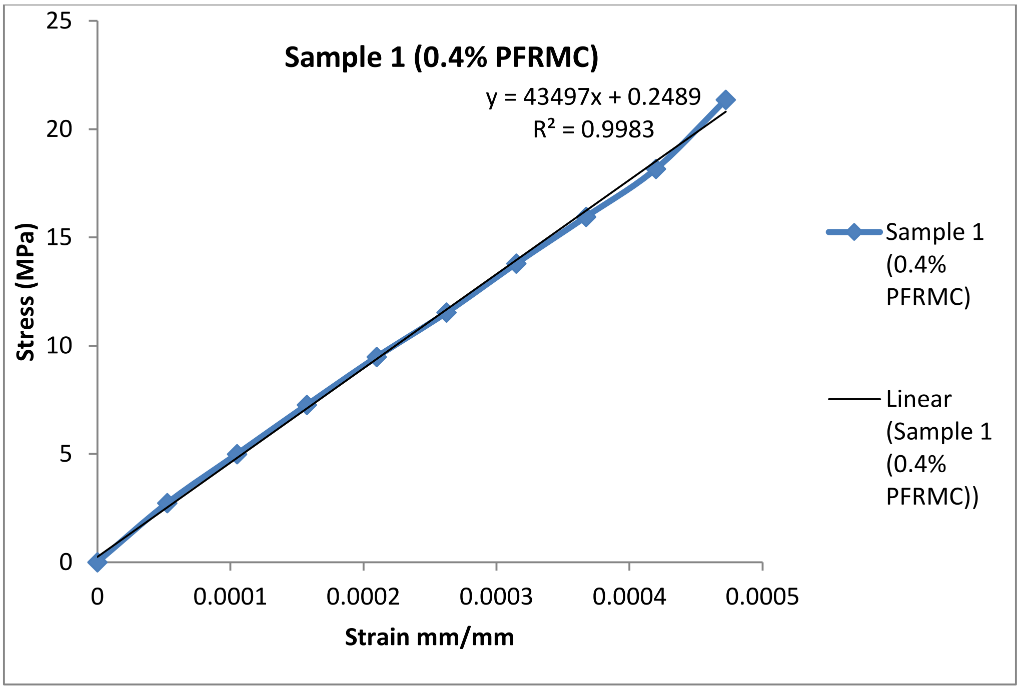

Figure 5.16: Stress-strain curve for sample with 0.4% PRFMC

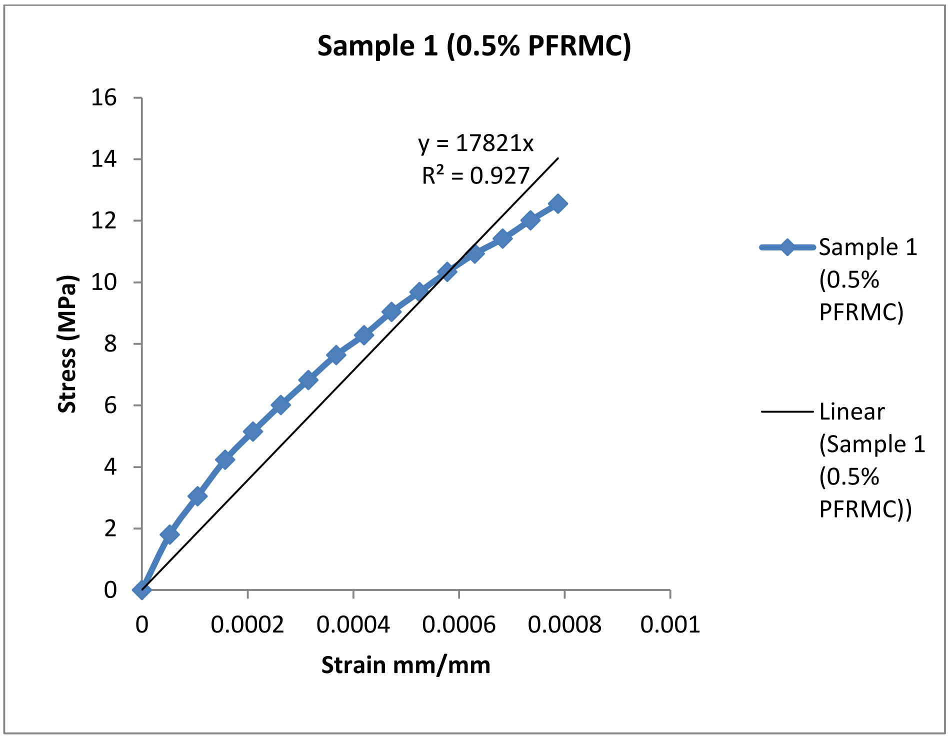

Figure 5.17: Stress-strain curve for sample with 0.5% PRFMC

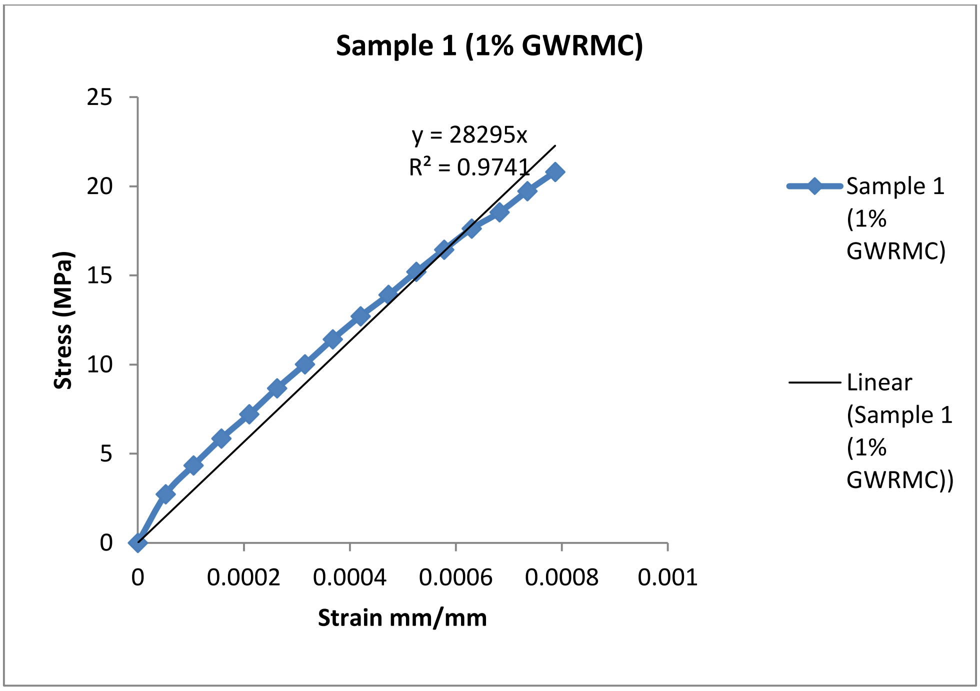

Figure 5.18: Stress-strain curve for sample with 1% GWRMC

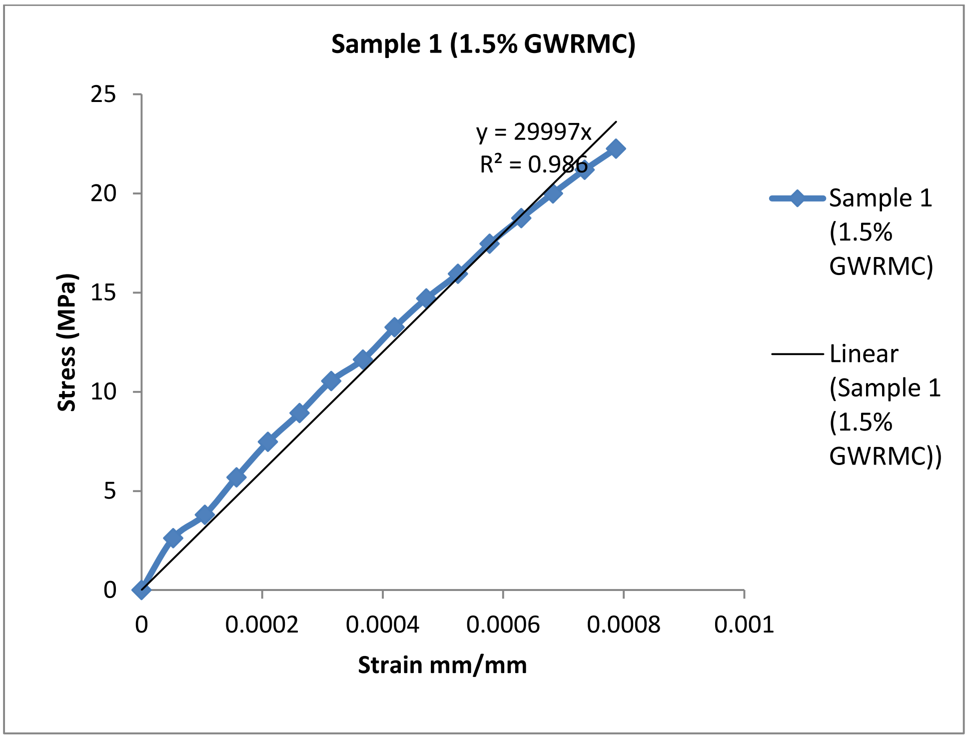

Figure 5.19: Stress-strain curve for sample with 1.5% GWRMC

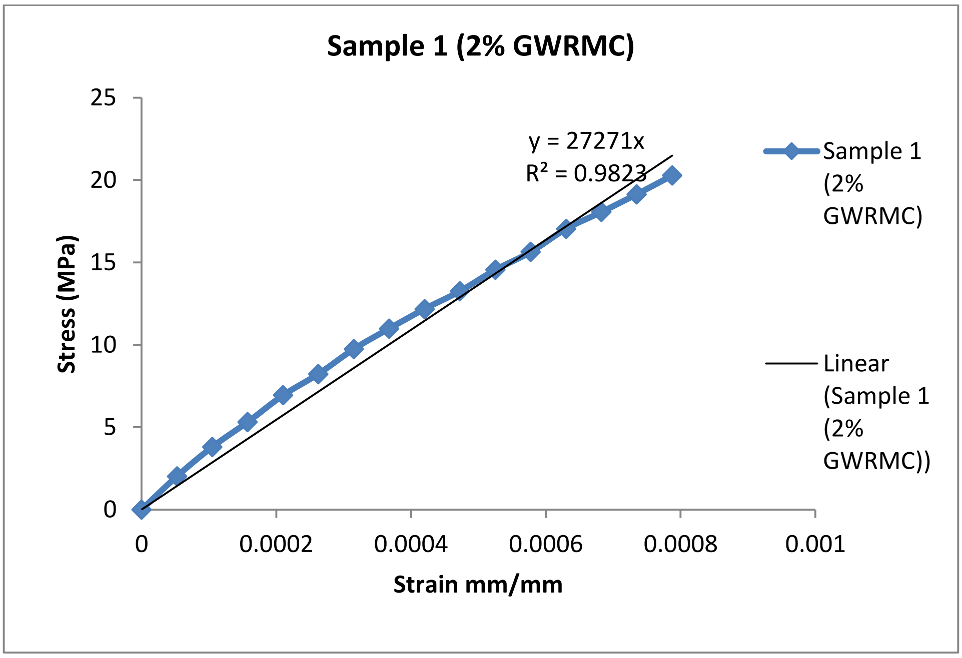

Figure 5.20: Stress-strain curve for sample with 2% GWRMC

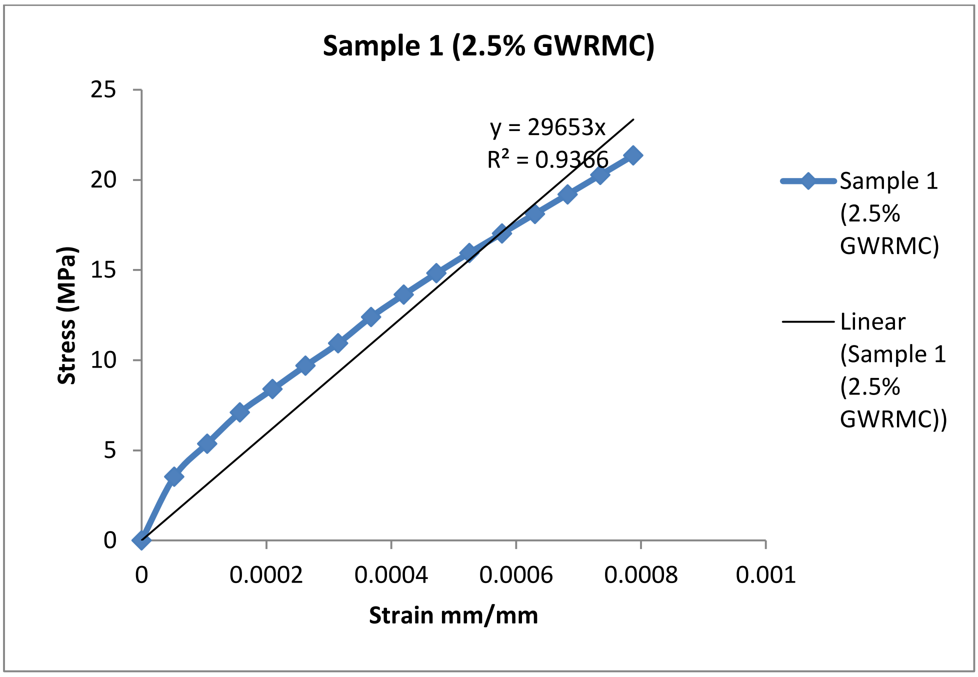

Figure 5.21: Stress-strain curve for sample with 2.5% GWRMC

Average Modulus of Elasticity values are presented in column charts on Figures 5.22 and 5.23 for an overall comparison.

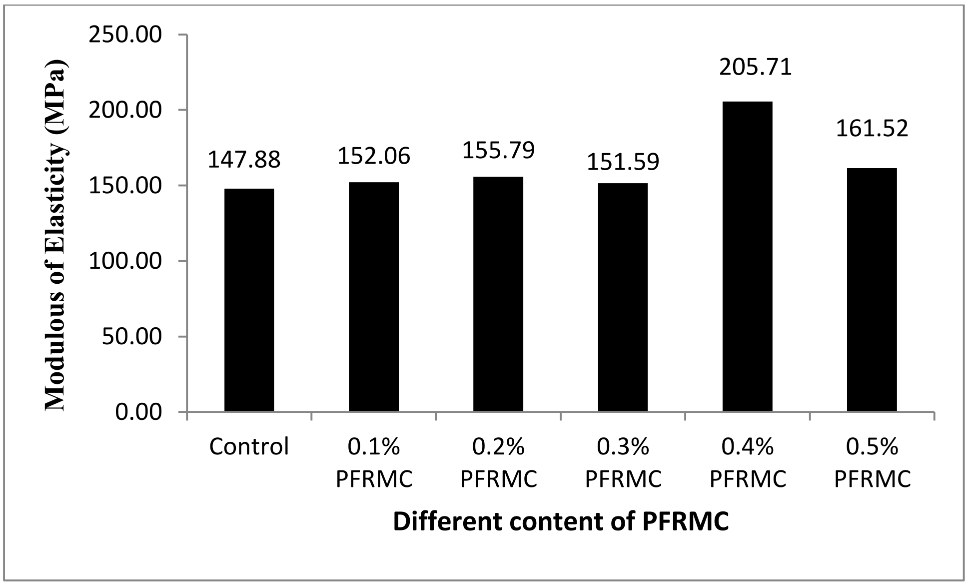

Figure 5.12: Change of Modulus of Elasticity with different content of PFRMC

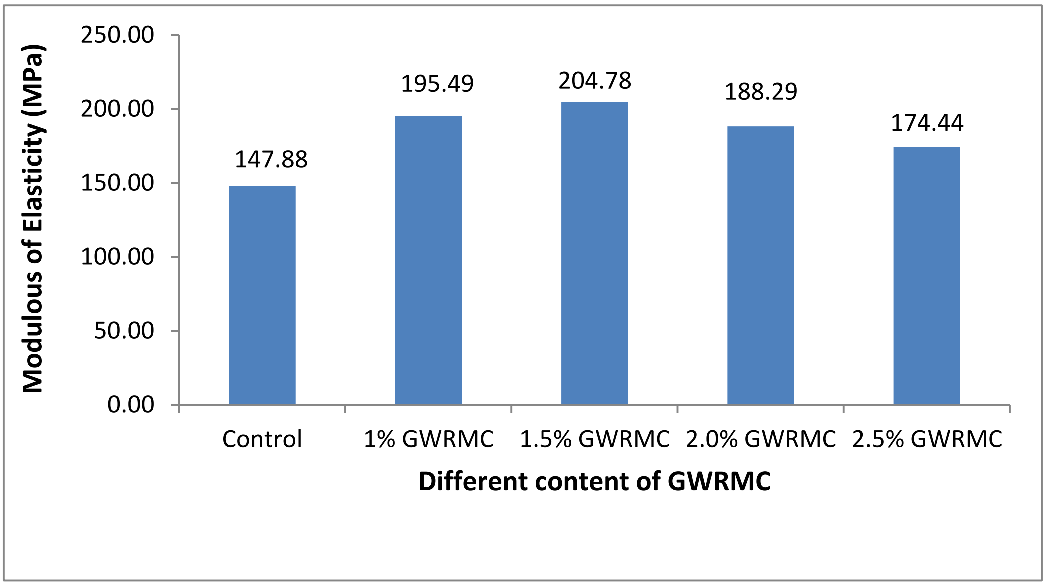

Figure 5.23: Change of Modulus of Elasticity with different content of GWRMC

5.4.2 Discussion

Modulus of Elasticity helps to predict stress-strain relationship within elastic limit and deflection under certain loading. As a result, for sizing reinforced and non-reinforced structural members, modulus of elasticity is used. Moreover, for establishing the quantity of reinforcement, and computing stress for observed strains within the conventional working stress range which is upto 40% of ultimate concrete strength, modulus of elasticity is very useful. One point must be noted that, Obtained modulus of elasticity values may be less than moduli derived under rapid load application (dynamic or seismic rates), and may be greater than values under slow load application or extended load duration in most cases, given other test conditions being the same (ASTM C469/ C469M, 2002).

From Figures 5.22 and 5.23, it is evident, for both cases (Polyester and GI wire addition) the trend of changing MoE (Modulus of elasticity) follows the changing pattern of compressive strength pattern as expected. For Polyester fiber maximum magnitude of MoE was found at fiber content 0.4% at which the compressive strength of concrete was also maximum. On the other hand for GI fiber maximum magnitude of MoE was found at 1.5% fiber content and maximum compressive strength was also found maximum at this content like previous case. Normally it is assumed Modulus of elasticity is proportional to the compressive strength and there are some empirical relationships between Modulus of Elasticity and compressive strength .So it can be said, in this research we found expected result while with the addition of fiber (both Polyester fiber and GI wire fiber) the compressive strength and Modulus of elasticity changed in almost same pattern..

On the other hand, if we look through the data sheet (Table A1-A10), it would be noticed the values of Modulus of elasticity found from test were erratic with high standard deviation and variances. So from these results it is tough to predict any trends or nature. So it is recommended to recheck this property in further research of Micro concrete.

5.5 Sorptivity Test

Sorptivity test was then carried out for determining the durability of GWRC. This section presents and analyses the results from Sorptivity test performed on 56 days old samples. The results and discussion on Sorptivity test is presented in this section.

5.5.1 Results

Determination of the susceptibility of an unsaturated concrete to the penetration of water and thereby harmful substances is the prime function of this test method. The samples are conditioned for about 18 days before the commencement of the test procedure as described in Chapter 4. Water absorption is plotted against the square root of time in seconds. The slopes of the best fit curves represent the rate of absorption. Initial rate of absorption, S_i is the slope of the curve up to 6 hours of the start of absorption. Secondary rate of absorption, S_s is the slope of the curve plotted with the data from day 1 to day 7 from the beginning of absorption. Typical graphs from the tests are presented below.

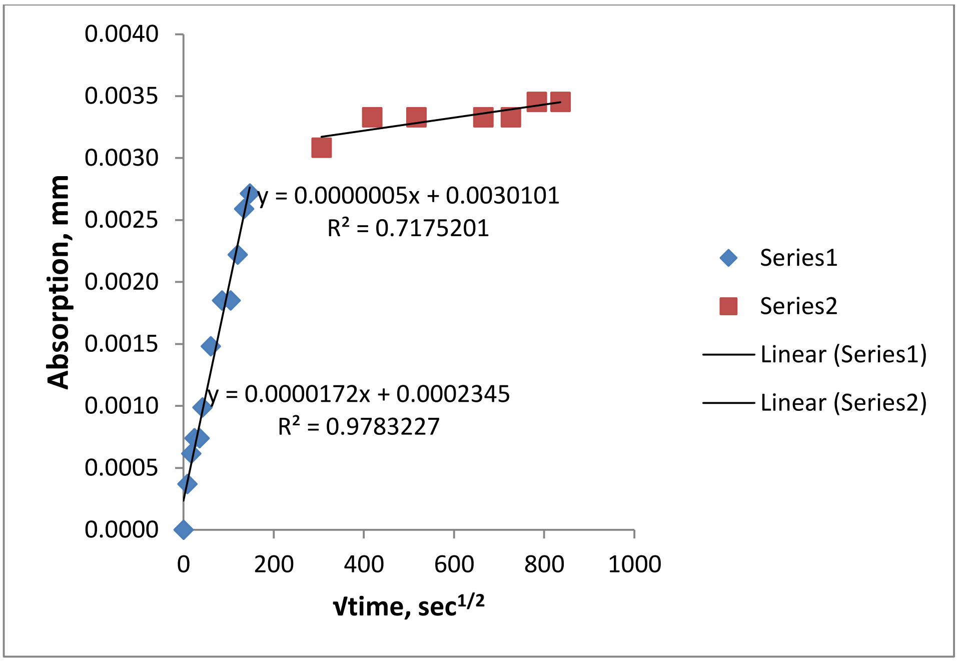

Figure 5.26: Absorption curve for Control sample-1

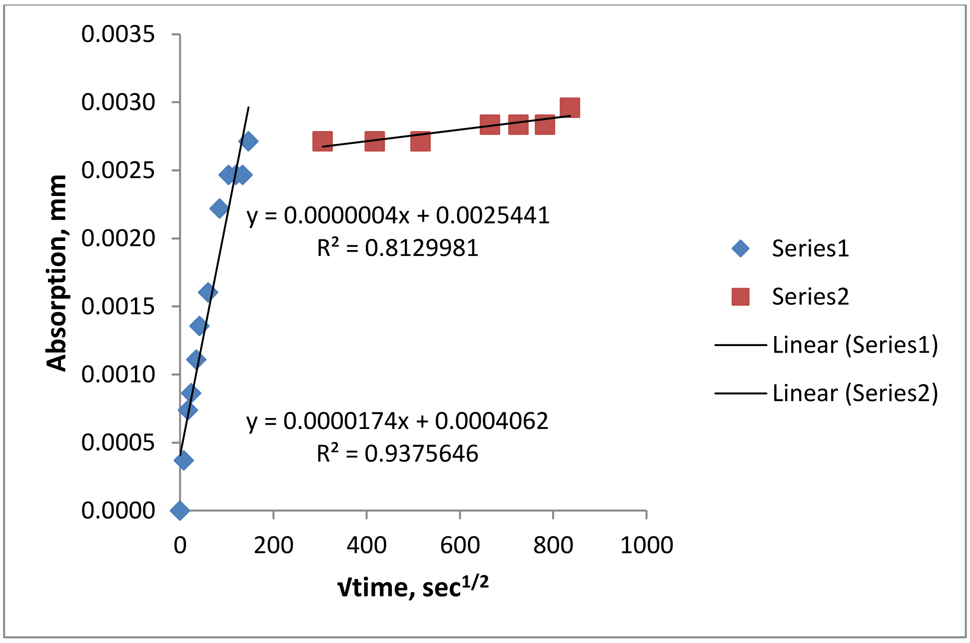

Figure 5.27: Absorption curve for 0.1% PFRMC sample-1

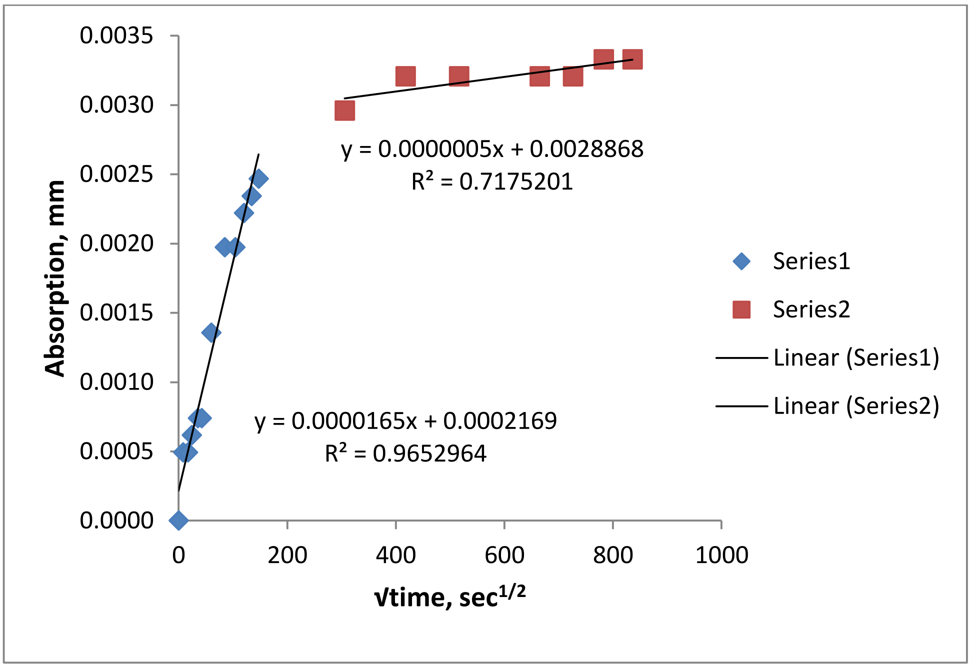

Figure 5.28: Absorption curve for 0.2% PFRMC sample-1

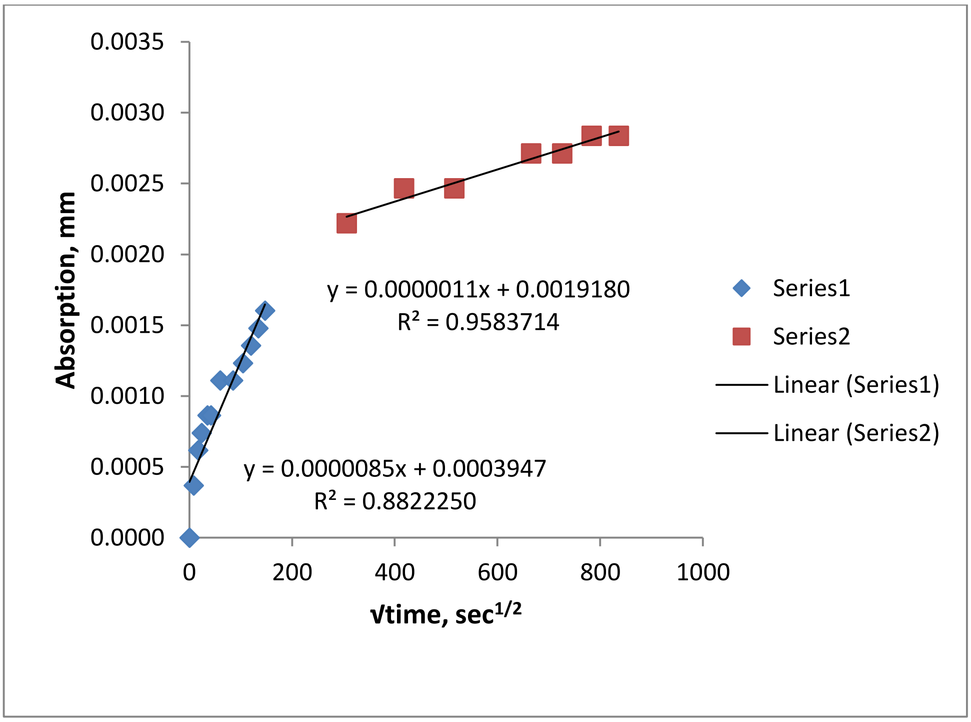

Figure 5.29: Absorption curve for 0.3% PFRMC sample-1

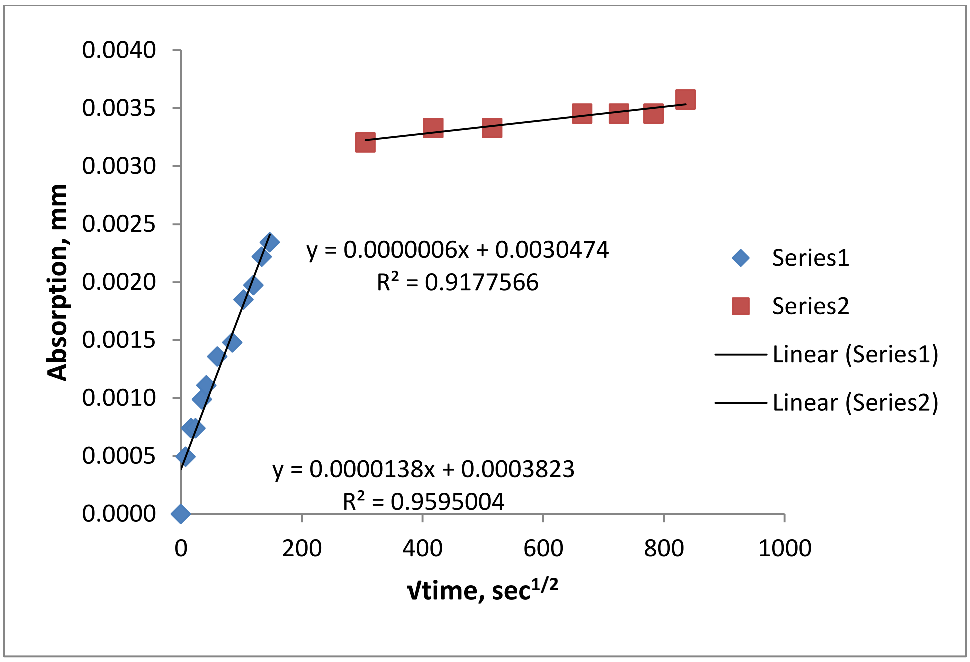

Figure 5.30: Absorption curve for 0.4% PFRMC sample-1

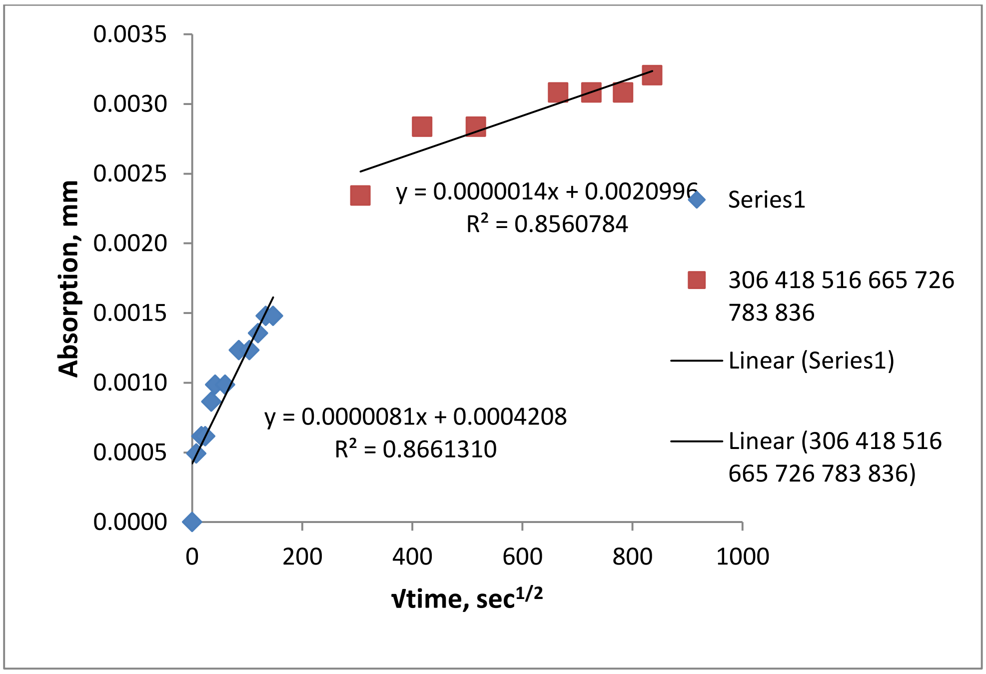

Figure 5.31: Absorption curve for 0.5% PFRMC sample-1

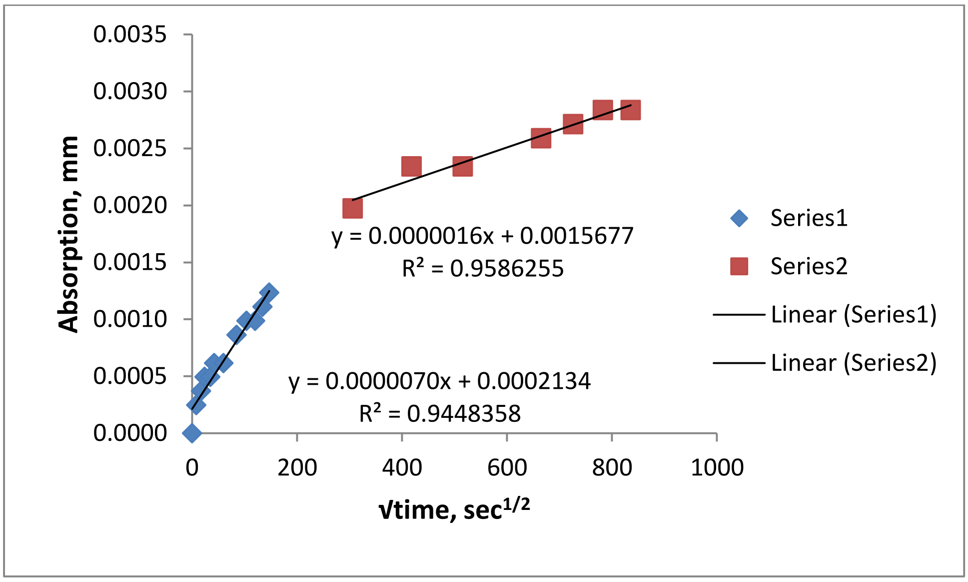

Figure 5.32: Absorption curve for 1% GWRMC sample-1

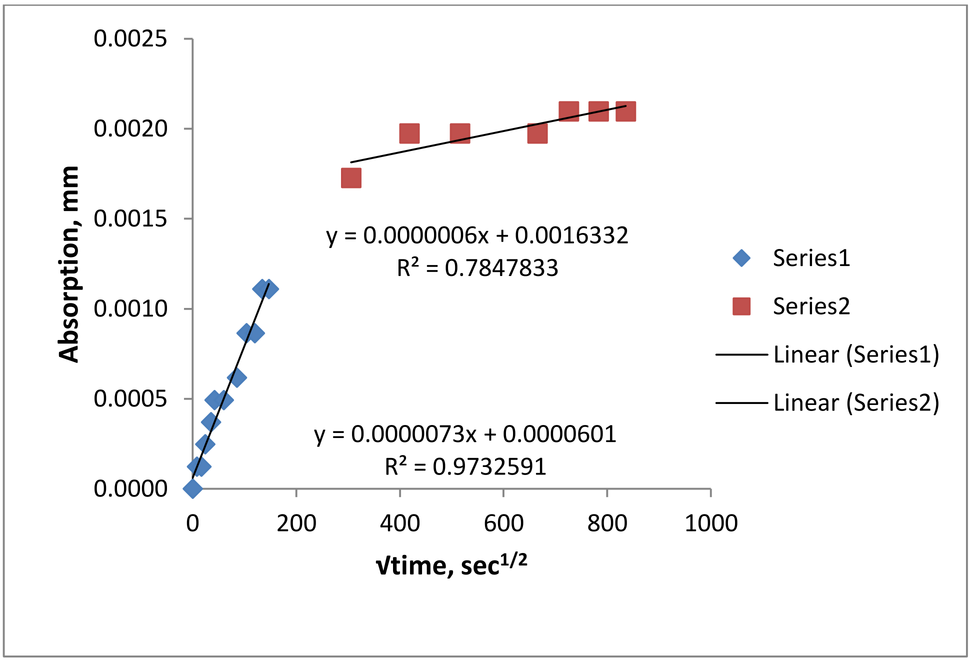

Figure 5.33: Absorption curve for 1.5% GWRMC sample-1

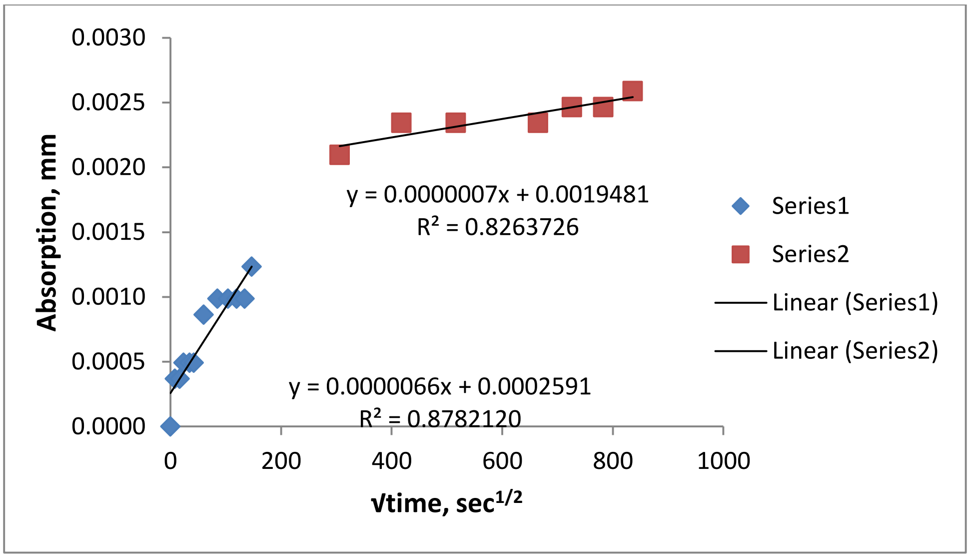

Figure 5. 34: Absorption curve for 2% GWRMC sample-1

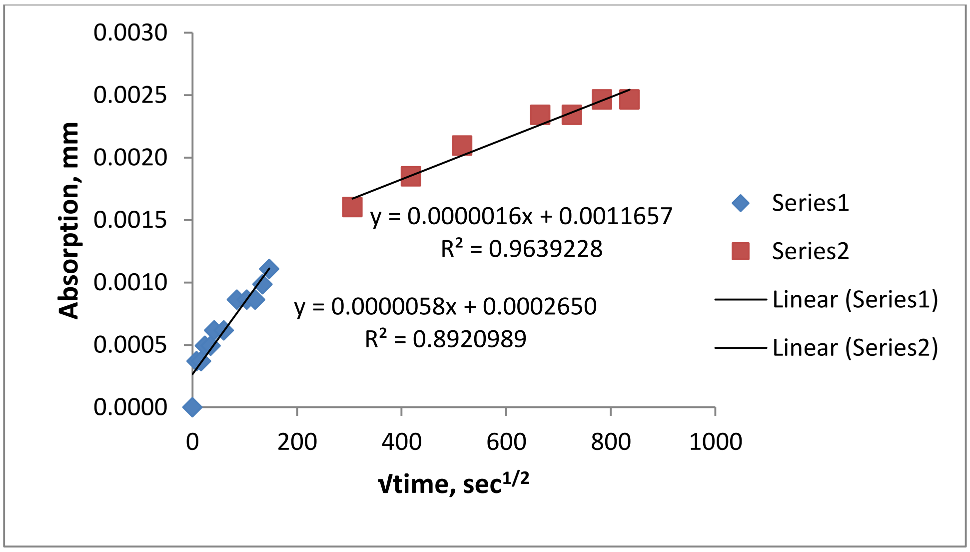

Figure 5. 35: Absorption curve for 2.5 % GWRMC sample-1

5.5.2 Discussion

Water absorption of Micro concrete is dependent on the pore structure of the matrix. The higher the pore content, the higher the rate of absorption. And porous concrete allows more ingress to deleterious ions along with water. Therefore, higher rate of absorption indicates weaker concrete with respect to durability. The results from the test are summarized in Table 5.3.

From the table, it can be seen that initial absorption rate and Secondary absorption rate of Micro concrete significantly lower than Normal light weight concrete. So from the Durability concern Micro concrete is more favorable than Normal concrete. Again it was found as the content of Polyester fiber and Galvanized Iron Wire increase in Micro concrete the initial absorption rate tends to decrease in most cases. For few cases the increment is not alarming. So it can be said, from Durability concern, fiber reinforced Micro concrete is more favorable than normal Micro concrete.

Table 5.3: Results from water absorption (Sorptivity) tests

Specimen	Initial Absorption (S_i), mm/s$^{1/2}$	Average Initial Absorption (S_i), mm/s$^{1/2}$	Secondary Absorption (S_s), mm/s$^{1/2}$	Average Secondary Absorption (S_s), mm/s$^{1/2}$
Control sample 1	0.0000172	0.00001497	0.00000053	0.00000068
Control sample 2	0.00001274		0.00000083	
0.1% PFRMC-1	0.0000174	0.000019155	0.00000042	0.000000395
0.1% PFRMC-2	0.00002091		0.00000037	
0.2% PFRMC-1	0.00001651	0.000019265	0.00000042	0.000000475
0.2% PFRMC-2	0.00002202		0.00000053	
0.3% PFRMC-1	0.00000852	0.00000944	0.00000114	0.000000985
0.3% PFRMC-2	0.00001036		0.00000083	
0.4% PFRMC-1	0.0000138	0.000011305	0.00000058	0.00000079
0.4% PFRMC-2	0.00000881		0.00000100	
0.5% PFRMC-1	0.0000081	0.00000915	0.00000136	0.00000103
0.5% PFRMC-2	0.0000102		0.00000070	
1% GWRMC-1	0.000007	0.00000715	0.0000016	0.0000016
1% GWRMC-2	0.0000073		0.00000160	
1.5% GWRMC-1	0.0000073	0.00000675	0.0000006	0.000001
1.5% GWRMC-2	0.0000062		0.00000140	
2% GWRMC-1	0.0000066	0.0000075	0.00000071	0.000000905
2% GWRMC-2	0.0000084		0.00000110	
2.5% GWRMC-1	0.0000058	0.00000485	0.0000016	0.00000175
2.5% GWRMC-2	0.0000039		0.00000190	

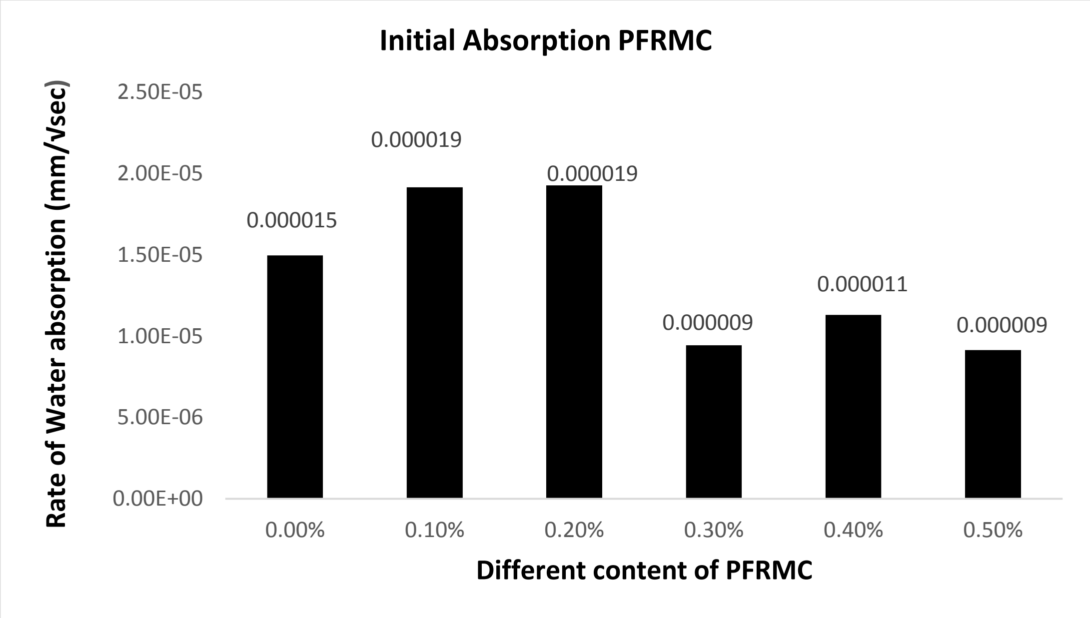

Figure 5.36: Change of initial absorption rate with different content of polyester fiber.

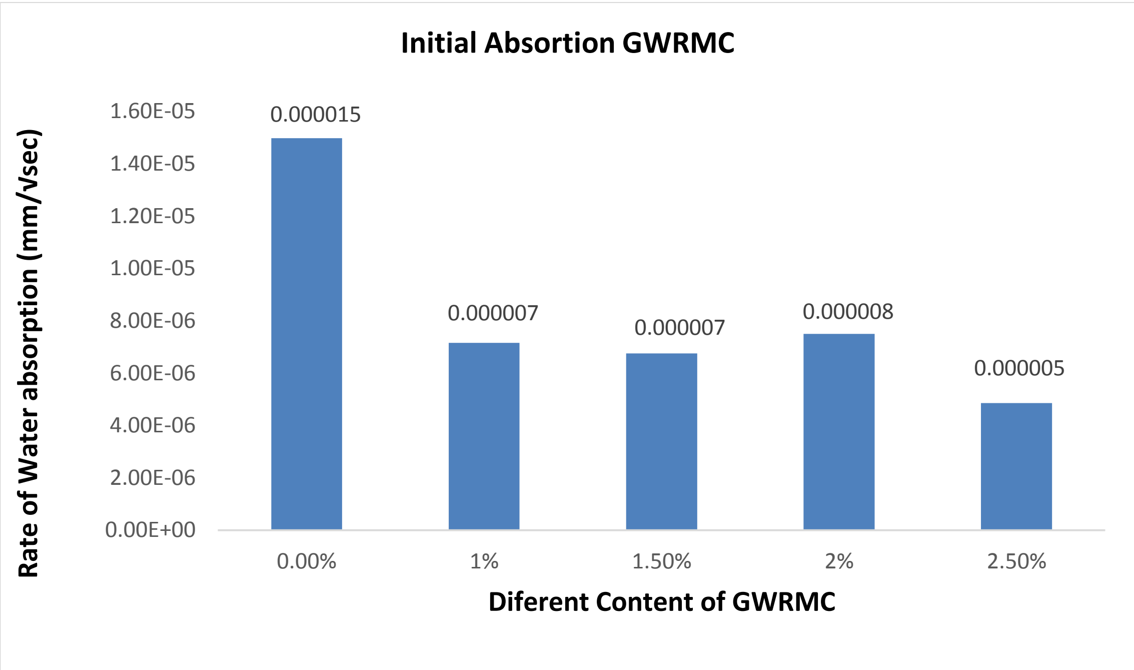

Figure 5.37: Change of initial absorption rate with different content of GI wire fiber.

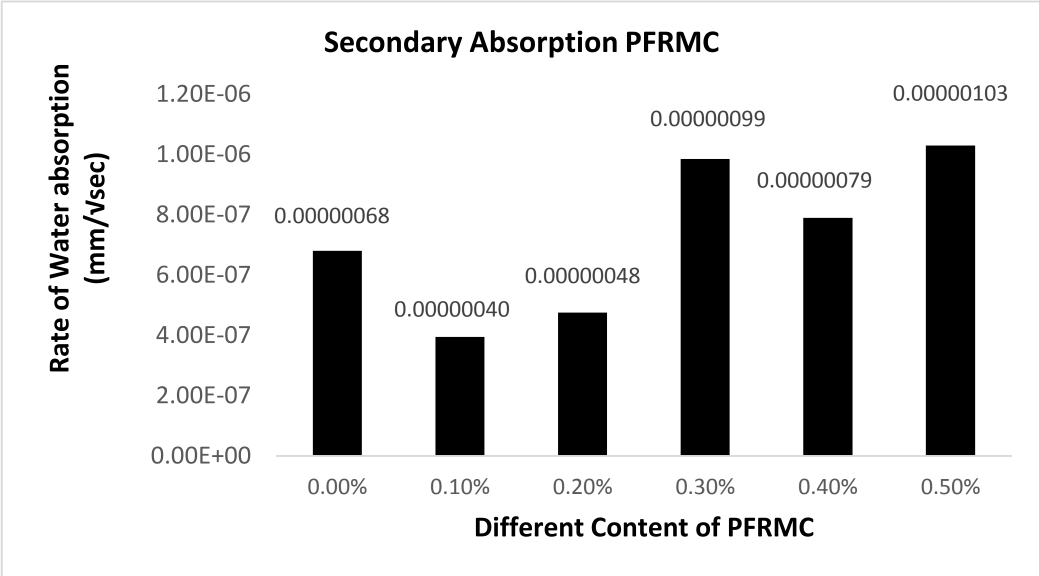

Figure 5.38: Change of secondary absorption rate with different content of polyester fiber.

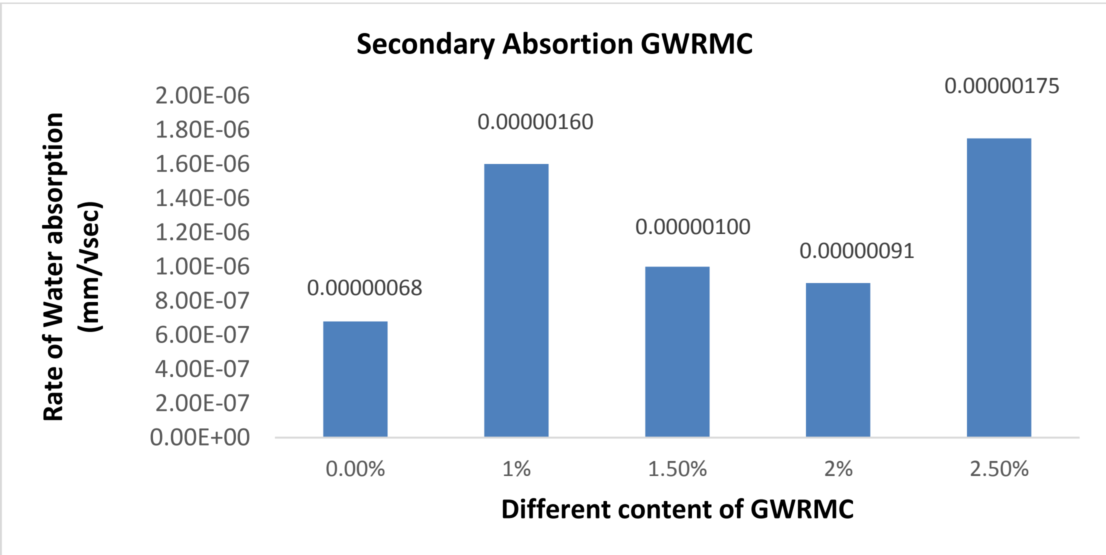

Figure 5.39: Change of secondary absorption rate with different content of GI wire fiber.

On the other, an increasing trend was found in secondary absorption rate for both PFRMC and GWRMC with respect to control though the increasing rate is not too high. But it must be noted that the initial absorption rate is more important because the pores in the concrete matrix stay unsaturated initially and durability of concrete started to hampers through initial absorption. If initial absorption rate can be reduced the Durability can be significantly improved.

5.6 Cost Study

For bulk purchase, locally produced GI wire costs about BDT 75,000-90,000 ($950-1150) per ton here in Bangladesh. Retail price for a kg in local market varies from BDT 80 to 100 ($ 1.00 to 1.25). Additional cost for processing of wire into fibers is about BDT 10,000 ($125) per ton. On the other hand, Recron-3S polyester fiber is not locally produced in our country but we can import this fiber from our neighbor countries. It will cost almost 250 tk. per 125 gm packet ($3). Steel fiber for use in FRMC is not produced in Bangladesh and importing fiber from China costs around BDT 120,000-200,000 ($1500-2500) per ton including shipment costs. Estimated cost analysis of materials for PFRMC and GWRMC with the mix design stipulated in Table 2 and 1.5% fiber content (weight basis) is presented in Table 4. It is found that GI wire fiber, if used as a substitute of steel fiber, can save BDT 1380 ($17.2), which means a cost reduction of almost 14%, per cubic meter of concrete when fiber dosage is 1% on weight basis. With higher dosage of fiber, reduction in cost increases proportionately

Table 5.4: Cost comparison between PFRMC and GIWRMC

Item	Amount (kg/m^3)	Unit price	GWRMC cost (per m^3)	PFRMC cost (per m^3)
Cement	550	BDT 500 ($6.5) per bag	BDT 5500 ($69)	5500 ($69)
Fine aggregate	700	BDT 60 ($ 0.75) per cft	BDT 955 ($12)	955 ($12)
Coarse Aggregate	965	BDT 150 ($ 1.9) per cft	BDT 3225($41)	BDT 3225($41)
Admixture	3.3 (Liter)	BDT 320 ($4)	BDT 1056 ($13)	BDT 1056 ($13)
GI wire (1.5%, wt. basis)	14.5	BDT 100 ($1.25) per Kg.	1450 ($19)	
Polyester fiber (0.2%, Volume basis)	2.75	BDT 2000 ($80) per Kg.		5500 ($69)
Total			BDT 12186 ($ 154)	BDT 16236 ($ 204)

From the chart it is clear though both polyester and steel fiber both help to improve the different property of concrete but with respect to our country GI steel fiber is more preferable compared to polyester fiber, because

1. GI fiber is locally produced on the other hand polyester fiber need to be imported from neighboring countries.
2. Use of GI fiber in Micro concrete as reinforcing materials reduces almost 33% cost compared to polyester fiber reinforced Micro concrete.
3. GI fiber is easily available throughout the country and one of vastly used materials in our country. On the other hand collection of polyester fiber is not only time consuming but also a lengthy process with respect to our country.

CHAPTER 6
CONCLUSION

6.1 General

An attempt for incorporating locally available GI wire fiber as a substitute for commercially available polyester fiber in Micro concrete in Bangladesh has been made in this study. However, the behavior and performance of such GI wire reinforced Micro concrete (GWRMC) and polyester fiber reinforced Micro concrete (PFRMC) are yet to be explored. Therefore, this research made an effort to discover several basic characteristics of GWRMC and PFRMC chiefly related to strength, ductility and durability. However, the central focus of the study was on the effect of fiber content on the aforementioned properties of GWRMC and PFRMC. As a result, fiber dosage was varied within low volume content while the mix design and fiber properties, in effect, were kept unchanged. Strength properties considered in the study are static compressive strength, splitting tensile strength and modulus of elasticity under compressive loading. Lastly, water absorption test was carried out in order to gauge the effect of fiber addition on durability of Micro concrete.

6.2 Conclusions

After completion of the tests and analysis of the results regarding strength, ductility and durability of fiber reinforced Micro concrete, following are the conclusions that can be deduced-

- Addition of both types of fiber reduces slump i.e. workability of Micro concrete It is more pronounced for polyester fiber than GI fiber and after the content of 0.4% polyester fiber the concrete almost retains its shape and slump drops down sharply.

- Compressive strength tests at 28 days on PFRMC samples showed a maximum increase of 43.3% at 0.4% fiber content and GWRMC samples showed a maximum increase of 47% at 1.5% fiber content with respect to control.

- Splitting tensile strength tests at 28 days on PFRMC samples displayed a maximum of 30.14% increment at 0.2% fiber content and for GWRMC it was 25.34% at 2% fiber content.

- Modulus of elasticity (MoE) of Micro concrete was also followed the same pattern like compressive strength and maximum MoE for polyester fiber reinforced Micro-concrerte was found at 0.4% fiber content and for Galvanized iron wire reinforced Micro-content maximum magnitude was found at 1.5% fiber content.

- Water absorption (Sorptivity) tests revealed that Micro concrete is more reliable in terms of durability than normal concrete. The initial water absorption rate and secondary water absorption rate is significantly lower than normal concrete which indicates batter durability. On the other hand fiber content (both polyester and GI fiber) reduces the initial absorption rate but in long term increases secondary absorption rate.

6.3 Major Finding

- For PFRMC 0.2 % fiber content may be considered as optimum content considering strength, ductility and durability parameter of Micro concrete.
- For GWRMC 1.5% fiber content may be considered as optimum content considering strength, ductility and durability parameter of Micro concrete.
- GI fiber is a very good alternatives for reinforcing Micro concrete with respect to Bangladesh.

6.4 Recommendations

During the course of the experiments and analysis, there was always an urge to expand the scope of the study in order to gather some more information and to achieve some better results. Moreover, as this is a relatively new field in construction sector of the country, opportunities for future researches are numerous. Some of these future research prospects are recommended below-

- To study performance of PFRMC with higher fiber contents up to 1 % by volume and for GWRMC up to 5% by weight with appropriate mix design.
- To investigate the response of PFRMC and GWRC under cyclic loading.
- To conduct experiments on any particular property of PFRMC or GWRMC with a large sample size in order to establish a statistically significant relationship between various characteristic properties.
- To study effect of aspect ratio of polyester fiber and as well as GI wire fiber on various properties of Micro concrete.
- To study performance of PFRMC and GWRMC for shrinkage.
- To study performance of PFRMC and GWRMC for Impact loading.

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APPENDIX A

Raw data for estimating Modulus of Elasticity of Micro concretefor different proportion of Polyester and Steel fiber.

Table A 1: Raw data of Modulus of elasticity (Control)

Dial reading (control sample)	Deformation (mm)	strain (mm/mm)	Load (kip) Sample 01	Load (kip) Sample 02	Load (kip) Sample 03	Stress (MPa)-01	Stress (MPa)-02	Stress (MPa)-03
0	0	0	0.00	0.00	0.00	0.00	0.00	0.00
2	0.004	0.00005	3.33	3.50	3.83	1.83	1.92	2.10
4	0.008	0.00010	4.97	4.08	4.15	2.73	2.24	2.28
6	0.012	0.00016	6.12	5.24	5.45	3.36	2.88	2.99
8	0.016	0.00021	7.60	6.77	7.27	4.17	3.72	3.99
10	0.02	0.00026	9.07	8.27	9.09	4.98	4.54	4.99
12	0.024	0.00031	10.51	10.37	12.83	5.77	5.69	7.04
14	0.028	0.00037	12.79	14.51	15.78	7.02	7.96	8.66
16	0.032	0.00042	14.89	17.26	18.74	8.17	9.47	10.28
18	0.036	0.00047	16.77	20.21	21.39	9.20	11.09	11.74
20	0.04	0.00052	19.23	23.16	24.05	10.55	12.71	13.20
22	0.044	0.00058	22.67	25.82	26.61	12.44	14.17	14.60
24	0.048	0.00063	26.12	28.58	29.46	14.33	15.68	16.17
26	0.052	0.00068	28.58	31.33	32.12	15.68	17.19	17.63
28	0.056	0.00073	31.82	33.99	34.28	17.46	18.65	18.81
30	0.06	0.00079	34.48	36.45	36.94	18.92	20.00	20.27

Table A 2: Raw data of Modulus of elasticity (0.1% PFRMC)

Dial reading (0.1% Polyester fiber)	Deformation (mm)	strain (in/in)	Load (kip) Sample 01	Load (kip) Sample 02	Load (kip) Sample 03	Stress (MPa)-01	Stress (MPa)-02	Stress (MPa)-03
0	0	0	0.00	0.00	0.00	0.00	0.00	0.00
2	0.004	0.00005	4.08	7.82	5.75	2.24	4.29	3.16
4	0.008	0.00010	6.73	10.08	8.70	3.70	5.53	4.78
6	0.012	0.00016	9.19	12.34	12.14	5.05	6.77	6.67
8	0.016	0.00021	11.16	14.31	14.41	6.13	7.85	7.91
10	0.02	0.00026	14.11	16.57	17.06	7.75	9.10	9.37
12	0.024	0.00031	15.49	18.74	17.95	8.50	10.28	9.85
14	0.028	0.00037	17.16	20.21	21.00	9.42	11.09	11.53
16	0.032	0.00042	18.83	21.69	22.87	10.34	11.90	12.55
18	0.036	0.00047	20.61	23.66	24.94	11.31	12.98	13.68
20	0.04	0.00052	22.67	25.72	27.00	12.44	14.12	14.82
22	0.044	0.00058	24.15	27.10	28.58	13.25	14.87	15.68
24	0.048	0.00063	25.92	28.77	29.95	14.22	15.79	16.44
26	0.052	0.00068	27.49	30.05	31.72	15.09	16.49	17.41
28	0.056	0.00073	29.07	31.23	33.20	15.95	17.14	18.22
30	0.06	0.00079	30.35	32.51	34.68	16.65	17.84	19.03

Table A 3: Raw data of Modulus of elasticity (0.2% PFRMC)

Dial reading (0.2% Polyester fiber)	Deformation (mm)	strain (in/in)	Load (kip) Sample 01	Load (kip) Sample 02	Load (kip) Sample 03	Stress (MPa) -01	Stress (MPa) -02	Stress (MPa) -03
0	0	0	0.00	0.00	0.00	0.00	0.00	0.00
2	0.004	0.00005	3.78	4.27	1.81	2.08	2.35	1.00
4	0.008	0.00010	6.14	7.03	3.98	3.37	3.86	2.18
6	0.012	0.00016	8.70	9.19	6.63	4.78	5.05	3.64
8	0.016	0.00021	10.77	11.36	9.09	5.91	6.23	4.99
10	0.02	0.00026	13.52	13.72	11.55	7.42	7.53	6.34
12	0.024	0.00031	15.88	15.78	13.92	8.72	8.66	7.64
14	0.028	0.00037	18.24	17.75	15.78	10.01	9.74	8.66
16	0.032	0.00042	19.92	19.43	18.15	10.93	10.66	9.96
18	0.036	0.00047	22.18	21.49	20.70	12.17	11.80	11.36
20	0.04	0.00052	24.15	23.66	23.16	13.25	12.98	12.71
22	0.044	0.00058	25.82	24.94	24.84	14.17	13.68	13.63
24	0.048	0.00063	27.69	26.90	27.49	15.20	14.76	15.09
26	0.052	0.00068	29.36	28.58	29.76	16.11	15.68	16.33
28	0.056	0.00073	31.04	30.35	32.02	17.03	16.65	17.57
30	0.06	0.00079	32.81	32.02	34.18	18.00	17.57	18.76

Table A 4: Raw data of Modulus of elasticity (0.3% PFRMC)

Dial reading (0.3% Polyester fiber)	deformation (mm)	strain (in/in)	Load (kip) Sample 01	Load (kip) Sample 02	Load (kip) Sample 03	Stress (MPa) -01	Stress (MPa) -02	Stress (MPa) -03
0	0	0	0.00	0.00	0.00	0.00	0.00	0.00
2	0.004	0.00005	2.80	4.47	3.68	1.54	2.45	2.02
4	0.008	0.00010	4.96	7.03	6.04	2.72	3.86	3.32
6	0.012	0.00016	7.82	9.59	7.91	4.29	5.26	4.34
8	0.016	0.00021	10.37	11.16	10.08	5.69	6.13	5.53
10	0.02	0.00026	13.03	13.33	11.95	7.15	7.31	6.56
12	0.024	0.00031	15.78	15.39	13.92	8.66	8.45	7.64
14	0.028	0.00037	18.24	17.06	15.59	10.01	9.37	8.56
16	0.032	0.00042	20.51	18.74	17.26	11.26	10.28	9.47
18	0.036	0.00047	22.67	20.61	18.74	12.44	11.31	10.28
20	0.04	0.00052	24.94	22.28	20.41	13.68	12.23	11.20
22	0.044	0.00058	26.80	23.66	21.98	14.71	12.98	12.07
24	0.048	0.00063	28.77	25.13	23.36	15.79	13.79	12.82
26	0.052	0.00068	31.04	26.61	24.74	17.03	14.60	13.58
28	0.056	0.00073	32.71	28.08	26.12	17.95	15.41	14.33
30	0.06	0.00079	34.48	29.26	27.30	18.92	16.06	14.98

Table A 5: Raw data of Modulus of elasticity (0.4% PFRMC)

Dial reading (0.4% Polyester fiber)	deformation (mm)	strain (in/in)	Load (kip) Sample 01	Load (kip) Sample 02	Load (kip) Sample 03	Stress (MPa)-01	Stress (MPa)-02	Stress (MPa)-03
0	0	0	0.00	0.00	0.00	0.00	0.00	0.00
2	0.004	0.00005	4.96	3.68	6.73	2.72	2.02	3.70
4	0.008	0.00010	9.09	6.44	10.67	4.99	3.53	5.86
6	0.012	0.00016	13.23	8.70	13.62	7.26	4.78	7.48
8	0.016	0.00021	17.26	10.77	15.59	9.47	5.91	8.56
10	0.02	0.00026	21.00	12.83	18.24	11.53	7.04	10.01
12	0.024	0.00031	25.13	15.10	20.90	13.79	8.29	11.47
14	0.028	0.00037	29.07	17.26	22.87	15.95	9.47	12.55
16	0.032	0.00042	33.10	18.54	24.84	18.17	10.18	13.63
18	0.036	0.00047	38.91	20.70	27.30	21.35	11.36	14.98
20	0.04	0.00052	0.00	22.77	29.56	0.00	12.50	16.22
22	0.044	0.00058	0.00	24.44	31.33	0.00	13.42	17.19
24	0.048	0.00063	0.00	26.51	33.00	0.00	14.55	18.11
26	0.052	0.00068	0.00	28.28	34.58	0.00	15.52	18.98
28	0.056	0.00073	0.00	30.05	36.45	0.00	16.49	20.00
30	0.06	0.00079	0.00	31.82	38.12	0.00	17.46	20.92

Table A 6: Raw data of Modulus of elasticity (0.5% PFRMC)

Dial reading (0.5% Polyester fiber)	deformation (mm)	strain (in/in)	Load (kip) Sample 01	Load (kip) Sample 02	Load (kip) Sample 03	Stress (MPa) -01	Stress (MPa) -02	Stress (MPa) -03
0	0	0	0.00	0.00	0.00	0.00	0.00	0.00
2	0.004	0.00005	3.29	2.01	3.09	1.81	1.10	1.70
4	0.008	0.00010	5.55	4.17	6.44	3.05	2.29	3.53
6	0.012	0.00016	7.72	6.24	9.78	4.24	3.43	5.37
8	0.016	0.00021	9.39	8.01	13.03	5.15	4.40	7.15
10	0.02	0.00026	10.96	9.88	16.08	6.02	5.42	8.83
12	0.024	0.00031	12.44	11.65	19.62	6.83	6.40	10.77
14	0.028	0.00037	13.92	13.13	22.77	7.64	7.21	12.50
16	0.032	0.00042	15.10	14.60	26.61	8.29	8.02	14.60
18	0.036	0.00047	16.47	16.08	31.04	9.04	8.83	17.03
20	0.04	0.00052	17.65	17.56	37.43	9.69	9.64	20.54
22	0.044	0.00058	18.83	18.74	0.00	10.34	10.28	0.00
24	0.048	0.00063	19.92	20.11	0.00	10.93	11.04	0.00
26	0.052	0.00068	20.80	21.39	0.00	11.42	11.74	0.00
28	0.056	0.00073	21.88	22.57	0.00	12.01	12.39	0.00
30	0.06	0.00079	22.87	23.66	0.00	12.55	12.98	0.00

Table A 7: Raw data of Modulus of elasticity (1% GWRMC)

Dial reading (1% Steel fiber)	deformation (mm)	strain (in/in)	Load (kip) Sample 01	Load (kip) Sample 02	Load (kip) Sample 03	Stress (MPa) -01	Stress (MPa) -02	Stress (MPa) -03
0	0	0	0.00	0.00	0.00	0.00	0.00	0.00
2	0.004	0.00005	4.96	6.44	6.44	2.72	3.53	3.53
4	0.008	0.00010	7.91	10.08	10.08	4.34	5.53	5.53
6	0.012	0.00016	10.67	13.52	13.52	5.86	7.42	7.42
8	0.016	0.00021	13.13	15.98	15.98	7.21	8.77	8.77
10	0.02	0.00026	15.78	18.44	18.44	8.66	10.12	10.12
12	0.024	0.00031	18.24	20.70	21.88	10.01	11.36	12.01
14	0.028	0.00037	20.80	23.16	24.15	11.42	12.71	13.25
16	0.032	0.00042	23.16	25.53	26.41	12.71	14.01	14.49
18	0.036	0.00047	25.33	27.79	28.58	13.90	15.25	15.68
20	0.04	0.00052	27.69	30.05	31.04	15.20	16.49	17.03
22	0.044	0.00058	29.95	32.41	33.69	16.44	17.79	18.49
24	0.048	0.00063	32.12	34.77	35.95	17.63	19.08	19.73
26	0.052	0.00068	33.79	37.43	37.92	18.54	20.54	20.81
28	0.056	0.00073	35.95	39.89	40.38	19.73	21.89	22.16
30	0.06	0.00079	37.92	0.00	0.00	20.81	0.00	0.00

Table A 8: Raw data of Modulus of elasticity (1.5% GWRMC)

Dial reading (1.5% Steel fiber)	deformation (mm)	strain (in/in)	Load (kip) Sample 01	Load (kip) Sample 02	Load (kip) Sample 03	Stress (MPa)-01	Stress (MPa)-02	Stress (MPa)-03
0	0	0	0.00	0.00	0.00	0.00	0.00	0.00
2	0.004	0.00005	4.77	11.85	4.96	2.62	6.50	2.72
4	0.008	0.00010	6.93	16.28	8.11	3.80	8.93	4.45
6	0.012	0.00016	10.37	19.82	11.85	5.69	10.88	6.50
8	0.016	0.00021	13.62	22.67	14.31	7.48	12.44	7.85
10	0.02	0.00026	16.28	25.43	16.47	8.93	13.95	9.04
12	0.024	0.00031	19.23	28.58	19.23	10.55	15.68	10.55
14	0.028	0.00037	21.20	31.82	21.39	11.63	17.46	11.74
16	0.032	0.00042	24.15	34.77	23.66	13.25	19.08	12.98
18	0.036	0.00047	26.80	38.12	25.82	14.71	20.92	14.17
20	0.04	0.00052	29.07	41.46	28.08	15.95	22.76	15.41
22	0.044	0.00058	31.82	0.00	30.54	17.46	0.00	16.76
24	0.048	0.00063	34.18	0.00	32.90	18.76	0.00	18.06
26	0.052	0.00068	36.45	0.00	34.97	20.00	0.00	19.19
28	0.056	0.00073	38.61	0.00	37.33	21.19	0.00	20.49
30	0.06	0.00079	40.58	0.00	39.30	22.27	0.00	21.57

Table A 9: Raw data of Modulus of elasticity (2% GWRMC)

Dial reading (2% Steel fiber)	deformation (mm)	strain (in/in)	Load (kip) Sample 01	Load (kip) Sample 02	Load (kip) Sample 03	Stress (MPa) -01	Stress (MPa) -02	Stress (MPa) -03
0	0	0	0.00	0.00	0.00	0.00	0.00	0.00
2	0.004	0.00005	3.68	4.96	3.98	2.02	2.72	2.18
4	0.008	0.00010	6.93	8.60	7.42	3.80	4.72	4.07
6	0.012	0.00016	9.68	11.85	10.18	5.32	6.50	5.59
8	0.016	0.00021	12.64	15.10	12.64	6.94	8.29	6.94
10	0.02	0.00026	15.00	17.95	14.51	8.23	9.85	7.96
12	0.024	0.00031	17.75	21.20	16.67	9.74	11.63	9.15
14	0.028	0.00037	20.02	24.15	18.54	10.99	13.25	10.18
16	0.032	0.00042	22.18	26.80	20.61	12.17	14.71	11.31
18	0.036	0.00047	24.15	29.46	22.57	13.25	16.17	12.39
20	0.04	0.00052	26.51	32.51	24.64	14.55	17.84	13.52
22	0.044	0.00058	28.48	35.27	26.12	15.63	19.35	14.33
24	0.048	0.00063	31.04	37.92	28.67	17.03	20.81	15.74
26	0.052	0.00068	32.90	39.89	30.54	18.06	21.89	16.76
28	0.056	0.00073	34.87	0.00	32.51	19.14	0.00	17.84
30	0.06	0.00079	36.94	0.00	34.48	20.27	0.00	18.92

Table A 10: Raw data of Modulus of elasticity (2.5% GWRMC)

Dial reading (2.5% Steel fiber)	deformation (mm)	strain (in/in)	Load (kip) Sample 01	Load (kip) Sample 02	Load (kip) Sample 03	Stress (MPa) -01	Stress (MPa) -02	Stress (MPa) -03
0	0	0	0.00	0.00	0.00	0.00	0.00	0.00
2	0.004	0.00005	6.44	4.67	4.27	3.53	2.56	2.35
4	0.008	0.00010	9.78	7.03	7.13	5.37	3.86	3.91
6	0.012	0.00016	12.93	9.88	10.08	7.10	5.42	5.53
8	0.016	0.00021	15.29	12.05	12.34	8.39	6.61	6.77
10	0.02	0.00026	17.65	14.60	13.72	9.69	8.02	7.53
12	0.024	0.00031	19.92	16.87	17.06	10.93	9.26	9.37
14	0.028	0.00037	22.57	19.23	19.23	12.39	10.55	10.55
16	0.032	0.00042	24.84	21.59	21.49	13.63	11.85	11.80
18	0.036	0.00047	27.00	23.66	23.85	14.82	12.98	13.09
20	0.04	0.00052	29.07	26.21	26.31	15.95	14.39	14.44
22	0.044	0.00058	31.04	28.38	28.08	17.03	15.57	15.41
24	0.048	0.00063	33.00	30.74	30.25	18.11	16.87	16.60
26	0.052	0.00068	34.97	32.90	32.22	19.19	18.06	17.68
28	0.056	0.00073	36.94	35.17	34.09	20.27	19.30	18.71
30	0.06	0.00079	38.91	36.94	35.95	21.35	20.27	19.73

APPENDIX B

Stress-strain Plots for computing Modulus of elasticity of Control sample and FRMC

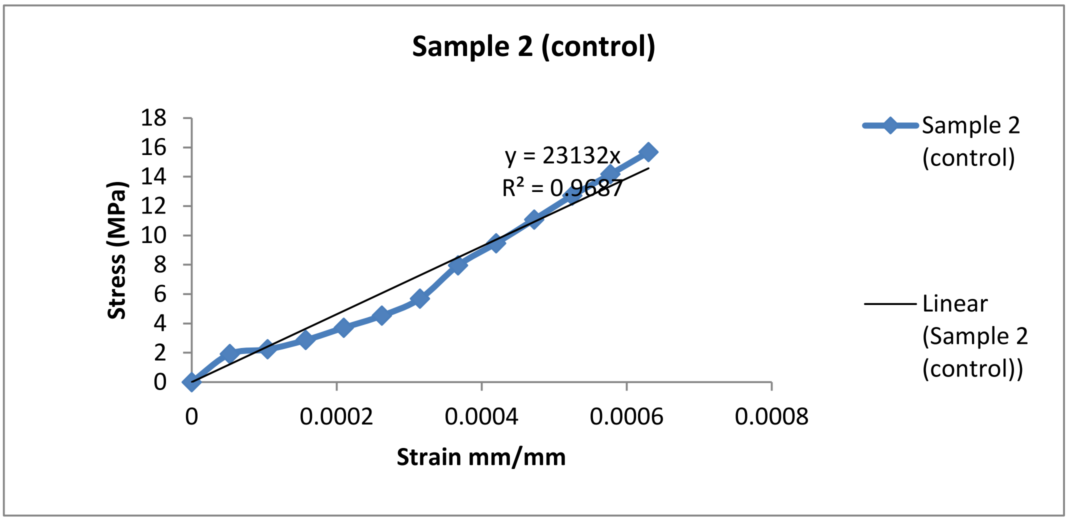

Figure B 2: Stress-strain curve for control sample 2

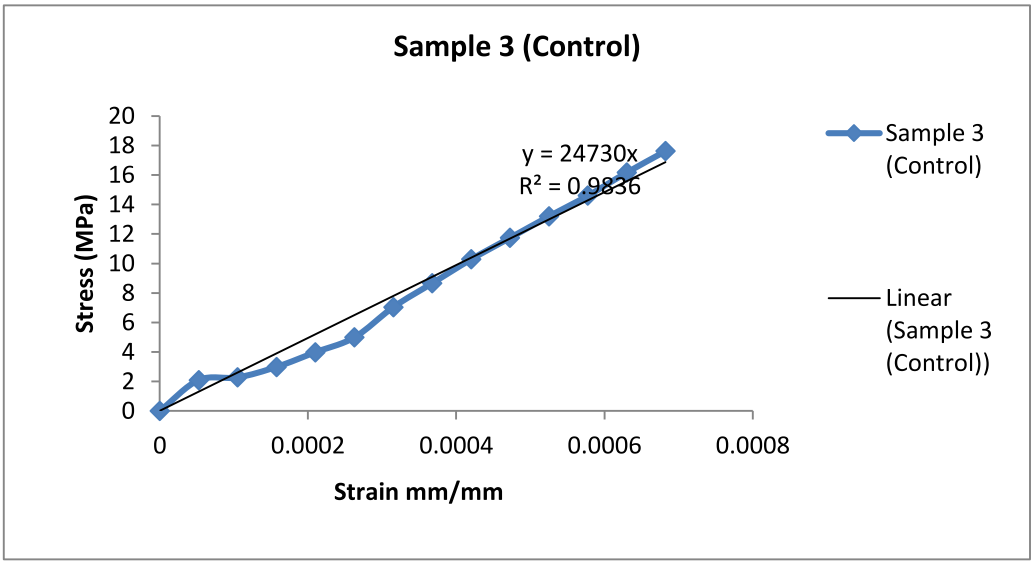

Figure B 1: Stress-strain curve for control sample 3

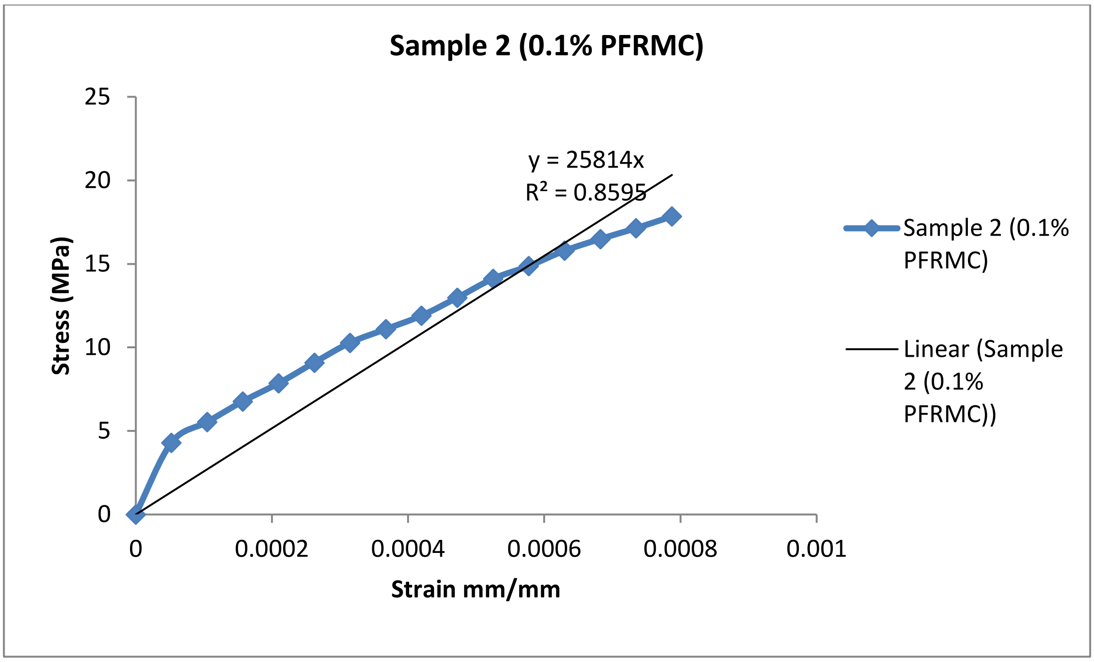

Figure B 3: Stress-strain curve for sample 2 with 0.1% PRFMC

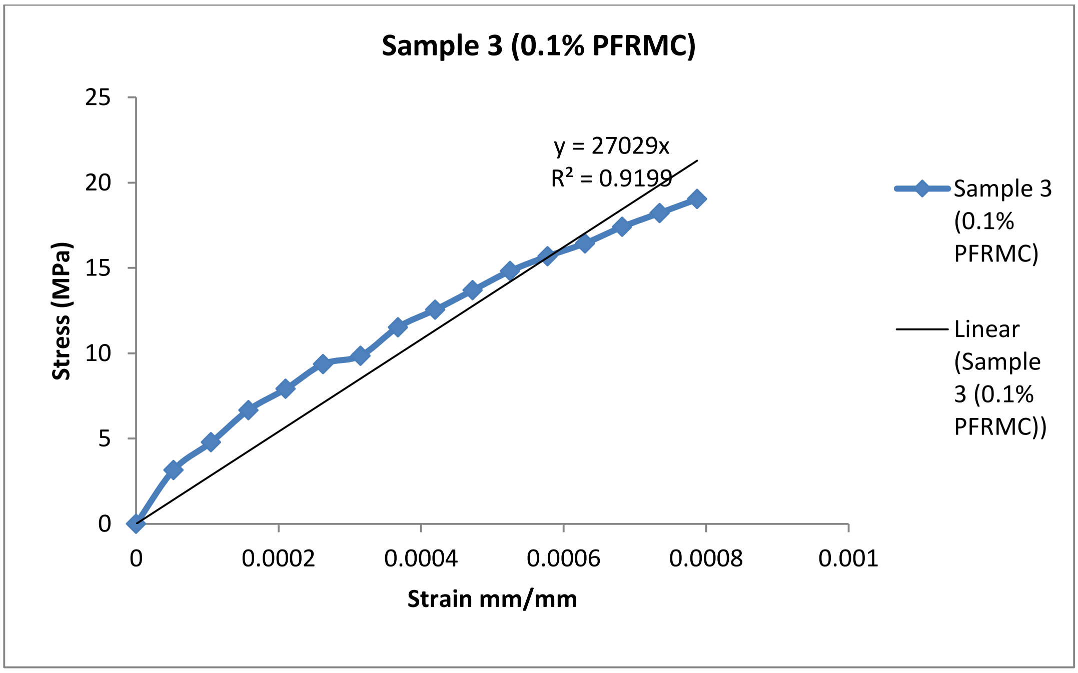

Figure B 4: Stress-strain curve for sample 3 with 0.1% PRFMC

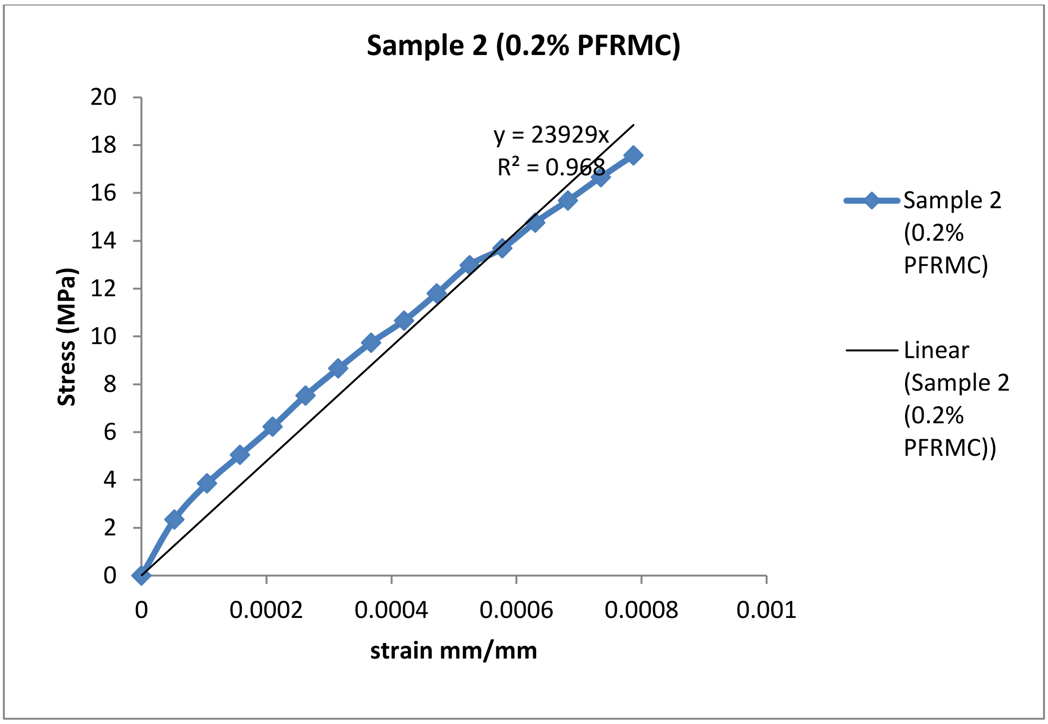

Figure B 5: Stress-strain curve for sample 2 with 0.2% PRFMC

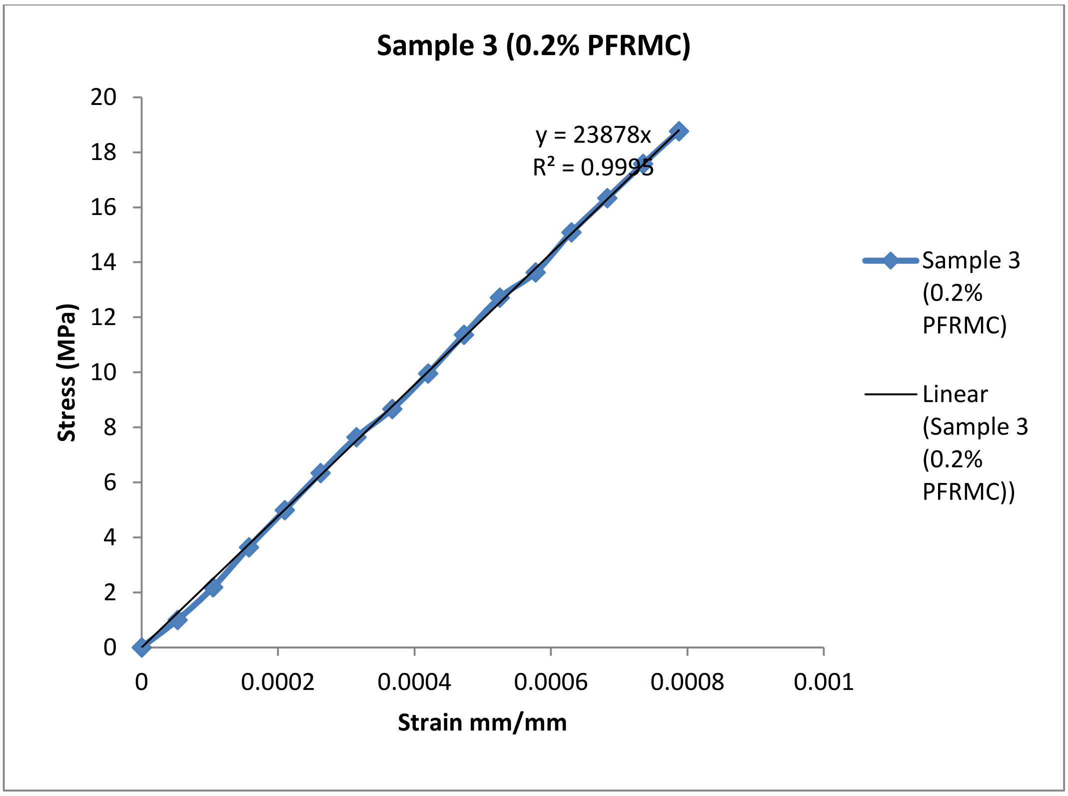

Figure B 6: Stress-strain curve for sample 3 with 0.2% PRFMC

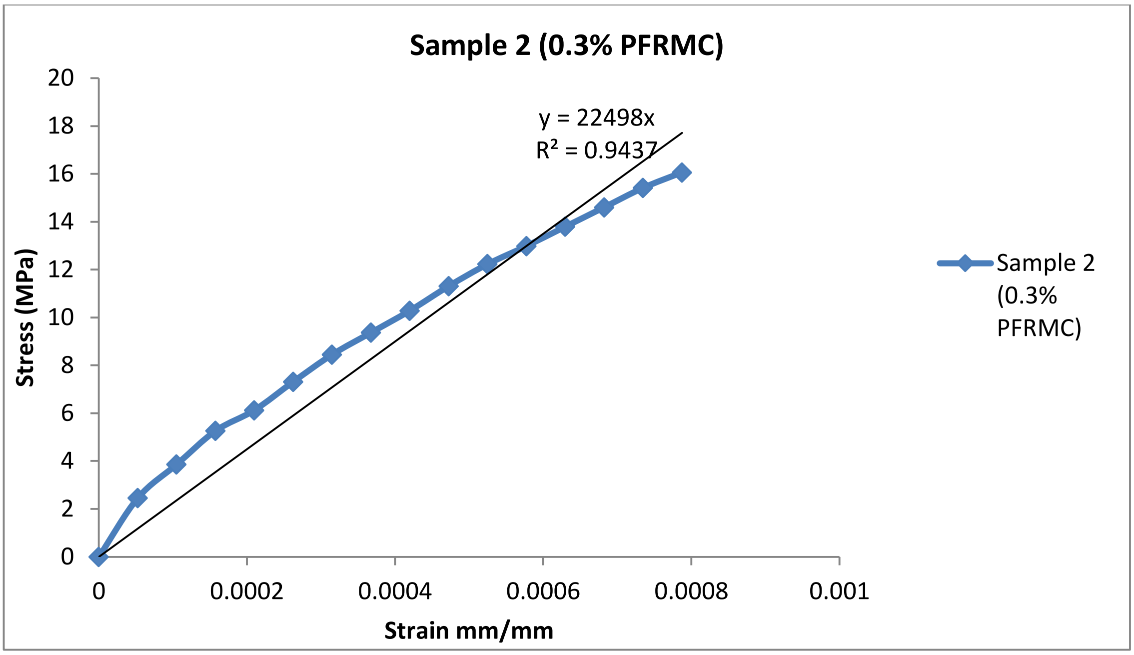

Figure B 7: Stress-strain curve for sample 2 with 0.3% PRFMC

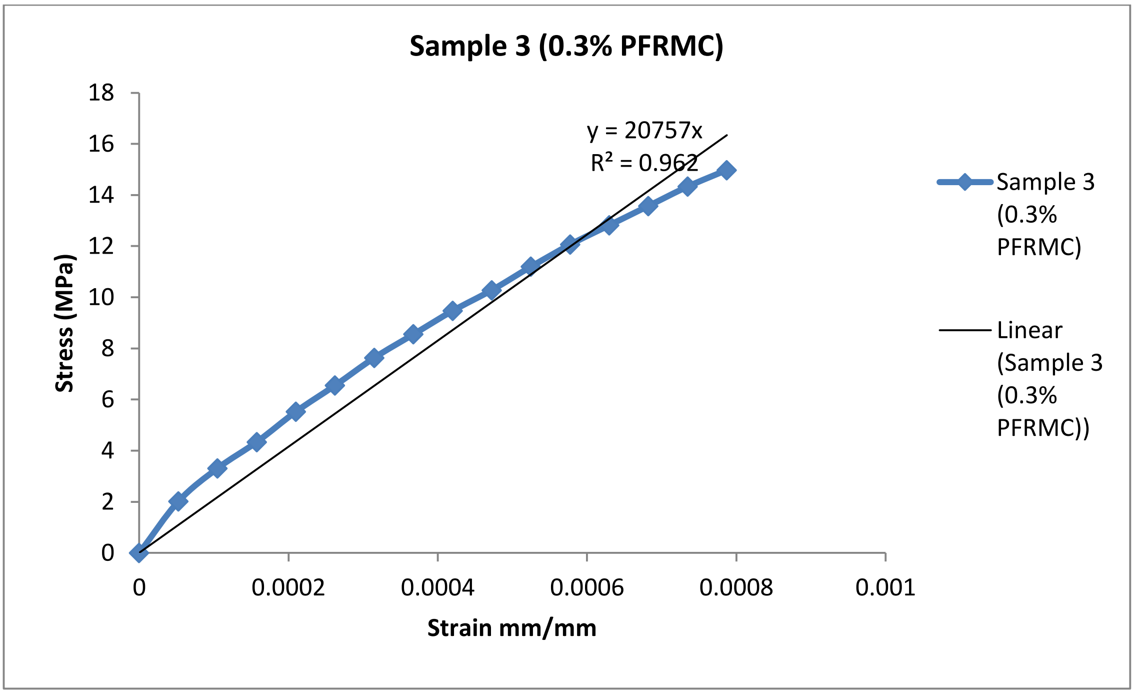

Figure B 8: Stress-strain curve for sample 3 with 0.3% PRFMC

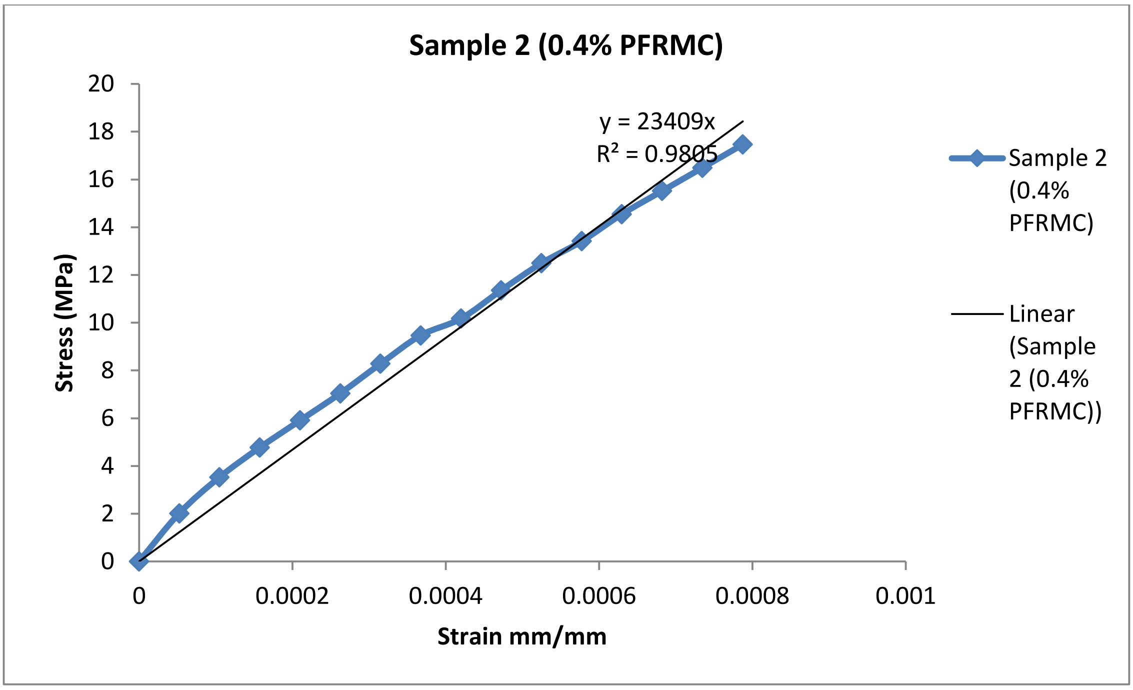

Figure B 9: Stress-strain curve for sample 2 with 0.4% PRFMC

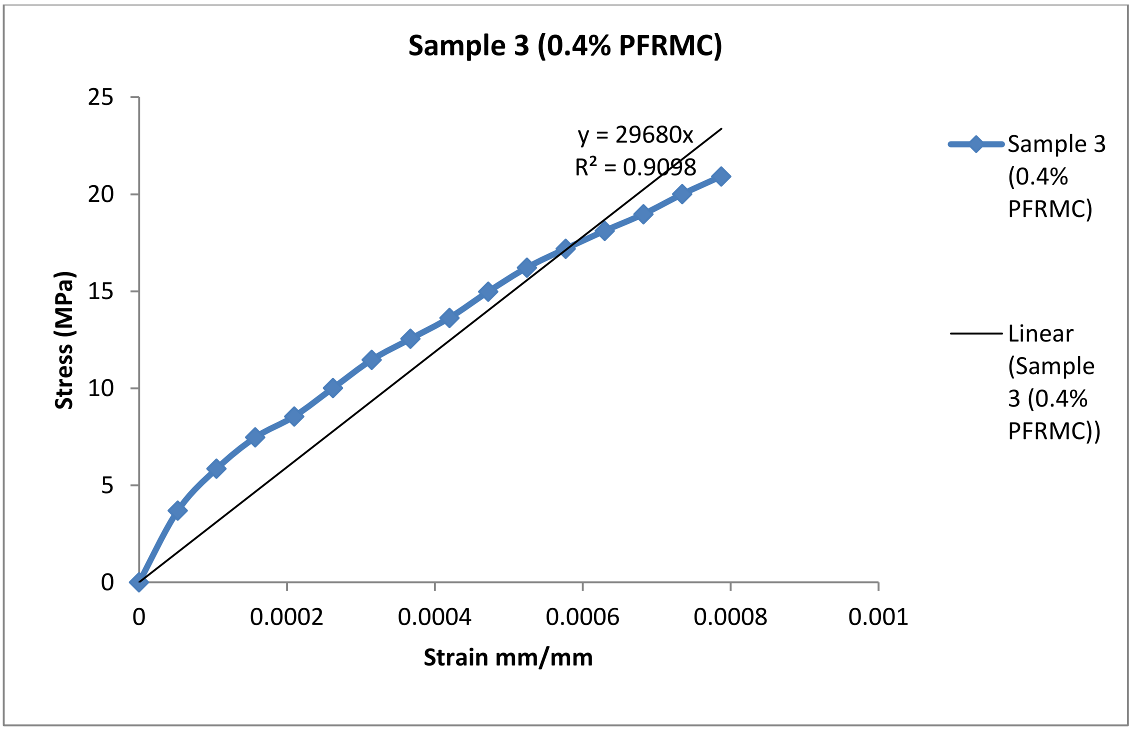

Figure B 10: Stress-strain curve for sample 3 with 0.4% PRFMC

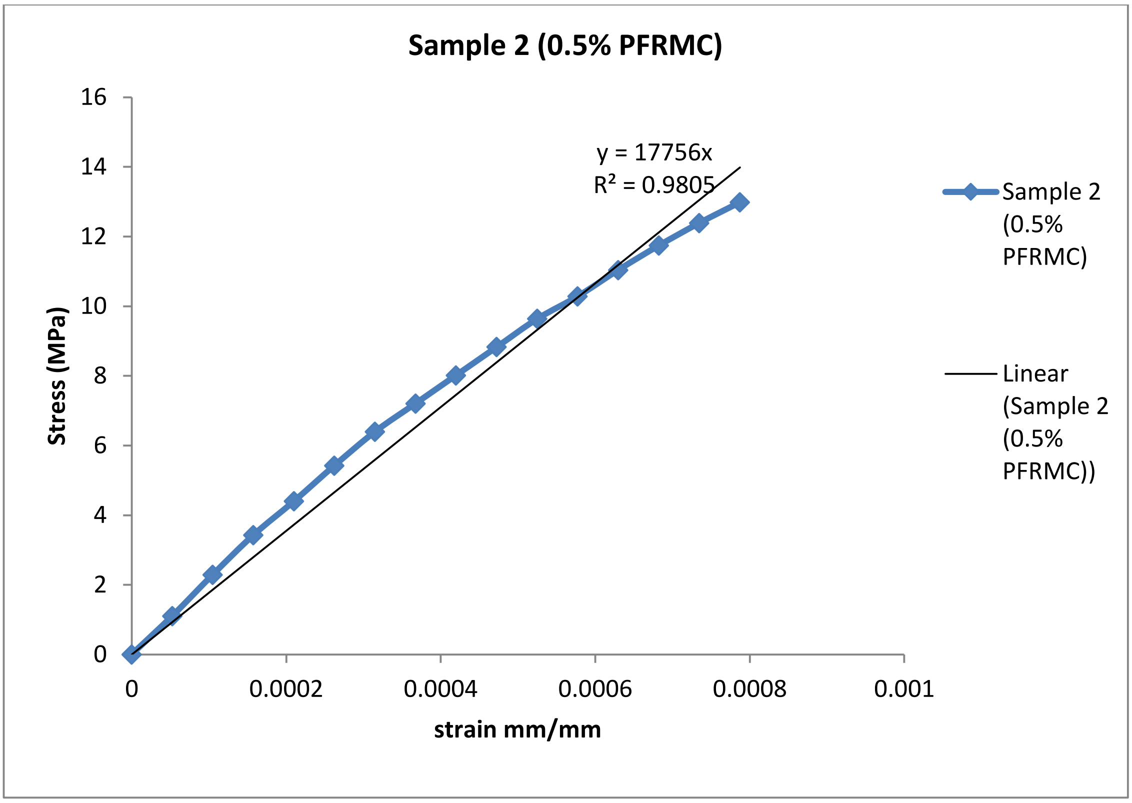

Figure B 11: Stress-strain curve for sample 2 with 0.5% PRFMC

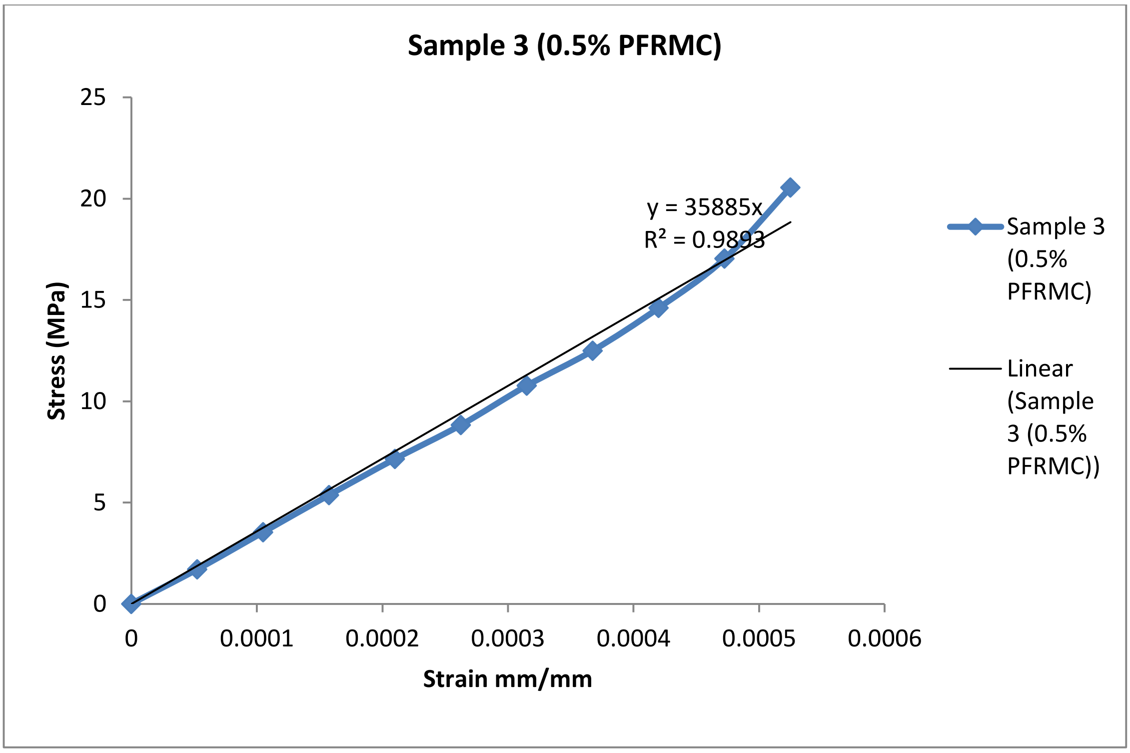

Figure B 12: Stress-strain curve for sample 3 with 0.5% PRFMC

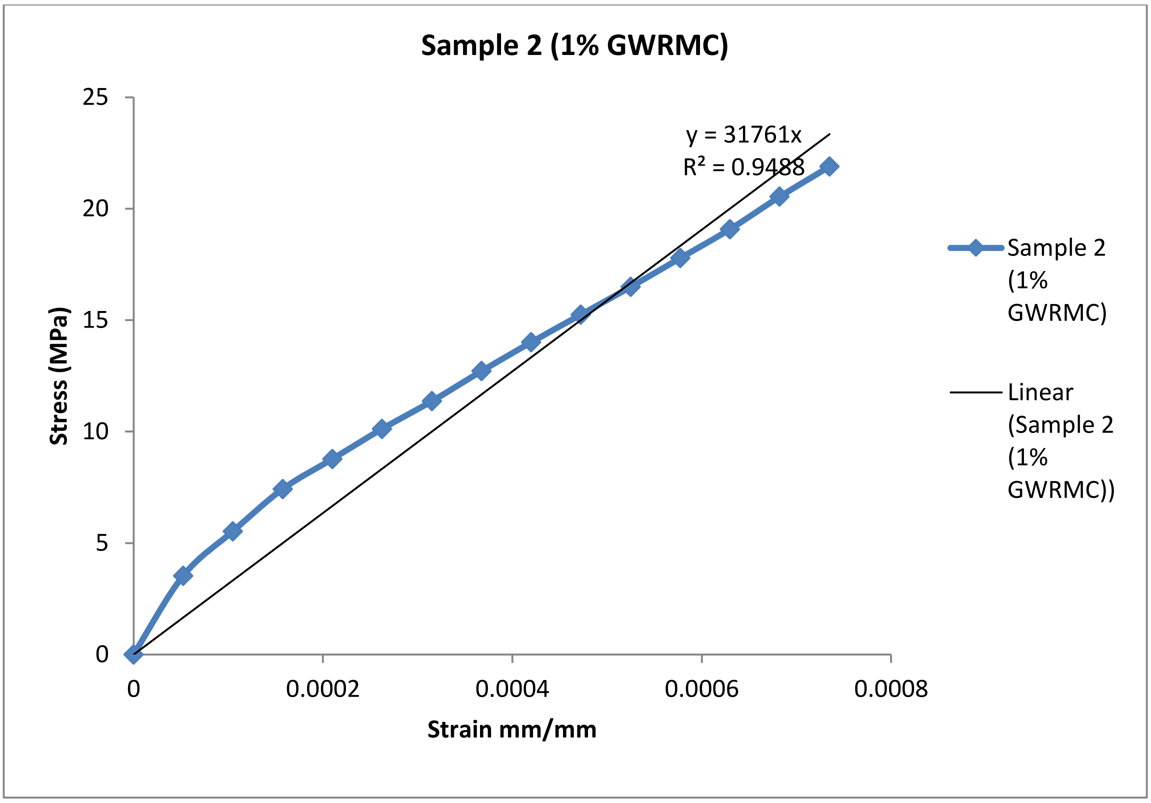

Figure B 13: Stress-strain curve for sample 2 with 1% GWRMC

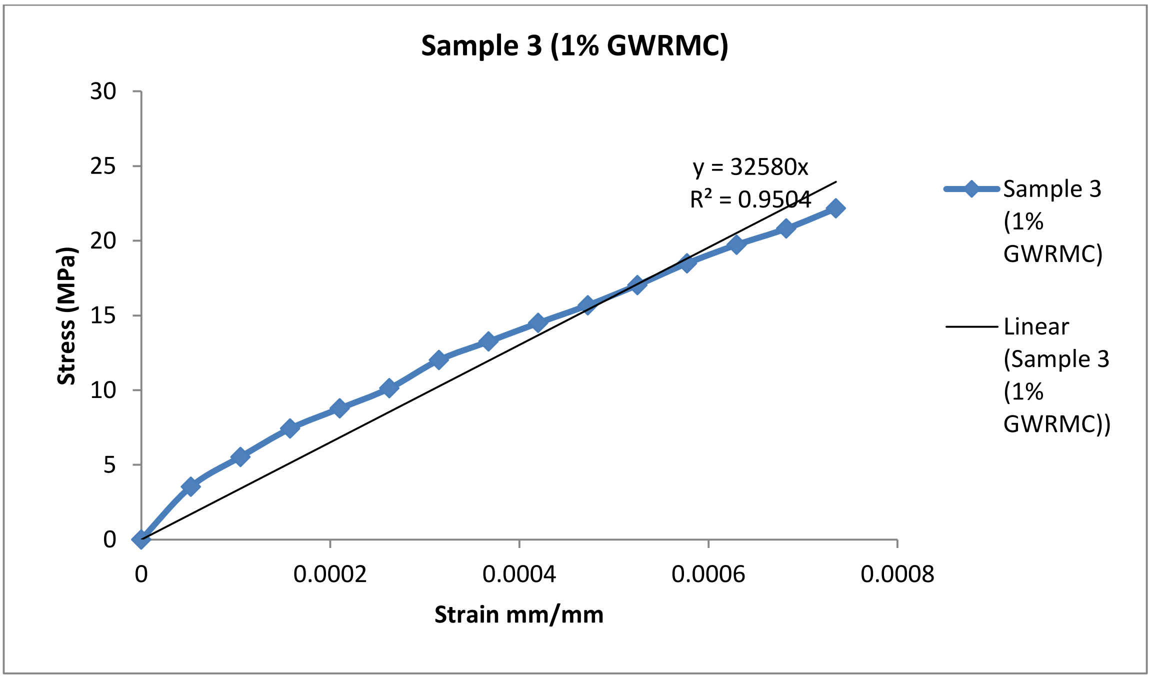

Figure B 14: Stress-strain curve for sample 3 with 1% GWRMC

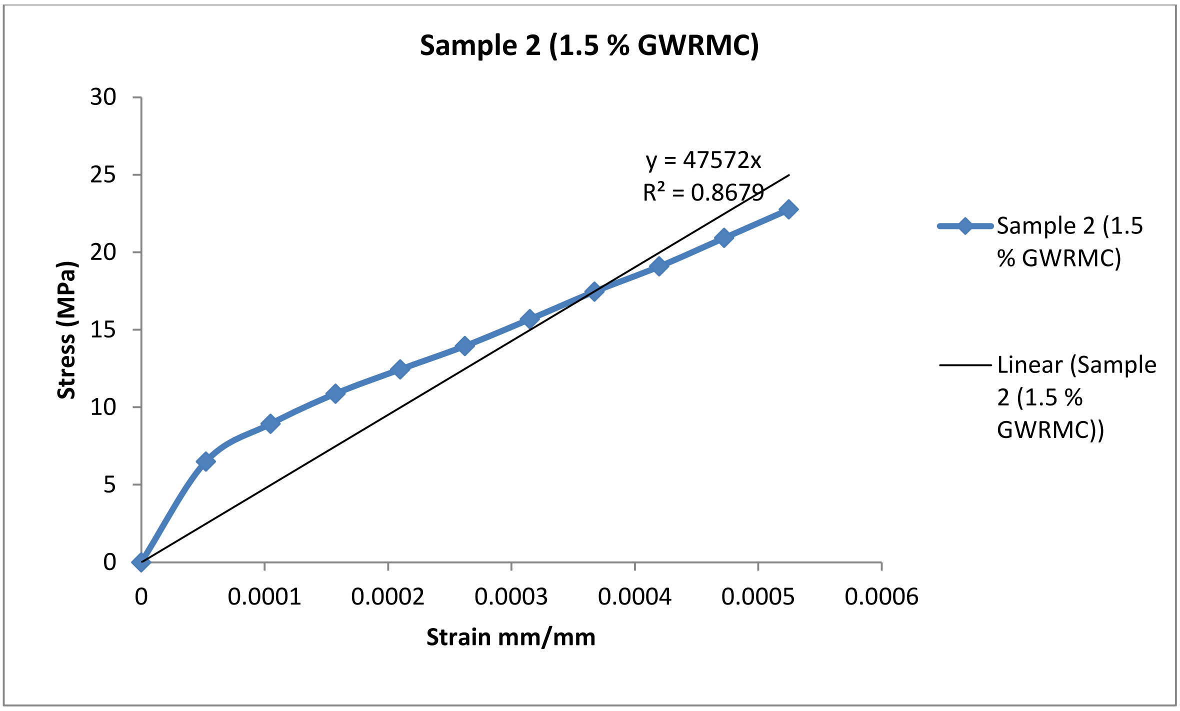

Figure B 15: Stress-strain curve for sample 2 with 1.5% GWRMC

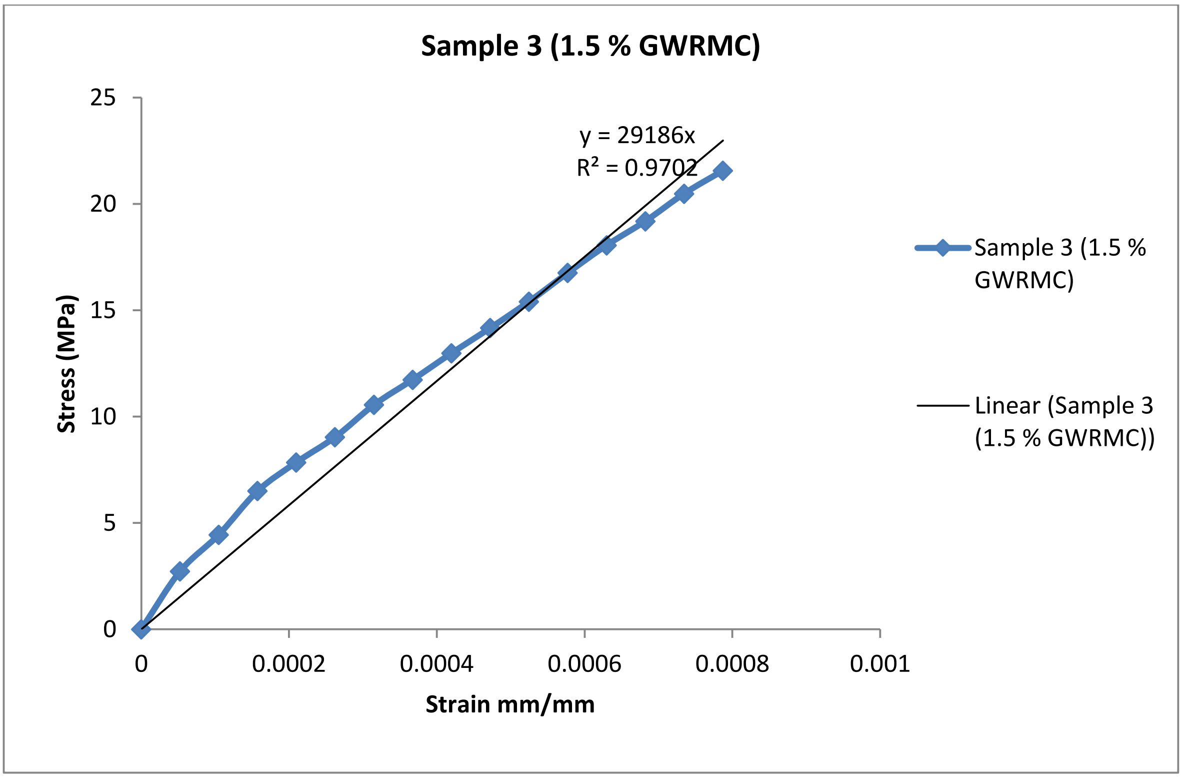

Figure B 16: Stress-strain curve for sample 3 with 1.5% GWRMC

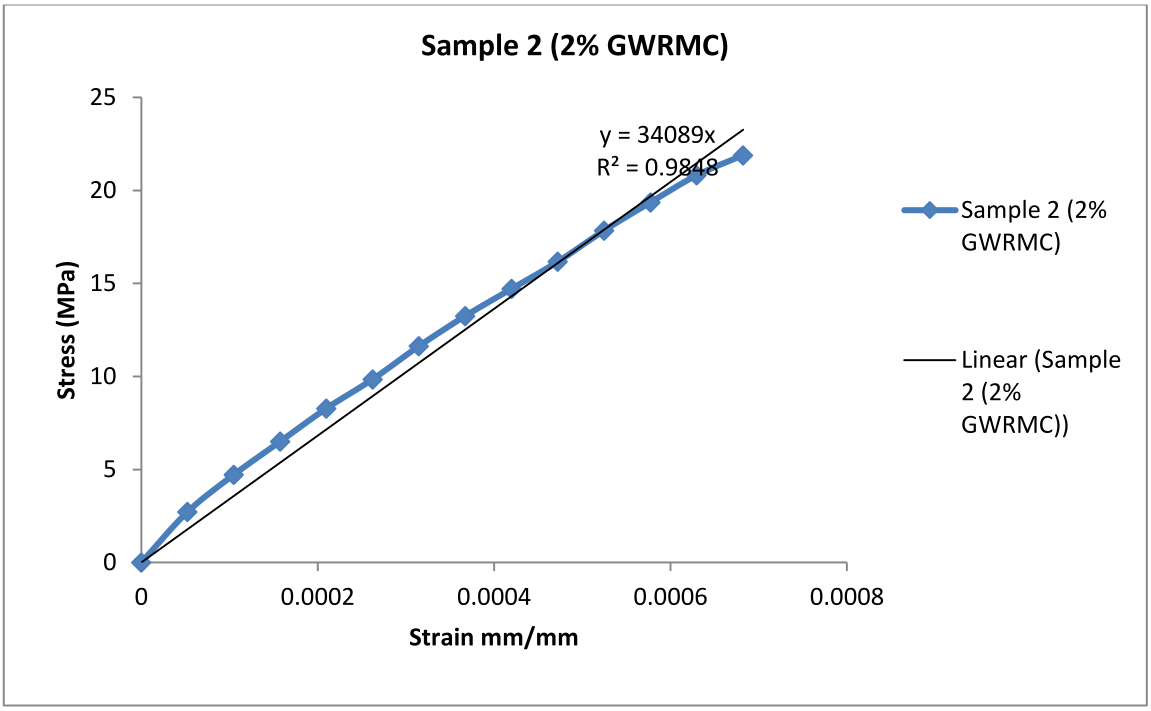

Figure B 17: Stress-strain curve for sample 2 with 2% GWRMC

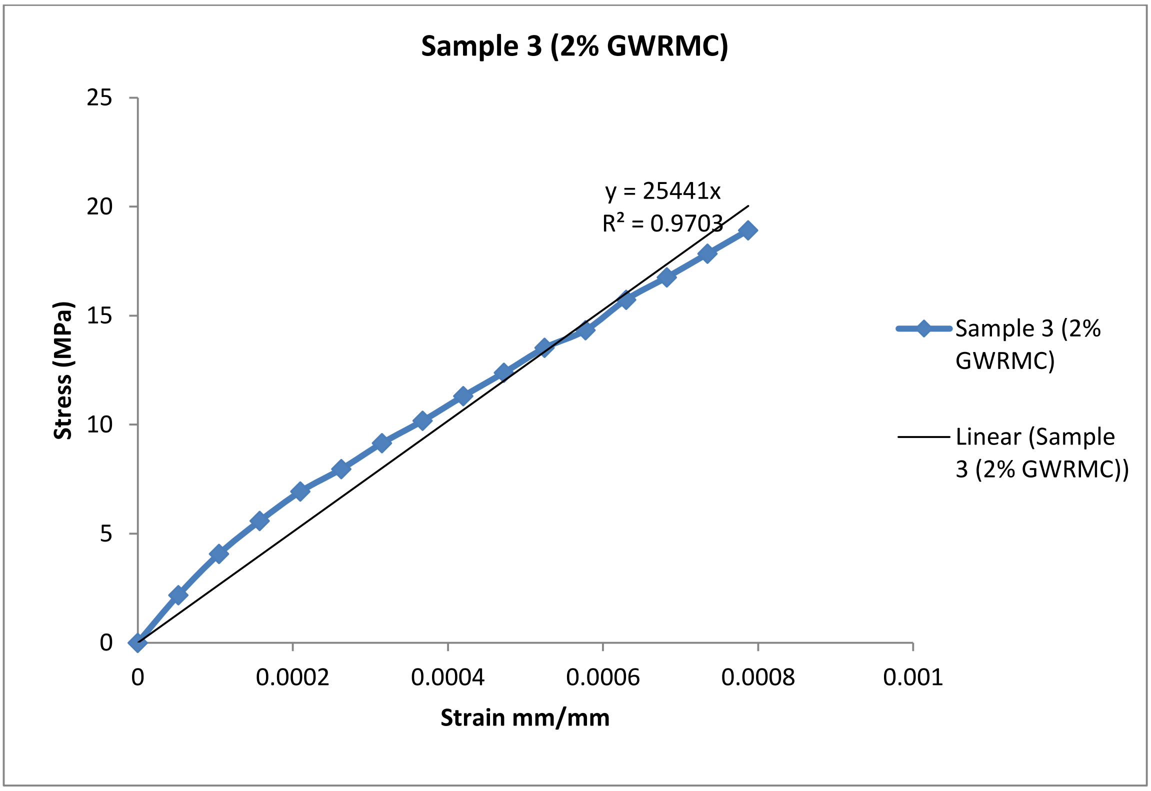

Figure B 18: Stress-strain curve for sample 3 with 2% GWRMC

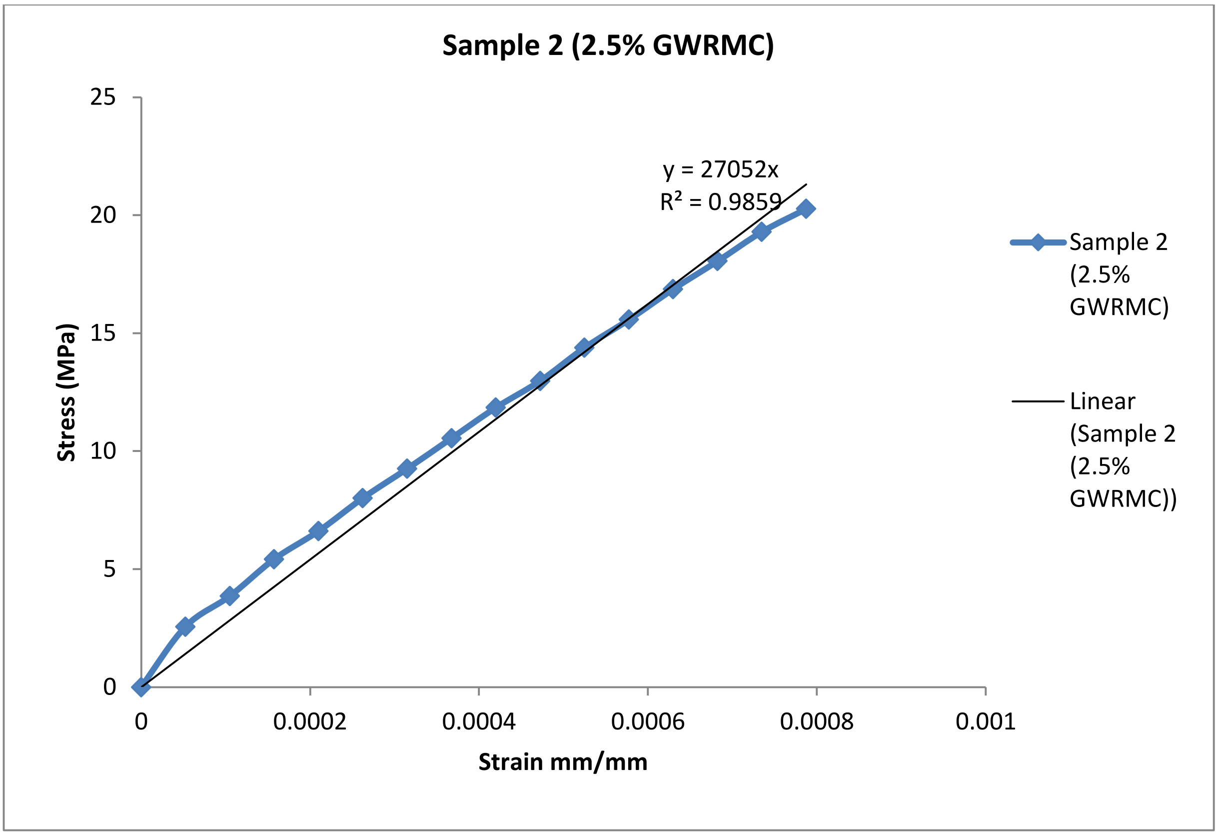

Figure B 19: Stress-strain curve for sample 2 with 2.5% GWRMC

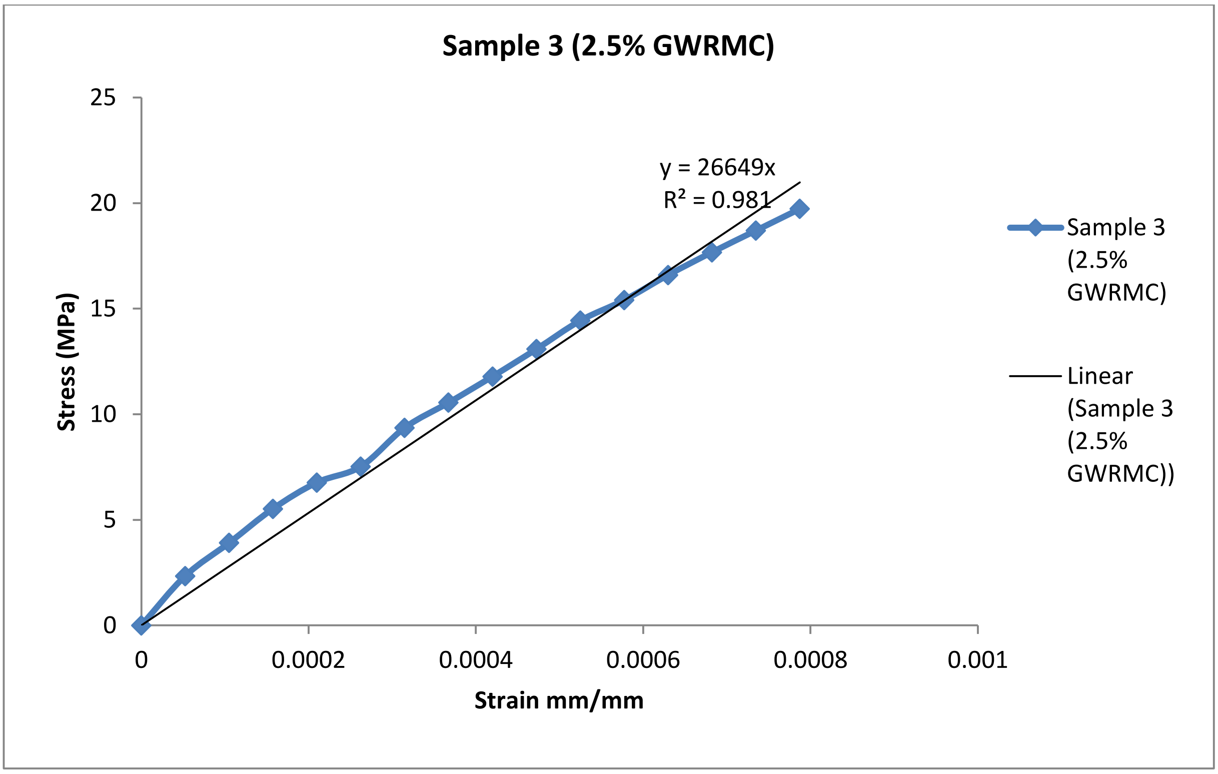

Figure B 20: Stress-strain curve for sample 3 with 2.5% GWRMC

APPENDIX C

Raw data for estimating Sorptivity for different content of fiber.

Table C 1: Calculation of water absorption rate of sample 1 (control sample)

Day (control 01)	`Second	Time √sec	Time √sec	Mass (g)	ΔMass (g)	Cumulative mass	Δmass/area/density of water= I (mm)
	0	0	0	0.928	0.000	0.000	0.0000000
	60	7.745967	8	0.931	0.003	0.003	0.0003700
	300	17.32051	17	0.933	0.002	0.005	0.0006167
	600	24.4949	24	0.934	0.001	0.006	0.0007401
	1200	34.64102	35	0.934	0.000	0.006	0.0007401
	1800	42.42641	42	0.936	0.002	0.008	0.0009868
	3600	60	60	0.940	0.004	0.012	0.0014801
	7200	84.85281	85	0.943	0.003	0.015	0.0018502
	10800	103.923	104	0.943	0.000	0.015	0.0018502
	14400	120	120	0.946	0.003	0.018	0.0022202
	18000	134.1641	134	0.949	0.003	0.021	0.0025902
	21600	146.9694	147	0.950	0.001	0.022	0.0027136
1	93600	305.9412	306	0.953	0.003	0.025	0.0030836
2	174600	417.8516	418	0.955	0.002	0.027	0.0033303
3	266440	516.1783	516	0.955	0.000	0.027	0.0033303
5	441900	664.7556	665	0.955	0.000	0.027	0.0033303
6	526500	725.6032	726	0.955	0.000	0.027	0.0033303
7	612900	782.8793	783	0.956	0.001	0.028	0.0034536
8	699300	836.2416	836	0.956	0.000	0.028	0.0034536

Table C 2: Calculation of water absorption rate of sample 2 (control sample)

Day (control 2)	second	Time √sec	Time √sec	Mass (g)	ΔMass (g)	Cumulative mass	Δmass/area/density of water= I (mm)
	0	0	0	0.926	0.000	0.000	0.0000000
	60	7.745967	8	0.928	0.002	0.002	0.0002467
	300	17.32051	17	0.928	0.000	0.002	0.0002467
	600	24.4949	24	0.929	0.001	0.003	0.0003700
	1200	34.64102	35	0.931	0.002	0.005	0.0006167
	1800	42.42641	42	0.931	0.000	0.005	0.0006167
	3600	60	60	0.932	0.001	0.006	0.0007401
	7200	84.85281	85	0.937	0.005	0.011	0.0013568
	10800	103.923	104	0.937	0.000	0.011	0.0013568
	14400	120	120	0.939	0.002	0.013	0.0016035
	18000	134.1641	134	0.941	0.002	0.015	0.0018502
	21600	146.9694	147	0.941	0.000	0.015	0.0018502
1	93600	305.9412	306	0.947	0.006	0.021	0.0025902
2	174600	417.8516	418	0.949	0.002	0.023	0.0028369
3	266440	516.1783	516	0.949	0.000	0.023	0.0028369
5	441900	664.7556	665	0.950	0.001	0.024	0.0029603
6	526500	725.6032	726	0.950	0.000	0.024	0.0029603
7	612900	782.8793	783	0.951	0.001	0.025	0.0030836
8	699300	836.2416	836	0.951	0.000	0.025	0.0030836

Table C 3: Calculation of water absorption rate of sample 1 (0.1% PFRMC)

Day (0.1% polyester - 01)	second	Time √sec	Time √sec	Mass (g)	ΔMass (g)	Cumulative mass	Δmass/area/density of water= I (mm)
	0	0	0	0.916	0.000	0.000	0.0000000
	60	7.745967	8	0.919	0.003	0.003	0.0003700
	300	17.32051	17	0.922	0.003	0.006	0.0007401
	600	24.4949	24	0.923	0.001	0.007	0.0008634
	1200	34.64102	35	0.925	0.002	0.009	0.0011101
	1800	42.42641	42	0.927	0.002	0.011	0.0013568
	3600	60	60	0.929	0.002	0.013	0.0016035
	7200	84.85281	85	0.934	0.005	0.018	0.0022202
	10800	103.923	104	0.936	0.002	0.020	0.0024669
	14400	120	120	0.936	0.000	0.020	0.0024669
	18000	134.1641	134	0.936	0.000	0.020	0.0024669
	21600	146.9694	147	0.938	0.002	0.022	0.0027136
1	93600	305.9412	306	0.938	0.000	0.022	0.0027136
2	174600	417.8516	418	0.938	0.000	0.022	0.0027136
3	266440	516.1783	516	0.938	0.000	0.022	0.0027136
5	441900	664.7556	665	0.939	0.001	0.023	0.0028369
6	526500	725.6032	726	0.939	0.000	0.023	0.0028369
7	612900	782.8793	783	0.939	0.000	0.023	0.0028369
8	699300	836.2416	836	0.940	0.001	0.024	0.0029603

Table C 4: Calculation of water absorption rate of sample 2 (0.1% PFRMC)

Day (0.1% polyester-02)	second	Time √sec	Time √sec	Mass (g)	ΔMass (g)	Cumulative mass	Δmass/area/density of water= I (mm)
	0	0	0	0.866	0.000	0.000	0.0000000
	60	7.745967	8	0.870	0.004	0.004	0.0004934
	300	17.32051	17	0.872	0.002	0.006	0.0007401
	600	24.4949	24	0.874	0.002	0.008	0.0009868
	1200	34.64102	35	0.875	0.001	0.009	0.0011101
	1800	42.42641	42	0.877	0.002	0.011	0.0013568
	3600	60	60	0.881	0.004	0.015	0.0018502
	7200	84.85281	85	0.885	0.004	0.019	0.0023435
	10800	103.923	104	0.888	0.003	0.022	0.0027136
	14400	120	120	0.889	0.001	0.023	0.0028369
	18000	134.1641	134	0.891	0.002	0.025	0.0030836
	21600	146.9694	147	0.892	0.001	0.026	0.0032069
1	93600	305.9412	306	0.899	0.007	0.033	0.0040704
2	174600	417.8516	418	0.900	0.001	0.034	0.0041937
3	266440	516.1783	516	0.900	0.000	0.034	0.0041937
5	441900	664.7556	665	0.900	0.000	0.034	0.0041937
6	526500	725.6032	726	0.900	0.000	0.034	0.0041937
7	612900	782.8793	783	0.901	0.001	0.035	0.0043170
8	699300	836.2416	836	0.901	0.000	0.035	0.0043170

Table C 5: Calculation of water absorption rate of sample 1 (0.2% PFRMC)

Day (0.2% polyester-01)	second	Time √sec	Time √sec	Mass (g)	ΔMass (g)	Cumulative mass	Δmass/area/density of water= I (mm)
	0	0	0	0.938	0.000	0.000	0.0000000
	60	7.745967	8	0.942	0.004	0.004	0.0004934
	300	17.32051	17	0.942	0.000	0.004	0.0004934
	600	24.4949	24	0.943	0.001	0.005	0.0006167
	1200	34.64102	35	0.944	0.001	0.006	0.0007401
	1800	42.42641	42	0.944	0.000	0.006	0.0007401
	3600	60	60	0.949	0.005	0.011	0.0013568
	7200	84.85281	85	0.954	0.005	0.016	0.0019735
	10800	103.923	104	0.954	0.000	0.016	0.0019735
	14400	120	120	0.956	0.002	0.018	0.0022202
	18000	134.1641	134	0.957	0.001	0.019	0.0023435
	21600	146.9694	147	0.958	0.001	0.020	0.0024669
1	93600	305.9412	306	0.962	0.004	0.024	0.0029603
2	174600	417.8516	418	0.964	0.002	0.026	0.0032069
3	266440	516.1783	516	0.964	0.000	0.026	0.0032069
5	441900	664.7556	665	0.964	0.000	0.026	0.0032069
6	526500	725.6032	726	0.964	0.000	0.026	0.0032069
7	612900	782.8793	783	0.965	0.001	0.027	0.0033303
8	699300	836.2416	836	0.965	0.000	0.027	0.0033303

Table C 6: Calculation of water absorption rate of sample 2 (0.2% PFRMC)

Day (0.2% polyester-02)	second	Time √sec	Time √sec	Mass (g)	ΔMass (g)	Cumulative mass	Δmass/area/density of water= I (mm)
	0	0	0	0.931	0.000	0.000	0.0000000
	60	7.745967	8	0.934	0.003	0.003	0.0003700
	300	17.32051	17	0.934	0.000	0.003	0.0003700
	600	24.4949	24	0.937	0.003	0.006	0.0007401
	1200	34.64102	35	0.940	0.003	0.009	0.0011101
	1800	42.42641	42	0.940	0.000	0.009	0.0011101
	3600	60	60	0.946	0.006	0.015	0.0018502
	7200	84.85281	85	0.951	0.005	0.020	0.0024669
	10800	103.923	104	0.953	0.002	0.022	0.0027136
	14400	120	120	0.954	0.001	0.023	0.0028369
	18000	134.1641	134	0.956	0.002	0.025	0.0030836
	21600	146.9694	147	0.956	0.000	0.025	0.0030836
1	93600	305.9412	306	0.958	0.002	0.027	0.0033303
2	174600	417.8516	418	0.958	0.000	0.027	0.0033303
3	266440	516.1783	516	0.958	0.000	0.027	0.0033303
5	441900	664.7556	665	0.959	0.001	0.028	0.0034536
6	526500	725.6032	726	0.959	0.000	0.028	0.0034536
7	612900	782.8793	783	0.959	0.000	0.028	0.0034536
8	699300	836.2416	836	0.960	0.001	0.029	0.0035770

Table C 7: Calculation of water absorption rate of sample 1 (0.3% PFRMC)

Day (0.3% polyester -01)	second	Time √sec	Time √sec	Mass (g)	ΔMass (g)	Cumulativ e mass	Δmass/area/densit y of water= I (mm)
	0	0	0	0.888	0.000	0.000	0.0000000
	60	7.745967	8	0.891	0.003	0.003	0.0003700
	300	17.32051	17	0.893	0.002	0.005	0.0006167
	600	24.4949	24	0.894	0.001	0.006	0.0007401
	1200	34.64102	35	0.895	0.001	0.007	0.0008634
	1800	42.42641	42	0.895	0.000	0.007	0.0008634
	3600	60	60	0.897	0.002	0.009	0.0011101
	7200	84.85281	85	0.897	0.000	0.009	0.0011101
	10800	103.923	104	0.898	0.001	0.010	0.0012334
	14400	120	120	0.899	0.001	0.011	0.0013568
	18000	134.1641	134	0.900	0.001	0.012	0.0014801
	21600	146.9694	147	0.901	0.001	0.013	0.0016035
1	93600	305.9412	306	0.906	0.005	0.018	0.0022202
2	174600	417.8516	418	0.908	0.002	0.020	0.0024669
3	266440	516.1783	516	0.908	0.000	0.020	0.0024669
5	441900	664.7556	665	0.910	0.002	0.022	0.0027136
6	526500	725.6032	726	0.910	0.000	0.022	0.0027136
7	612900	782.8793	783	0.911	0.001	0.023	0.0028369
8	699300	836.2416	836	0.911	0.000	0.023	0.0028369

Table C 8: Calculation of water absorption rate of sample 2 (0.3% PFRMC)

Day (0.3% polyester-02)	second	Time √sec	Time √sec	Mass (g)	ΔMass (g)	Cumulative mass	Δmass/area/density of water= I (mm)
	0	0	0	0.847	0.000	0.000	0.0000000
	60	7.745967	8	0.849	0.002	0.002	0.0002467
	300	17.32051	17	0.852	0.003	0.005	0.0006167
	600	24.4949	24	0.854	0.002	0.007	0.0008634
	1200	34.64102	35	0.855	0.001	0.008	0.0009868
	1800	42.42641	42	0.855	0.000	0.008	0.0009868
	3600	60	60	0.858	0.003	0.011	0.0013568
	7200	84.85281	85	0.859	0.001	0.012	0.0014801
	10800	103.923	104	0.859	0.000	0.012	0.0014801
	14400	120	120	0.860	0.001	0.013	0.0016035
	18000	134.1641	134	0.860	0.000	0.013	0.0016035
	21600	146.9694	147	0.862	0.002	0.015	0.0018502
1	93600	305.9412	306	0.865	0.003	0.018	0.0022202
2	174600	417.8516	418	0.867	0.002	0.020	0.0024669
3	266440	516.1783	516	0.867	0.000	0.020	0.0024669
5	441900	664.7556	665	0.868	0.001	0.021	0.0025902
6	526500	725.6032	726	0.868	0.000	0.021	0.0025902
7	612900	782.8793	783	0.869	0.001	0.022	0.0027136
8	699300	836.2416	836	0.869	0.000	0.022	0.0027136

Table C 9: Calculation of water absorption rate of sample 1 (0.4% PFRMC)

Day (0.4% polyester-01)	second	Time √sec	Time √sec	Mass (g)	ΔMass (g)	Cumulative mass	Δmass/area/density of water= I (mm)
	0	0	0	0.922	0.000	0.000	0.0000000
	60	7.745967	8	0.926	0.004	0.004	0.0004934
	300	17.32051	17	0.928	0.002	0.006	0.0007401
	600	24.4949	24	0.928	0.000	0.006	0.0007401
	1200	34.64102	35	0.930	0.002	0.008	0.0009868
	1800	42.42641	42	0.931	0.001	0.009	0.0011101
	3600	60	60	0.933	0.002	0.011	0.0013568
	7200	84.85281	85	0.934	0.001	0.012	0.0014801
	10800	103.923	104	0.937	0.003	0.015	0.0018502
	14400	120	120	0.938	0.001	0.016	0.0019735
	18000	134.1641	134	0.940	0.002	0.018	0.0022202
	21600	146.9694	147	0.941	0.001	0.019	0.0023435
1	93600	305.9412	306	0.948	0.007	0.026	0.0032069
2	174600	417.8516	418	0.949	0.001	0.027	0.0033303
3	266440	516.1783	516	0.949	0.000	0.027	0.0033303
5	441900	664.7556	665	0.950	0.001	0.028	0.0034536
6	526500	725.6032	726	0.950	0.000	0.028	0.0034536
7	612900	782.8793	783	0.950	0.000	0.028	0.0034536
8	699300	836.2416	836	0.951	0.001	0.029	0.0035770

Table C 10: Calculation of water absorption rate of sample 2 (0.4% PFRMC)

Day (0.4% polyester-02)	second	Time √sec	Time √sec	Mass (g)	ΔMass (g)	Cumulative mass	Δmass/area/density of water= I (mm)
	0	0	0	0.908	0.000	0.000	0.0000000
	60	7.745967	8	0.910	0.002	0.002	0.0002467
	300	17.32051	17	0.912	0.002	0.004	0.0004934
	600	24.4949	24	0.913	0.001	0.005	0.0006167
	1200	34.64102	35	0.914	0.001	0.006	0.0007401
	1800	42.42641	42	0.914	0.000	0.006	0.0007401
	3600	60	60	0.915	0.001	0.007	0.0008634
	7200	84.85281	85	0.917	0.002	0.009	0.0011101
	10800	103.923	104	0.918	0.001	0.010	0.0012334
	14400	120	120	0.918	0.000	0.010	0.0012334
	18000	134.1641	134	0.920	0.002	0.012	0.0014801
	21600	146.9694	147	0.920	0.000	0.012	0.0014801
1	93600	305.9412	306	0.926	0.006	0.018	0.0022202
2	174600	417.8516	418	0.928	0.002	0.020	0.0024669
3	266440	516.1783	516	0.929	0.001	0.021	0.0025902
5	441900	664.7556	665	0.930	0.001	0.022	0.0027136
6	526500	725.6032	726	0.930	0.000	0.022	0.0027136
7	612900	782.8793	783	0.930	0.000	0.022	0.0027136
8	699300	836.2416	836	0.931	0.001	0.023	0.0028369

Table C 11: Calculation of water absorption rate of sample 1 (0.5% PFRMC)

Day (0.5% polyester-01)	second	Time √sec	Time √sec	Mass (g)	ΔMass (g)	Cumulative mass	Δmass/area/density of water= I (mm)
	0	0	0	0.866	0.000	0.000	0.0000000
	60	7.745967	8	0.870	0.004	0.004	0.0004934
	300	17.32051	17	0.871	0.001	0.005	0.0006167
	600	24.4949	24	0.871	0.000	0.005	0.0006167
	1200	34.64102	35	0.873	0.002	0.007	0.0008634
	1800	42.42641	42	0.874	0.001	0.008	0.0009868
	3600	60	60	0.874	0.000	0.008	0.0009868
	7200	84.85281	85	0.876	0.002	0.010	0.0012334
	10800	103.923	104	0.876	0.000	0.010	0.0012334
	14400	120	120	0.877	0.001	0.011	0.0013568
	18000	134.1641	134	0.878	0.001	0.012	0.0014801
	21600	146.9694	147	0.878	0.000	0.012	0.0014801
1	93600	305.9412	306	0.885	0.007	0.019	0.0023435
2	174600	417.8516	418	0.889	0.004	0.023	0.0028369
3	266440	516.1783	516	0.889	0.000	0.023	0.0028369
5	441900	664.7556	665	0.891	0.002	0.025	0.0030836
6	526500	725.6032	726	0.891	0.000	0.025	0.0030836
7	612900	782.8793	783	0.891	0.000	0.025	0.0030836
8	699300	836.2416	836	0.892	0.001	0.026	0.0032069

Table C 12: Calculation of water absorption rate of sample 2 (0.5% PFRMC)

Day (0.5% polyester-02)	second	Time √sec	Time √sec	Mass (g)	ΔMass (g)	Cumulative mass	Δmass/area/density of water= I (mm)
	0	0	0	0.876	0.000	0.000	0.0000000
	60	7.745967	8	0.879	0.003	0.003	0.0003700
	300	17.32051	17	0.880	0.001	0.004	0.0004934
	600	24.4949	24	0.881	0.001	0.005	0.0006167
	1200	34.64102	35	0.881	0.000	0.005	0.0006167
	1800	42.42641	42	0.884	0.003	0.008	0.0009868
	3600	60	60	0.885	0.001	0.009	0.0011101
	7200	84.85281	85	0.888	0.003	0.012	0.0014801
	10800	103.923	104	0.888	0.000	0.012	0.0014801
	14400	120	120	0.888	0.000	0.012	0.0014801
	18000	134.1641	134	0.889	0.001	0.013	0.0016035
	21600	146.9694	147	0.889	0.000	0.013	0.0016035
1	93600	305.9412	306	0.896	0.007	0.020	0.0024669
2	174600	417.8516	418	0.898	0.002	0.022	0.0027136
3	266440	516.1783	516	0.898	0.000	0.022	0.0027136
5	441900	664.7556	665	0.899	0.001	0.023	0.0028369
6	526500	725.6032	726	0.899	0.000	0.023	0.0028369
7	612900	782.8793	783	0.899	0.000	0.023	0.0028369
8	699300	836.2416	836	0.900	0.001	0.024	0.0029603

Table C 13: Calculation of water absorption rate of sample 1 (1% GWRMC)

Day (1% Steel Fiber-01)	second	Time √sec	Time √sec	Mass (g)	ΔMass (g)	Cumulative mass	Δmass/area/density of water= I (mm)
	0	0	0	0.949	0.000	0.000	0.0000000
	60	7.745967	8	0.951	0.002	0.002	0.0002467
	300	17.32051	17	0.952	0.001	0.003	0.0003700
	600	24.4949	24	0.953	0.001	0.004	0.0004934
	1200	34.64102	35	0.953	0.000	0.004	0.0004934
	1800	42.42641	42	0.954	0.001	0.005	0.0006167
	3600	60	60	0.954	0.000	0.005	0.0006167
	7200	84.85281	85	0.956	0.002	0.007	0.0008634
	10800	103.923	104	0.957	0.001	0.008	0.0009868
	14400	120	120	0.957	0.000	0.008	0.0009868
	18000	134.1641	134	0.958	0.001	0.009	0.0011101
	21600	146.9694	147	0.959	0.001	0.010	0.0012334
1	93600	305.9412	306	0.965	0.006	0.016	0.0019735
2	174600	417.8516	418	0.968	0.003	0.019	0.0023435
3	266440	516.1783	516	0.968	0.000	0.019	0.0023435
5	441900	664.7556	665	0.970	0.002	0.021	0.0025902
6	526500	725.6032	726	0.971	0.001	0.022	0.0027136
7	612900	782.8793	783	0.972	0.001	0.023	0.0028369
8	699300	836.2416	836	0.972	0.000	0.023	0.0028369

Table C 14: Calculation of water absorption rate of sample 2 (1% GWRMC)

Day (1% Steel Fiber-02)	second	Time √sec	Time √sec	Mass (g)	ΔMass (g)	Cumulative mass	Δmass/area/density of water= I (mm)
	0	0	0	0.951	0.000	0.000	0.0000000
	60	7.745967	8	0.952	0.001	0.001	0.0001233
	300	17.32051	17	0.954	0.002	0.003	0.0003700
	600	24.4949	24	0.955	0.001	0.004	0.0004934
	1200	34.64102	35	0.955	0.000	0.004	0.0004934
	1800	42.42641	42	0.955	0.000	0.004	0.0004934
	3600	60	60	0.957	0.002	0.006	0.0007401
	7200	84.85281	85	0.958	0.001	0.007	0.0008634
	10800	103.923	104	0.959	0.001	0.008	0.0009868
	14400	120	120	0.959	0.000	0.008	0.0009868
	18000	134.1641	134	0.961	0.002	0.010	0.0012334
	21600	146.9694	147	0.961	0.000	0.010	0.0012334
1	93600	305.9412	306	0.966	0.005	0.015	0.0018502
2	174600	417.8516	418	0.968	0.002	0.017	0.0020968
3	266440	516.1783	516	0.970	0.002	0.019	0.0023435
5	441900	664.7556	665	0.971	0.001	0.020	0.0024669
6	526500	725.6032	726	0.972	0.001	0.021	0.0025902
7	612900	782.8793	783	0.973	0.001	0.022	0.0027136
8	699300	836.2416	836	0.973	0.000	0.022	0.0027136

Table C 15: Calculation of water absorption rate of sample 1 (1.5% GWRMC)

Day (1.5% Steel Fiber-01)	second	Time √sec	Time √sec	Mass (g)	ΔMass (g)	Cumulative mass	Δmass/area/density of water= I (mm)
	0	0	0	0.927	0.000	0.000	0.0000000
	60	7.745967	8	0.928	0.001	0.001	0.0001233
	300	17.32051	17	0.928	0.000	0.001	0.0001233
	600	24.4949	24	0.929	0.001	0.002	0.0002467
	1200	34.64102	35	0.930	0.001	0.003	0.0003700
	1800	42.42641	42	0.931	0.001	0.004	0.0004934
	3600	60	60	0.931	0.000	0.004	0.0004934
	7200	84.85281	85	0.932	0.001	0.005	0.0006167
	10800	103.923	104	0.934	0.002	0.007	0.0008634
	14400	120	120	0.934	0.000	0.007	0.0008634
	18000	134.1641	134	0.936	0.002	0.009	0.0011101
	21600	146.9694	147	0.936	0.000	0.009	0.0011101
1	93600	305.9412	306	0.941	0.005	0.014	0.0017268
2	174600	417.8516	418	0.943	0.002	0.016	0.0019735
3	266440	516.1783	516	0.943	0.000	0.016	0.0019735
5	441900	664.7556	665	0.943	0.000	0.016	0.0019735
6	526500	725.6032	726	0.944	0.001	0.017	0.0020968
7	612900	782.8793	783	0.944	0.000	0.017	0.0020968
8	699300	836.2416	836	0.944	0.000	0.017	0.0020968

Table C 16: Calculation of water absorption rate of sample 2 (1.5% GWRMC)

Day (1.5% Steel Fiber -02)	second	Time √sec	Time √sec	Mass (g)	ΔMass (g)	Cumulative mass	Δmass/area/density of water= I (mm)
	0	0	0	0.930	0.000	0.000	0.0000000
	60	7.745967	8	0.932	0.002	0.002	0.0002467
	300	17.32051	17	0.933	0.001	0.003	0.0003700
	600	24.4949	24	0.934	0.001	0.004	0.0004934
	1200	34.64102	35	0.934	0.000	0.004	0.0004934
	1800	42.42641	42	0.934	0.000	0.004	0.0004934
	3600	60	60	0.935	0.001	0.005	0.0006167
	7200	84.85281	85	0.936	0.001	0.006	0.0007401
	10800	103.923	104	0.937	0.001	0.007	0.0008634
	14400	120	120	0.938	0.001	0.008	0.0009868
	18000	134.1641	134	0.938	0.000	0.008	0.0009868
	21600	146.9694	147	0.939	0.001	0.009	0.0011101
1	93600	305.9412	306	0.944	0.005	0.014	0.0017268
2	174600	417.8516	418	0.946	0.002	0.016	0.0019735
3	266440	516.1783	516	0.948	0.002	0.018	0.0022202
5	441900	664.7556	665	0.949	0.001	0.019	0.0023435
6	526500	725.6032	726	0.950	0.001	0.020	0.0024669
7	612900	782.8793	783	0.950	0.000	0.020	0.0024669
8	699300	836.2416	836	0.950	0.000	0.020	0.0024669

Table C 17: Calculation of water absorption rate of sample 1 (2% GWRMC)

Day (2% Steel Fiber-01)	second	Time √sec	Time √sec	Mass (g)	ΔMass (g)	Cumulative mass	Δmass/area/density of water= I (mm)
	0	0	0	0.922	0.000	0.000	0.0000000
	60	7.745967	8	0.925	0.003	0.003	0.0003700
	300	17.32051	17	0.925	0.000	0.003	0.0003700
	600	24.4949	24	0.926	0.001	0.004	0.0004934
	1200	34.64102	35	0.926	0.000	0.004	0.0004934
	1800	42.42641	42	0.926	0.000	0.004	0.0004934
	3600	60	60	0.929	0.003	0.007	0.0008634
	7200	84.85281	85	0.930	0.001	0.008	0.0009868
	10800	103.923	104	0.930	0.000	0.008	0.0009868
	14400	120	120	0.930	0.000	0.008	0.0009868
	18000	134.1641	134	0.930	0.000	0.008	0.0009868
	21600	146.9694	147	0.932	0.002	0.010	0.0012334
1	93600	305.9412	306	0.939	0.007	0.017	0.0020968
2	174600	417.8516	418	0.941	0.002	0.019	0.0023435
3	266440	516.1783	516	0.941	0.000	0.019	0.0023435
5	441900	664.7556	665	0.941	0.000	0.019	0.0023435
6	526500	725.6032	726	0.942	0.001	0.020	0.0024669
7	612900	782.8793	783	0.942	0.000	0.020	0.0024669
8	699300	836.2416	836	0.943	0.001	0.021	0.0025902

Table C 18: Calculation of water absorption rate of sample 2 (2% GWRMC)

Day (2% Steel Fiber-02)	second	Time √sec	Time √sec	Mass (g)	ΔMass (g)	Cumulative mass	Δmass/area/density of water= I (mm)
	0	0	0	0.921	0.000	0.000	0.0000000
	60	7.745967	8	0.925	0.004	0.004	0.0004934
	300	17.32051	17	0.925	0.000	0.004	0.0004934
	600	24.4949	24	0.926	0.001	0.005	0.0006167
	1200	34.64102	35	0.927	0.001	0.006	0.0007401
	1800	42.42641	42	0.927	0.000	0.006	0.0007401
	3600	60	60	0.928	0.001	0.007	0.0008634
	7200	84.85281	85	0.930	0.002	0.009	0.0011101
	10800	103.923	104	0.932	0.002	0.011	0.0013568
	14400	120	120	0.932	0.000	0.011	0.0013568
	18000	134.1641	134	0.932	0.000	0.011	0.0013568
	21600	146.9694	147	0.933	0.001	0.012	0.0014801
1	93600	305.9412	306	0.940	0.007	0.019	0.0023435
2	174600	417.8516	418	0.941	0.001	0.020	0.0024669
3	266440	516.1783	516	0.943	0.002	0.022	0.0027136
5	441900	664.7556	665	0.944	0.001	0.023	0.0028369
6	526500	725.6032	726	0.944	0.000	0.023	0.0028369
7	612900	782.8793	783	0.944	0.000	0.023	0.0028369
8	699300	836.2416	836	0.945	0.001	0.024	0.0029603

Table C 19: Calculation of water absorption rate of sample 1 (2.5% GWRMC)

Day (2.5% Steel Fiber-01)	second	Time √sec	Time √sec	Mass (g)	ΔMass (g)	Cumulative mass	Δmass/area/density of water= I (mm)
	0	0	0	0.907	0.000	0.000	0.0000000
	60	7.745967	8	0.910	0.003	0.003	0.0003700
	300	17.32051	17	0.910	0.000	0.003	0.0003700
	600	24.4949	24	0.911	0.001	0.004	0.0004934
	1200	34.64102	35	0.911	0.000	0.004	0.0004934
	1800	42.42641	42	0.912	0.001	0.005	0.0006167
	3600	60	60	0.912	0.000	0.005	0.0006167
	7200	84.85281	85	0.914	0.002	0.007	0.0008634
	10800	103.923	104	0.914	0.000	0.007	0.0008634
	14400	120	120	0.914	0.000	0.007	0.0008634
	18000	134.1641	134	0.915	0.001	0.008	0.0009868
	21600	146.9694	147	0.916	0.001	0.009	0.0011101
1	93600	305.9412	306	0.920	0.004	0.013	0.0016035
2	174600	417.8516	418	0.922	0.002	0.015	0.0018502
3	266440	516.1783	516	0.924	0.002	0.017	0.0020968
5	441900	664.7556	665	0.926	0.002	0.019	0.0023435
6	526500	725.6032	726	0.926	0.000	0.019	0.0023435
7	612900	782.8793	783	0.927	0.001	0.020	0.0024669
8	699300	836.2416	836	0.927	0.000	0.020	0.0024669

Table C 20: Calculation of water absorption rate of sample 2 (2.5% GWRMC)

Day (2.5% Steel Fiber-02)	second	Time √sec	Time √sec	Mass (g)	ΔMass (g)	Cumulative mass	Δmass/area/density of water= I (mm)
	0	0	0	0.925	0.000	0.000	0.0000000
	60	7.745967	8	0.927	0.002	0.002	0.0002467
	300	17.32051	17	0.927	0.000	0.002	0.0002467
	600	24.4949	24	0.928	0.001	0.003	0.0003700
	1200	34.64102	35	0.928	0.000	0.003	0.0003700
	1800	42.42641	42	0.928	0.000	0.003	0.0003700
	3600	60	60	0.929	0.001	0.004	0.0004934
	7200	84.85281	85	0.929	0.000	0.004	0.0004934
	10800	103.923	104	0.929	0.000	0.004	0.0004934
	14400	120	120	0.930	0.001	0.005	0.0006167
	18000	134.1641	134	0.931	0.001	0.006	0.0007401
	21600	146.9694	147	0.931	0.000	0.006	0.0007401
1	93600	305.9412	306	0.936	0.005	0.011	0.0013568
2	174600	417.8516	418	0.939	0.003	0.014	0.0017268
3	266440	516.1783	516	0.940	0.001	0.015	0.0018502
5	441900	664.7556	665	0.943	0.003	0.018	0.0022202
6	526500	725.6032	726	0.943	0.000	0.018	0.0022202
7	612900	782.8793	783	0.944	0.001	0.019	0.0023435
8	699300	836.2416	836	0.944	0.000	0.019	0.0023435

APPENDIX D

Water absorption plots for different contents of Polyester and Steel fibers.

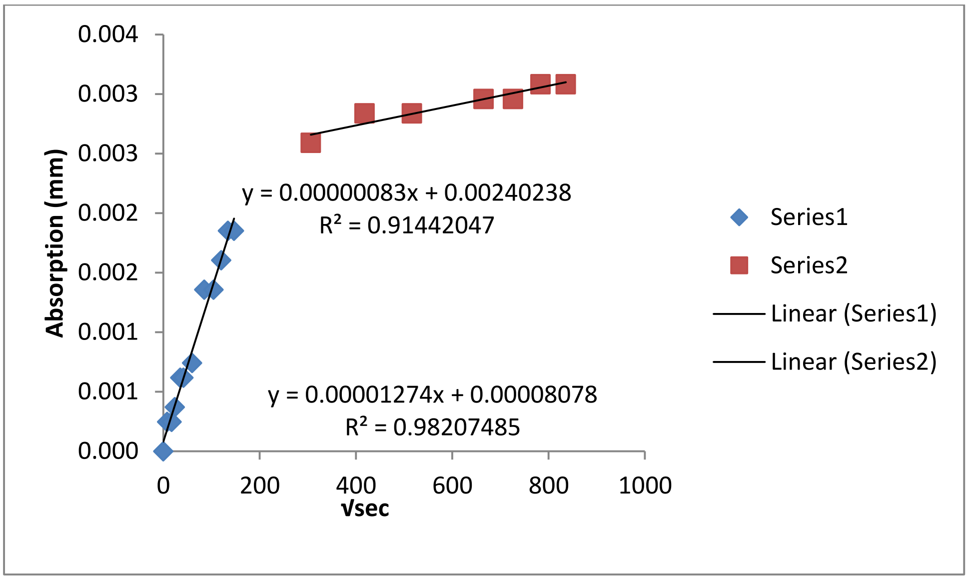

Figure D 1: Absorption curve for Control sample-2

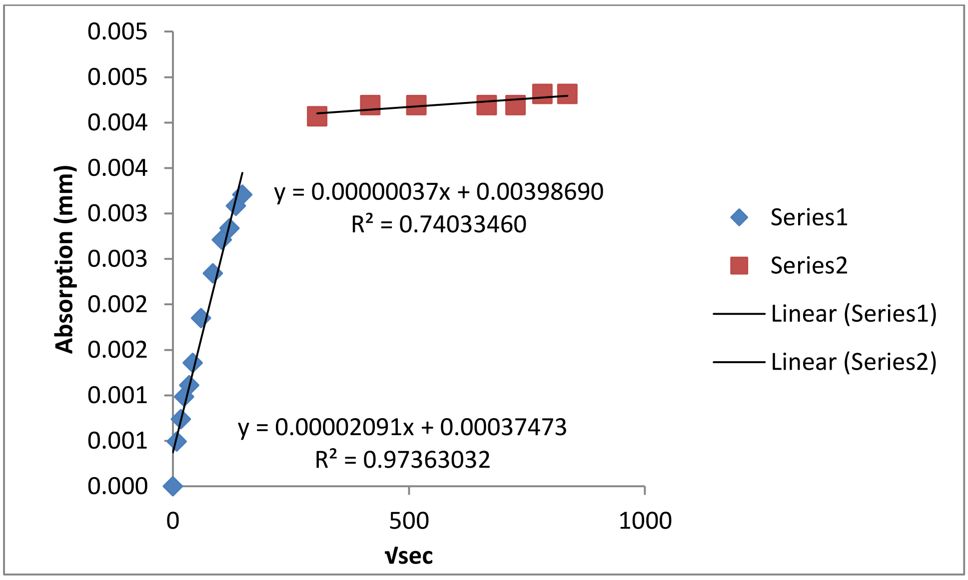

Figure D 2: Absorption curve for 0.1% PFRMC (Sample 2)

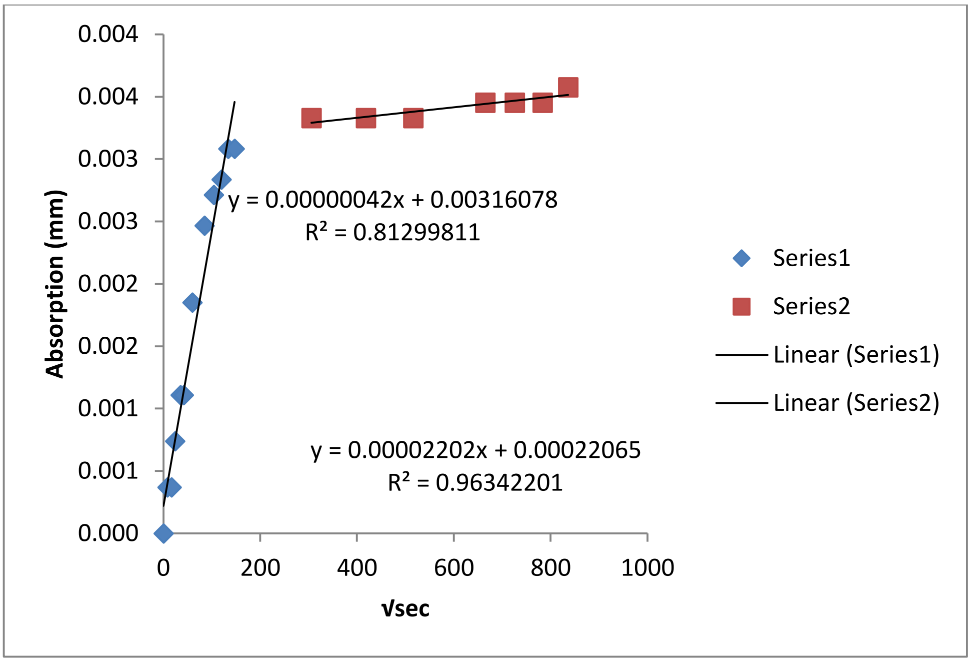

Figure D 3: Absorption curve for 0.2% PFRMC (Sample 2)

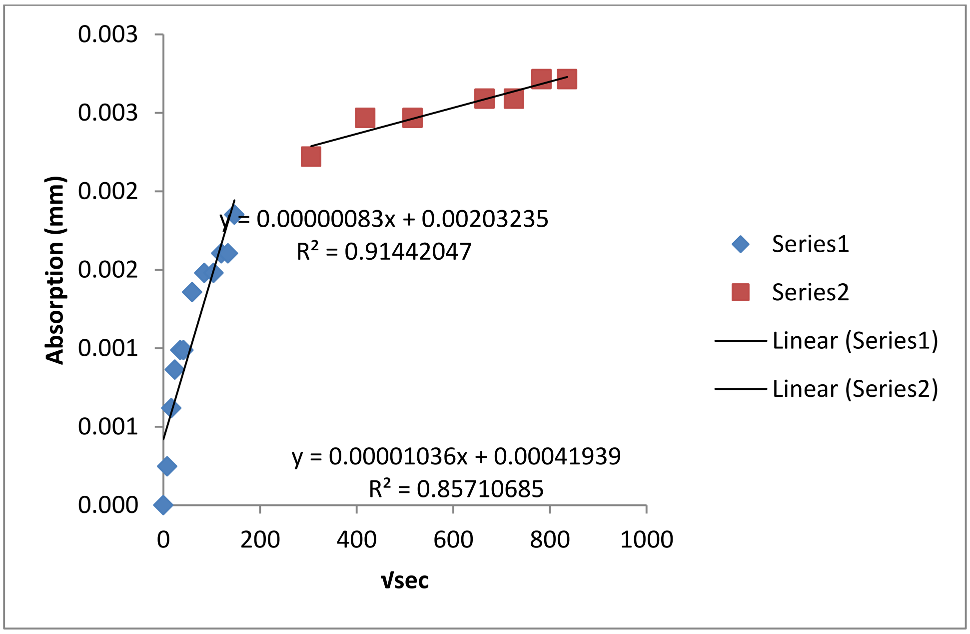

Figure D 4: Absorption curve for 0.3% PFRMC (Sample 2)

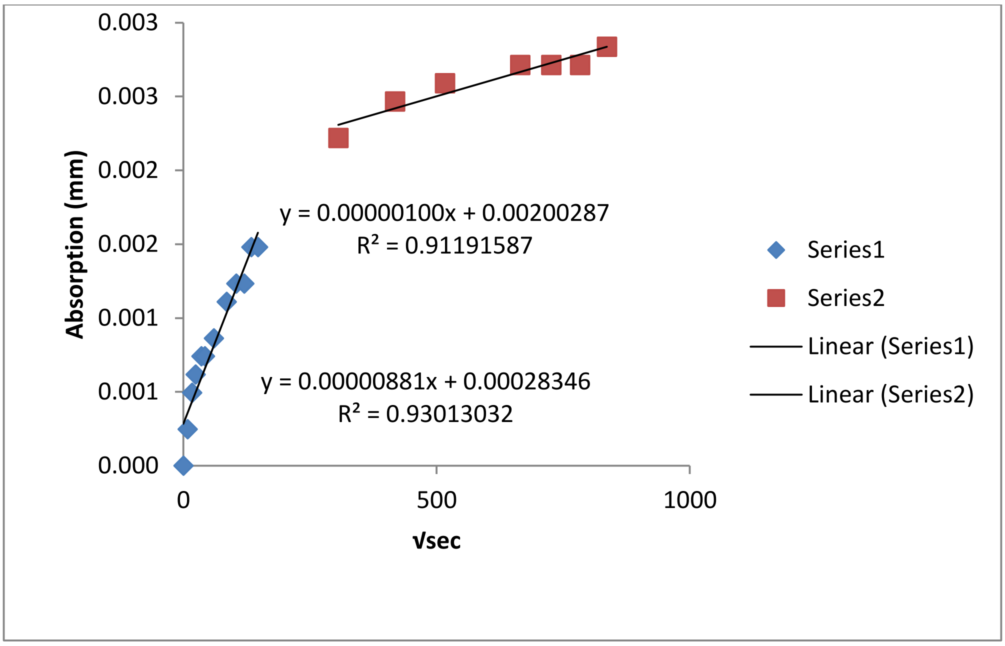

Figure D 5: Absorption curve for 0.4% PFRMC (Sample 2)

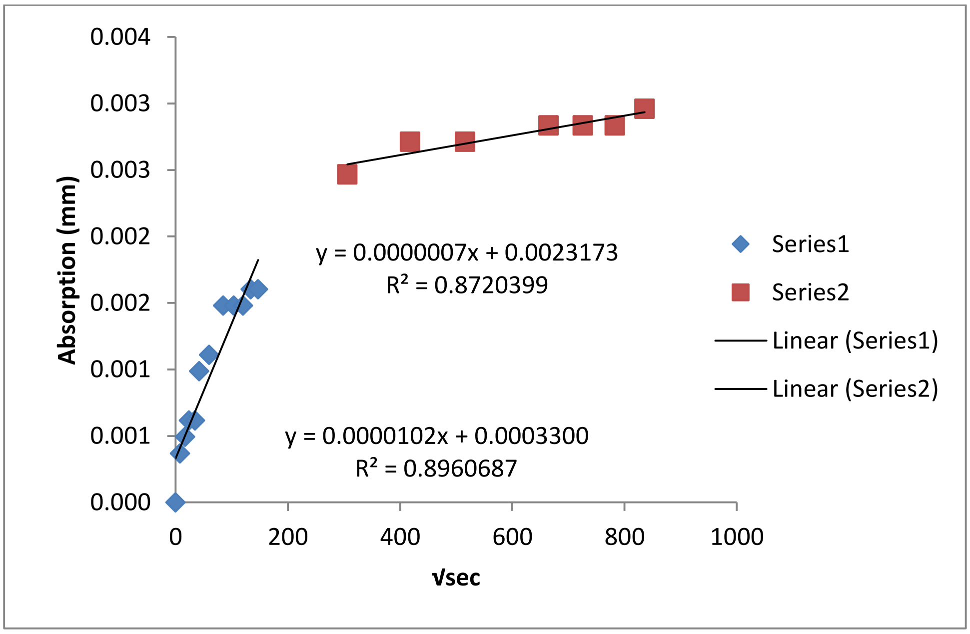

Figure D 6: Absorption curve for 0.5% PFRMC (Sample 2)

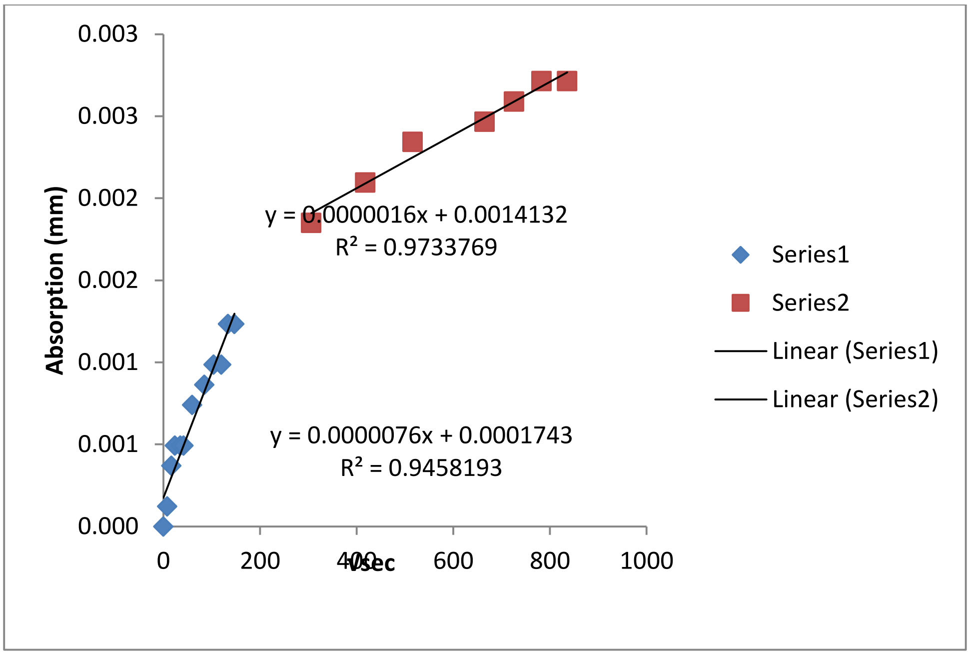

Figure D 7: Absorption curve for 1% GWRMC (Sample 2)

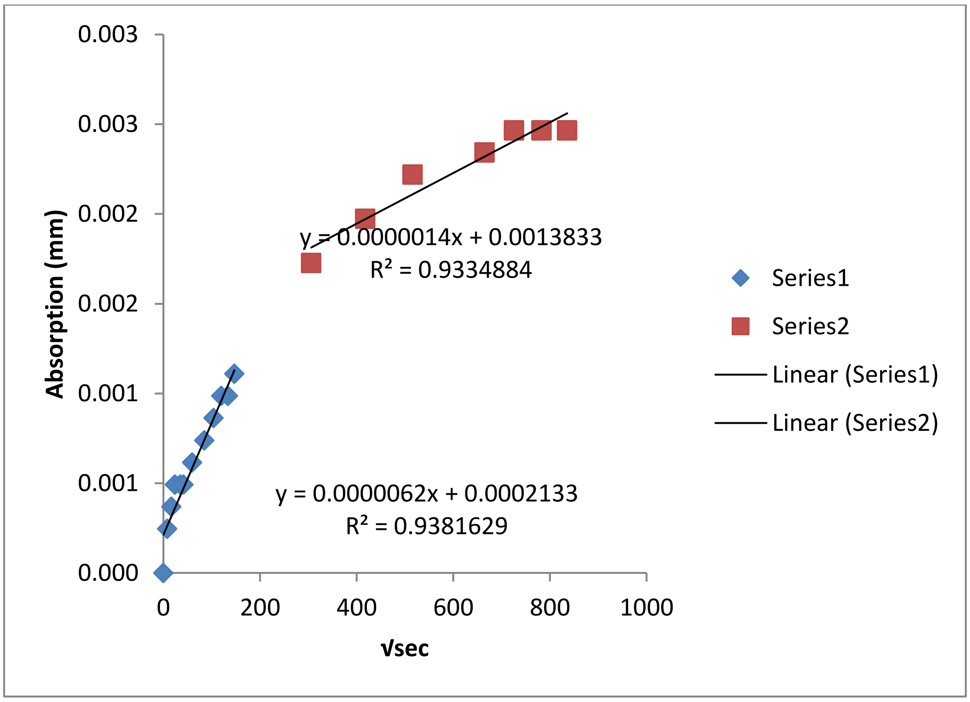

Figure D 8: Absorption curve for 1.5% GWRMC (Sample 2)

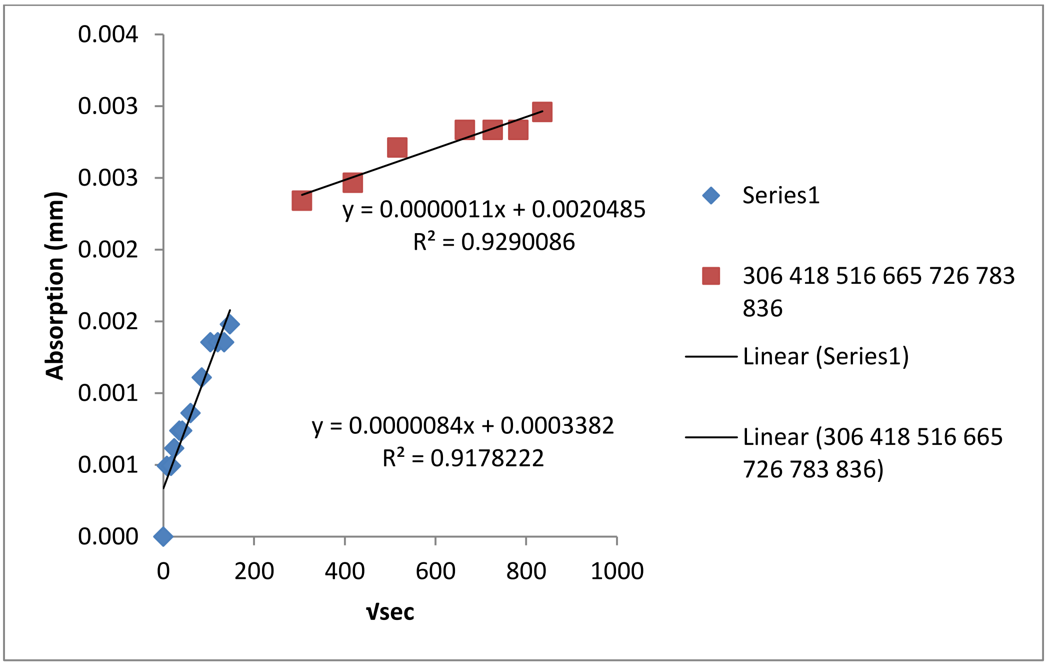

Figure D 9: Absorption curve for 2% GWRMC (Sample 2)

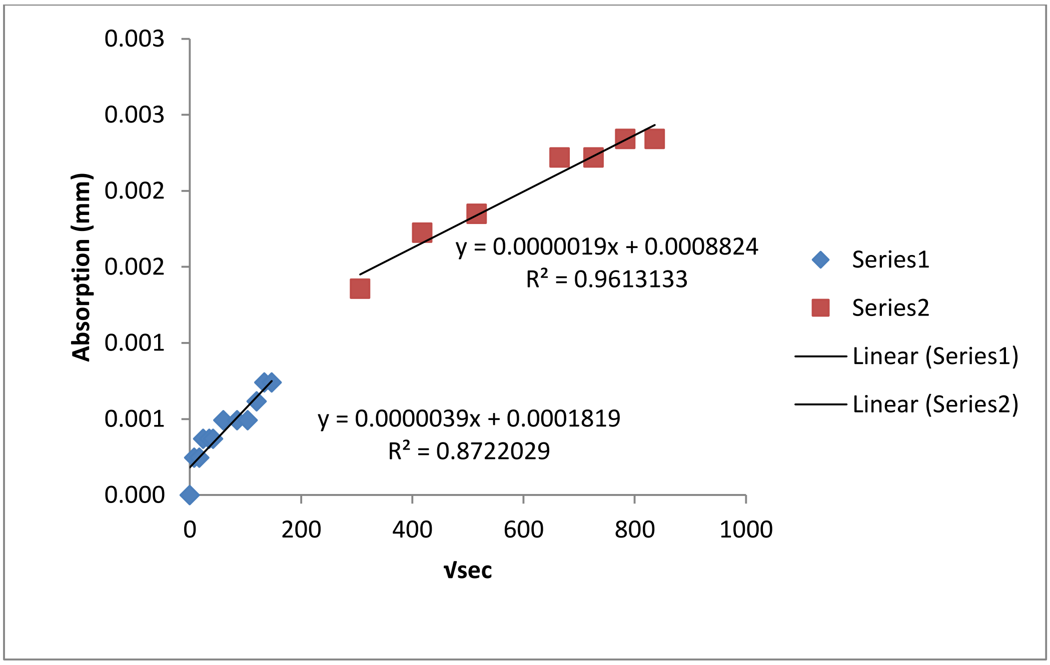

Figure D 10: Absorption curve for 2.5% GWRMC (Sample 2)