BEHAVIOR OF G.I. FIBER REINFORCED CONCRETE MADE WITH NATURAL AND RECYCLED AGGREGATES

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The author would like to dedicate the whole work to his beloved parents.

DECLARATION

It is hereby declared that, except where specific references are made, the work embodied in this thesis is the result of investigation carried out by the author under the supervision of Dr. Mohammad Al Amin Siddique, Assistant Professor, Department of Civil Engineering, BUET.

Neither this project nor any part of it is concurrently submitted to any other institution in candidature for any degree.

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ABSTRACT

The use of recycled aggregates from construction and demolition waste (CDW) as the replacement of coarse aggregates has increased in recent years in order to reduce the high consumption of natural resources by civil infrastructure construction sectors. In addition, steel fiber reinforced concrete has been used in many applications such as concrete pavements, overlays, patching repair of hydraulic structures, thin shells and precast products over the past several decades. Nowadays, it is well established that the incorporation of steel fibers improves engineering performance of structural and nonstructural concrete, including better crack resistance, increase in ductility and toughness as well as enhancement in resistance to fatigue and impact. In this work an experimental investigation is carried out to observe the influence of Galvanized Iron (G.I.) fiber reinforcement on the stress-strain behavior of concrete made with brick aggregate and recycled brick aggregate. In addition, compressive strength by destructive test as well as non-destructive test, Splitting tensile strength and Young's modulus are also determined. Two types of coarse aggregates, brick and recycled brick aggregates having the same gradation and water cement ratio (w/c=0.44) are used. Hooked end G.I. wires with 50 mm of length and aspect ratio of 55.6 are used as fiber reinforcements in a volume fraction of 0%, 0.50% and 1.00%, respectively for the both cases. The experimental results show that around 10% to 15% and 40% to 60% increase in 28 days compressive strength and tensile strength of GI fiber reinforced concrete, respectively compared to control case (0% G.I. fiber replacement) for both the aggregates. It is seen that effect of addition of 1% fiber on the concrete compressive strength is little compared to that of 0.5% G.I. fiber addition for both the aggregate types. On the other hand, concrete strain at failure of G.I. fiber reinforced concrete has increased almost 2 times compared to the control case (0% GI fiber replacement) for both the aggregate types. It is also observed that effect of fiber reinforced concrete made with 1% fiber is more than 0.5% fiber for the both cases of aggregates in the terms of maximum strain of concrete.

Keywords: Brick aggregate, Recycled Brick aggregate, G.I. fiber, Compressive strength, Tensile strength, Young's Modulus, Stress-strain behavior.

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INTRODUCTION

1.1 General

Fiber reinforced concrete (FRC) may be defined as a composite materials made with Portland cement, aggregate, and incorporating discrete discontinuous fibers (ACI 544.4R-88, 1999). Plain, unreinforced concrete is a brittle material and a low strain capacity. Concrete made with Portland cement has certain characteristics. It is relatively strong in compression but weak in tension and tends to be brittle. The weakness in tension can be overcome by the use of conventional reinforcements and to some extent by the inclusion of a sufficient volume of certain fibers. The use of fibers also alters the behavior of the fiber-matrix composite after it has cracked, thereby improving its toughness.

1.2 FRC- Historical perspective

Fiber reinforced concrete progresses gradually (Wikipedia (2014). This progress is shown below.

a) BC Horse hair
b) 1900 Asbestos fiber, hatcheck process
c) 1920 Griffith, theoretical vs. apparent strength.
d) 1950 Composite Materials
e) 1960 FRC
f) 1970New initiative for asbestos cement replacement
g) 1970 SFRC,GFRC,PPFRC, shotcrete
h) 1990 micromechanics, hybrid system, wood based fiber systems manufacturing
i) Techniques, secondary reinforcement, high strength concrete ductility issues, shrinkage crack control
j) 2000 +Structural applications, code integration, new products

A number of research works had been conducted on fiber reinforced concrete in the earlier of 20^{th} century. As a result a vast development has been occurred in the fiber and fiber reinforced concrete. Now a days, comprehensive research programs are being done to evaluate the physical and mechanical properties of fiber as well as concrete made with fiber.

1.3 Definition of fiber reinforced Concrete

Concrete containing hydraulic cement, water, fine aggregate, coarse aggregate, and incorporating discrete discontinuous fibers is called fiber reinforced concrete (Kayat et al, 2014). It may also contain pozolans and other admixtures commonly used in conventional concrete. Fibers of various shapes and sizes produced from steel, plastic, glass, and natural materials are being used of all the fibers. There is considerable improvement in post cracking behavior of concretes containing fibers. Although in the fiber reinforced concrete the ultimate tensile strengths do not increase appreciably but the tensile strains at rupture do. Compare to plain concrete fiber reinforced concrete is much tougher and more resistant to impact. Figure 1.1 shows two cylinders made with steel fiber.

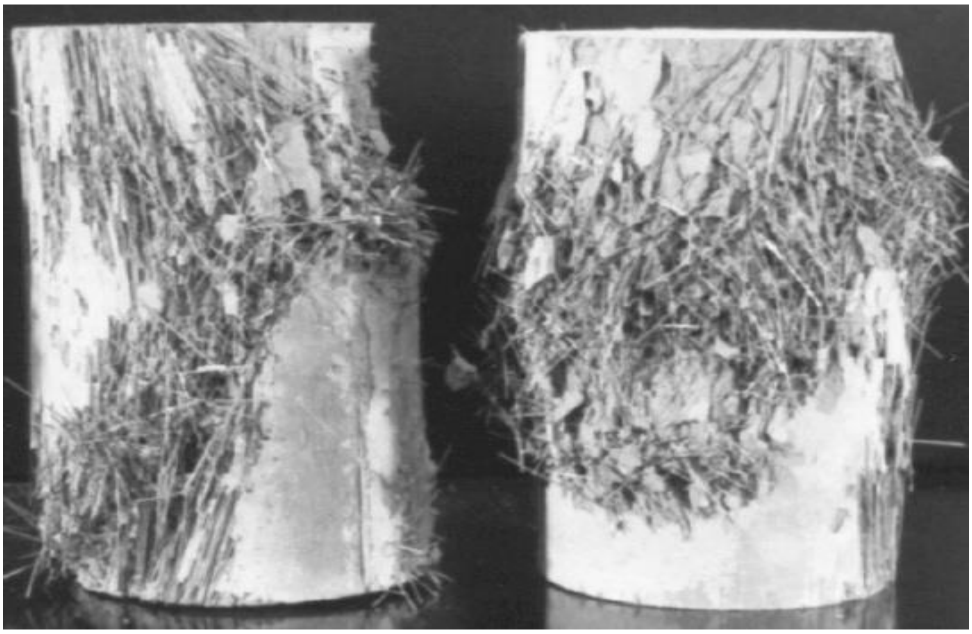


Fig 1.1: Fiber reinforced concrete, (Wikipedia, 2014)

1.4 Basic concept of fiber reinforced concrete (FRC)

If the fibers are sufficiently strong, sufficiently bonded to material, then they permit the FRC to carry significant stresses over a relatively large strain capacity in the post-cracking stage (Johnston C.D, 1974). When the fiber reinforcement is in the form of short discrete fibers, they act effectively as rigid inclusions in the concrete matrix. The real contribution of the fibers is to increase the toughness of the concrete. Toughness is defined as the area under a load-deflection (or stress-strain) curve. As can be seen from Figure 1.2, adding fibers to concrete greatly increases the toughness of the material (Concrete Society, 1973, El-Ashkar et al, 2006). Plain concrete fails suddenly once the ultimate flexural strength is exceeded. On the other hand, fiber reinforced concrete continues to sustain considerable loads even at deflections considerably in excess of the fracture deflection of the plain concrete. Fiber-reinforced concrete is able to sustain load at deflections or strains much greater than those at which cracking first appears in the matrix. Because of the inherent material properties of fiber concrete, the presence of fibers in the body of the concrete or the provision of a tensile skin of fiber concrete can be expected to improve the resistance of conventionally reinforced structural members to cracking, deflection and other serviceability conditions.

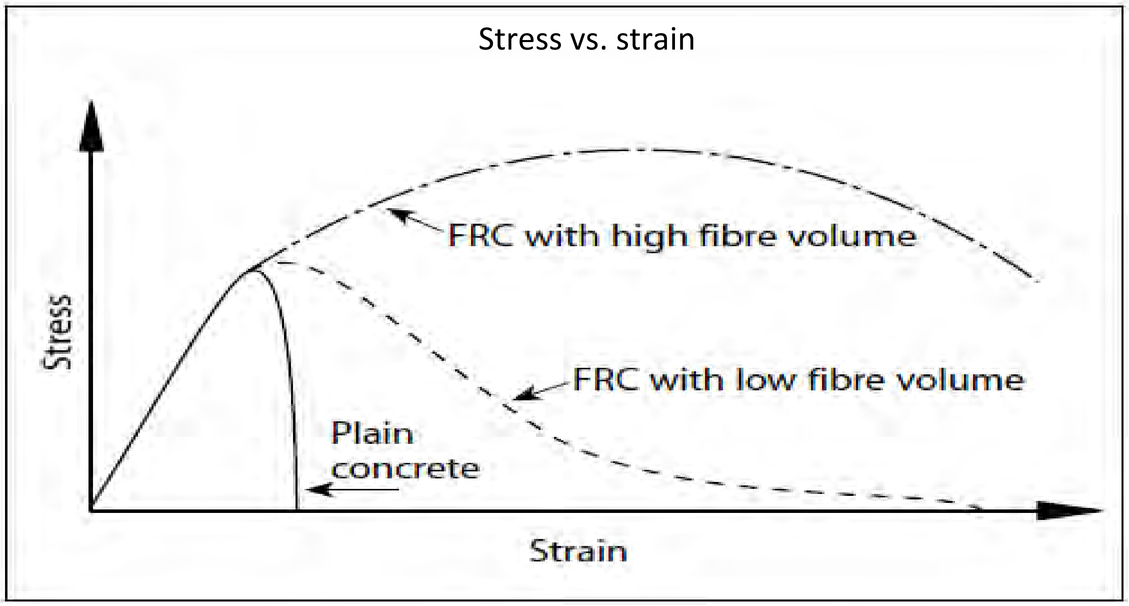


Fig: 1.2 Typical stress-strain curve for steel FRC (El-Ashkar et al, 2006)

1.5 Advantages of Steel FRC (SFRC)

Advantages of steel fiber reinforced concrete (SFRC) can be summarized as below

a) Easily placed
   i. Cast
   ii. Sprayed
   iii. Less labor intensive than placing rebar
b) Can be made into thin sheets or irregular shapes

c) Used when placing rebar is difficult
d) Decorative concrete
e) 85% crack reduction
f) Improved hydration
g) Improved freeze/thaw resistance

Steel fiber reinforced concrete has become very popular because of its advantages over the plain concrete. It has been observed that steel fiber reinforced concrete in terms of durability is the best (Kamran et al, 2013). Strain capacity at failure is also increased compare to plain concrete. Fibers are cheap and easily available in the market. From the above discussions, it is observed that there are many advantages of FRC compare to the traditional concrete.

1.6 Disadvantages of SFRC

Though steel fiber reinforced concrete has numerous advantages, it has certain concerns that are yet to be resolved completely (Wikipedia, 2014).

a) There are complications involved in attaining uniform dispersal of fibers and consistent concrete characteristics.
b) The use of SFRC requires a more precise configuration compared to normal concrete.
c) Another problem is that unless steel fibers are added in adequate quantity, the desired improvements cannot be obtained.
d) Not highly effective in improving compressive strength
e) Reduce Workability of concrete

1.7 Areas of application of fiber reinforced concrete materials

There are various applications of fiber reinforced concrete in construction sectors. Areas of application of FRC can be summarized as follows:

a) Thin Sheets
b) Shingles
c) Roof Tiles
d) Pipes

e) Prefabricated Shapes
f) Panels
g) Shotcrete
h) Curtain wall
i) Slabs on Grade
j) Precast Elements
k) Composite Decks
l) Air craft Parking and pavement
m) Impact Resisting Structures
n) Dams
o) Runway
p) Vaults, Safes
q) Hydraulic Structures

Fig 1.3: FRC Project at Trillium Building, Woodland Hills, California (Wikipedia, 2014)

Figure 1.3 shows application of fiber reinforced concrete in high-rise buildings. As recommended by ACI committee 544, when used in structural applications, steel fiber reinforced concrete should only be used in a supplementary role to inhibit cracking to improve resistance to impact or dynamic loading and to resist material disintegration. The uses of SFRC over the past thirty years have been so varied and so widespread, that it is difficult to categorize them. The most common applications are pavement, tunnel linings, pavements, slabs, concrete and now concrete also containing silica fume and fibers. To increase the tensile strength and particularly to make more ductile that the structure can take some post cracking ductility certain amounts (0.5%-1.5%) of fiber are being used (ACI 544.4R-88, 1999).

1.8 Background and present state of the problem

The use of recycled aggregates from construction and demolition waste (CDW) as replacement of fine and coarse natural aggregates has increased in recent years in order to reduce the high consumption of natural resources by construction sectors. In addition, steel fiber reinforced concrete has been used in many applications such as concrete pavements, overlays, patching repair of hydraulic structures, thin shells and precast products over the past several decades (ACI 544.4R-88, 1988). Now a days, it is well established that the incorporation of steel fibers improves engineering performance of structural and nonstructural concrete, including better crack resistance, increase in ductility and toughness as well as enhancement in resistance to fatigue and impact (Bentur and Mindess, 1990). From the viewpoint of sustainability, the use of steel fiber reinforced concrete may increase the environmental impact of the plain concrete due to energy consumption and CO_2 emissions related to the production and shipping of the fibers. However, fiber reinforced concrete can extend the maintenance free life of the structures and thus reduce the overall environmental impact of the construction (Gielen et al, 2008). To improve the environmental performance of the steel fiber reinforced concrete, studies have been conducted regarding the use of metal waste recycled fibers as reinforcement (Meddah and Bencheikh, 2009, Tlemat et al, 2006, Wang et al, 2006) as well as the use of recycled aggregates to replace the natural aggregates (Prasad et al, 2007, Bhikshma et al, 2008, Vytlacilova, 2011). Although the use of CDW as recycled aggregate in substitution of natural aggregate has been proved to be a good solution to minimize consumption of natural resources (Rao 2007, Lima, 2010), the structural behavior of CDW concrete is not yet fully understood and its use in structural applications is limited by European and Japanese standards (DIN 4226-100, 2000, Bulletin of chemical society, 1977) and not authorized by Brazilian standard (ABNT, NBR 15116, 2004). In this work, an experimental investigation is carried out to investigate the influence of galvanized iron (G.I.) wires as fiber reinforcements on the compressive strength, Young's Modulus, stress-strain behavior of concrete made with both brick and recycled brick aggregates. Splitting tensile strength of both the concrete is also be assessed. In addition, non-destructive test (Rebound hammer test) has been carried out on both the concrete to evaluate the compressive strength of concrete. In this study, two types of coarse aggregate are used, fresh brick chips and recycled brick chips. Recycled brick aggregate is collected from the structural member of demolished building. In this study, Sylhet sand is used as fine aggregate. Hooked end galvanized iron (G.I.) fiber with 0.90 mm diameter and 50 mm length are used as steel fiber in a percentage of 0%, 0.5% and 1% for the both types of aggregate. A comprehensive study is conducted to understand the effect of fiber replacements, effect of aggregate types and effect of age on the mechanical strength of fiber reinforced concrete. All mechanical properties are assessed at 7, 14, and 28 days.

1.9 Scopes and Objectives of the study

Based on the background summarized above the present study aims at the following objectives:

a) To determine and compare the stress- strain behavior of both plain brick aggregate concrete and recycled brick aggregate concrete.
b) To determine and compare the stress- strain behavior and Modulus of elasticity of G.I. fiber reinforced concrete made with brick aggregate and recycled brick aggregates.
c) To determine and compare the compressive strength by destructive and non destructive test of the both plain concrete and G.I. fiber reinforced concrete made with brick and recycled brick aggregate.
d) To determine and compare the splitting tensile strength of both the plain and G.I. fiber reinforced concrete made with brick and recycled brick aggregate.

The outcome of the work will provide Identification of the effectiveness of G.I. fiber reinforced concrete in comparison to normal concrete. Feasibility of using Rebound Hammer test to evaluate the compressive strength of plain and G.I. fiber reinforced concrete made with natural and recycled aggregates

1.10 Research methodology

An experimental investigation is to be carried out to investigate the influence of G.I. fiber reinforcement on the stress–strain behavior of concrete that will be made with brick and recycled brick aggregates. In addition, splitting tensile strength of the concrete is to be determined. Non-destructive test (NDT) using Rebound hammer will also be done to evaluate the compressive strength of concrete. Two types of coarse aggregates, brick and recycled brick aggregate having the same gradation and water cement ratio will also be same for all mixes. The maximum size of the coarse aggregate will be 19 mm, sand to aggregate and cement content will also be same for all cases. Hooked end G. I. wires with 50 mm of length and aspect ratio of 55.56 (Jodilson et al, 2014) are to be used as fiber reinforcements in a volume fraction of 0%, 0.50% and 1.00%, respectively (Soroushian et al, 1991, Jodilson et al, 2014). Four sets of specimens will be cast for compressive strength, tensile strength, stress-strain behavior, and rebound hammer test. Concrete cylinder (4″ x 8″) will be tested to determine the compressive strength as per ASTM C39M-03 as well as

Chapter 2 is mainly based on the literature review related to the present study. It provides a brief description of mechanism of fiber reinforced concrete, Characteristics of fiber reinforced systems, Fresh concrete properties of FRC, Mechanical properties of hardened fiber reinforced concrete, Structural behavior of fiber reinforced concrete, different types of fiber and their properties, Size & shape of different types of steel fiber, some research related to the steel fiber reinforced concrete, Composition of Portland composite cement (PCC), Properties of fine and coarse aggregate (brick & recycled brick).

Chapter 3 provides experimental program for the present study, physical and mechanical properties of different materials like brick aggregate, recycled brick aggregate, and sand. This chapter also provides the information about the making procedure and different properties of G.I. fiber. Total cases in addition the mix design of this study is also provided in this chapter. Then, it provides information about concrete mixing, casting, and curing. Finally, it provides a description of fresh (workability) and hardened concrete properties i.e. Compressive strength by destructive and non destructive test, Tensile strength, Modulus of elasticity and Stress- strain behavior at 7, 14, and 28 days.

Chapter 4 provides the results of fresh concrete properties. In the fresh concrete properties, the effects of fiber replacements and fiber types on workability of concrete are observed. In the hardened concrete properties, the effects of fiber replacements (0%, 0.5%, and 1%) on compressive strength by destructive test, tensile strength, modulus of elasticity and stress-strain behavior are assessed. This chapter also provides the information about the effects of aggregate types (brick & recycled brick) and ages (7, 14, and 28 day) on compressive strength by destructive test, tensile strength, modulus of elasticity and stress-strain behavior of concrete. And finally it also presents some relationships of strength between brick & recycled brick aggregate concrete as well as plain and fiber reinforced concrete.

Chapter 5 presents the experimental method and hardened concrete properties (compressive strength) of plain and fiber reinforced concrete by using nondestructive (Rebound hammer) test. It provides the results about the effects of fiber replacements (0%, 0.5%, and 1%), effect of aggregate types (brick & recycled brick) and ages (7, 14, and 28 day) on compressive strength of concrete. Finally, it provides a relationship between non destructive (NDT) and destructive strength test.

Chapter 6 presents discussions and conclusion and also suggestions for future work.

Chapter 2

LITERATURE REVIEW

2.1 General

Concrete is relatively brittle and its tensile strength is typically only about one tenths of its compressive strength (Bentur and Mindess, 1990). Regular concrete is therefore normally reinforced with steel reinforcing bars. For many applications, it is becoming increasingly popular to reinforce the concrete with small amount of randomly distributed fibers. Their main purpose is to increase the energy absorption capacity and toughness of the materials and also increase the tensile and flexural strengths of concrete. They also lessen the permeability of concrete and therefore reduce the flow of water (Kamran et al, 2013). Some types of fibers create greater impact, abrasion and shatter resistance in the concrete (Kamran et al, 2013). Usually fibers do not raise the flexural concrete strength. The quantity of fibers required for a concrete mix is normally determined as a percentage of the total volume of the composite materials. The fibers are bonded to the material, and allow the fiber reinforced concrete to withstand considerable stresses during the post-cracking stage. However, understanding the mechanism of fiber reinforced concrete knowledge on mechanical behavior and constitutive properties of concrete, a detail observation on mechanical behavior of galvanized iron (G.I.) fiber reinforced concrete will also be provided in this study. In this chapter, a summary of the fiber reinforced concrete, cement, coarse aggregate, recycled coarse aggregate and fine aggregate is made based on the literature review. This review has been made to understand state-of-the-art knowledge of fiber reinforced concrete (ACI 554 IR 82) associated with properties of the coarse aggregate, recycled coarse aggregate, sand and cement in addition their compositions, advantages and disadvantages etc.

2.2 Mechanism of fiber reinforced Concrete

The mechanism of randomly distributes discontinuous fibers is to bridge across the cracks that develop provides some post- cracking "ductility" (Bentur and Mindess, 1990). If the fibers are sufficiently strong, sufficiently bonded to material, then they permit the FRC to carry significant stresses over a relatively large strain capacity in the post-cracking stage (Johnston, 1974). There are, of course, other (and probably cheaper) ways of increasing the strength of concrete. The real contribution of the fibers is to increase the toughness of the concrete (defined as some function of the area under the load vs. deflection curve), under any type of loading that absorption in post-peak portion of the load vs. deflection curve. When the fiber reinforcement is in the form of short discrete fibers, they act effectively as rigid inclusions in the concrete matrix. Physically, they have thus the same order of magnitude as aggregate inclusions; steel fiber reinforcement cannot therefore be regarded as a direct replacement of longitudinal reinforcement in reinforced and prestressed structural members. However, because of the inherent material properties of fiber concrete, the presence of fibers in the body of the concrete or the provision of a tensile skin of fiber concrete can be expected to improve the resistance of conventionally reinforced structural members to cracking, deflection and other serviceability conditions. The fiber reinforcement may be used in the form of three dimensionally randomly distributed fibers throughout the structural member when the added advantages of the fiber to shear resistance and crack control can be further utilized.

2.3 Characteristics of fiber reinforced systems

There are some characteristics of fiber reinforced systems on concrete, they are given below.

(a) Fibers distributed through given cross section, reinforcement bars only placed where required

(b) Fibers are short and closely spaced, reinforcing bars are continuous

(c) Small reinforcement ratio when compared to reinforcement bars

(d) Fibers do not do anything to stop the first crack; it slows down the propagation of cracks.

(e) Toughness of material can be increased (15-30%)

(f) Creep results don’t show much difference.

(g) Drying shrinkage show some difference.

(h) They use it for cavitations’ damage.

2.4 Fresh concrete properties of FRC

There are two types of properties of fiber reinforced concrete: Fresh concrete properties and hardened concrete properties.

Fresh concrete properties are given below

a) Cement hydration
b) Setting time
c) Workability
d) Fiber clumping/consolidation
e) Shrinkage: Plastic, Free, Drying
f) Internal curing and autogenous shrinkage

(a) Cement hydration: addition of fibers has little to no effect on cement hydration. It is shown in Figure 2.1

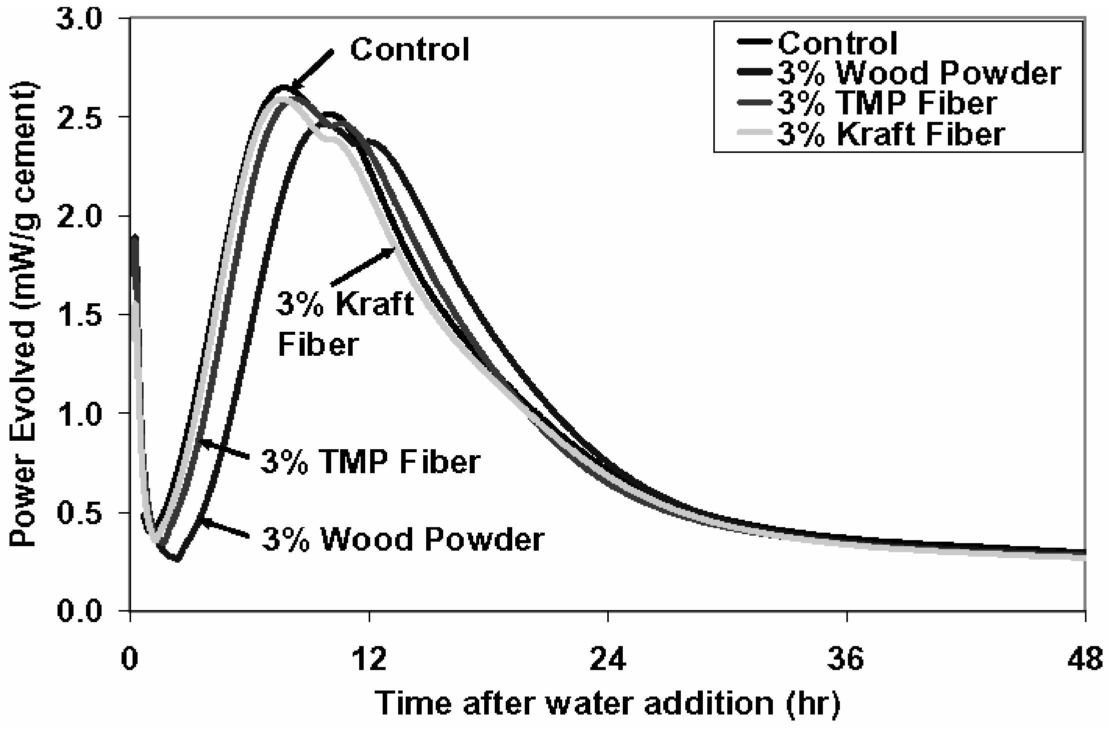


Fig: 2.1 Cement Hydration of FRC (Kamran et al, 2013)

(b) Setting time: Lignin can be used as a set retarder .Fibers with lignin or other chemicals can have adverse effects on setting time. Fibers may absorb/desorbs water from the cement matrix or atmosphere effecting set time.

(c) Workability: Addition of fibers decreases workability due to an increase in surface area. Low fiber fractions (<1% by mass) can significantly reduce slump ASTM C995 better indicator for workability than slump for FRC placed by vibration. Figure 2.2 shows the workability of FRC

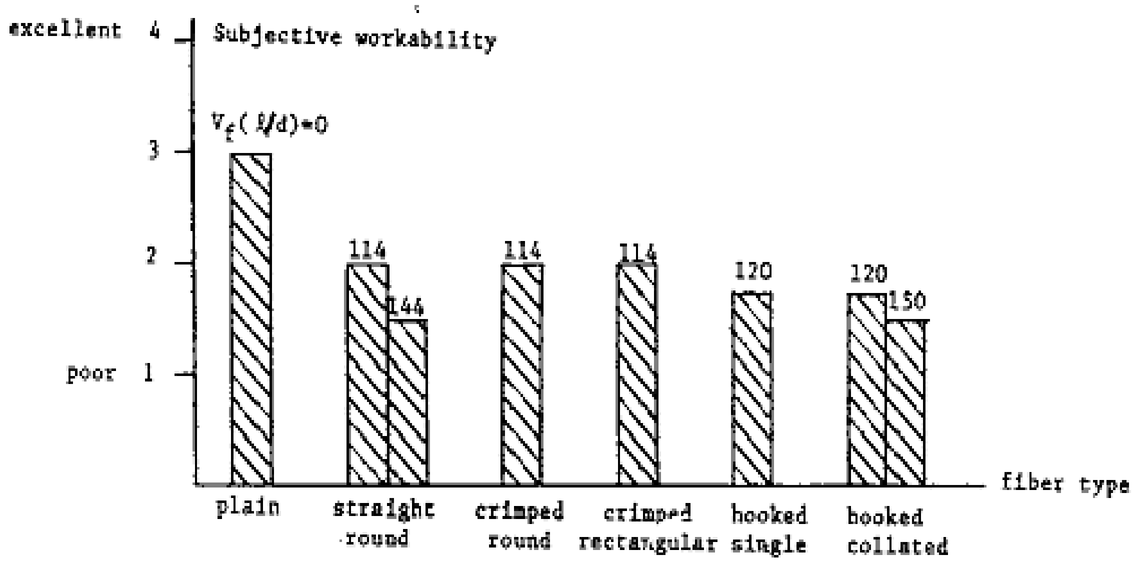


Fig: 2.2 Workability of FRC (Parviz Soroushian and Ziad Bayasi, 1991)

2.5 Mechanical properties of hardened fiber reinforced concrete

Addition of fibers to concrete influences its mechanical properties which significantly depend on the type and percentage of fiber (Johnston, 1974).

(a) Compressive Strength: The presence of fibers may alter the failure mode of cylinders, but the fiber effect will be minor on the improvement of compressive strength values (0 to 15 percent). High fiber content composites can have reduced compressive strengths. Strength reduction most likely due to increased amount of entrapped air due to presence of fibers most research agrees that volume fractions up to about 1% does not significantly affect compressive strength. The effect of steel fibers on the compressive strength of concrete is variable. Documented increases for concrete (as opposed to mortar) range from negligible in most cases to 23 % for concrete containing 2 % by volume of fiber with *e/d* = 100, %-in. (19-mm) maximum-size aggregate, and tested with 6 x 12 in. (150 x 300 mm) cylinders (Williamson, 1974). For mortar mixtures, the reported increase in compressive strength ranges from negligible (Williamson 1974) to slight (Fanella and Naaman, 1985). Typical stress-strain curves for steel fiber reinforced concrete in compression are shown in

Figure 2.3 (Wang et al. 1978). In these curves, a substantial increase in the strain at the peak stress can be noted, and the slope of the descending portion is less steep than that of control specimens without fibers. This is indicative of substantially higher toughness, where toughness is a measure of ability to absorb energy during deformation, and it can be estimated from the area under the stress-strain curves or load-deformation curves.

(b) Toughness: For FRC, toughness is about 10 to 40 times that of plain concrete. The greatest advantage of fiber reinforcement of concrete is the improvement in flexural toughness (total energy absorbed in breaking a specimen in flexure). Toughness is defined as the area under a load-deflection (or stress-strain) curve. As can be seen from Figure 2.4, adding fibers to concrete greatly increases the toughness of the material (Concrete society, 1973, El-Ashkar, 2006, Nataraja et al, 1999).

(c) Modulus of Elasticity: Modulus of elasticity of FRC increases slightly with an increase in the fibers content. It was found that for each 1-5% percent increase in fiber content by volume there is an increase of 2 percent in the modulus of elasticity (Misba Gul et al, 2014). Figure 2.5 shows the increase of modulus of elasticity with respect to volume of fiber fraction.

(d) Flexure: The flexural strength was reported to be increased by 2.5 times using 4 percent fibers. A typical Load vs. deflection curve has been shown in Figure 2.6.

(e) Durability: Fiber-reinforced concrete is generally made with a high cement content and low water/cement ratio. When well compacted and cured concretes containing steel fibers, seem to possess excellent durability as long as fibers remain protected by cement paste. Ordinary glass fiber cannot be used in Portland cement mortars and concretes because of chemical attack by the alkaline cement paste

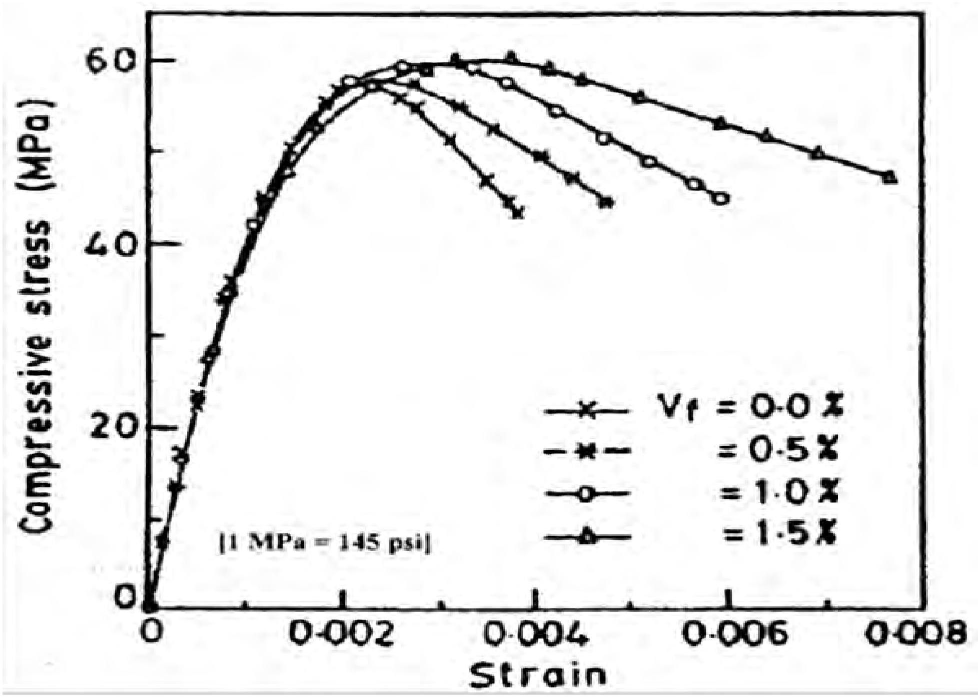


Fig 2.3: Compressive stress –strain relationship of FRC (Wang et al. 1978)

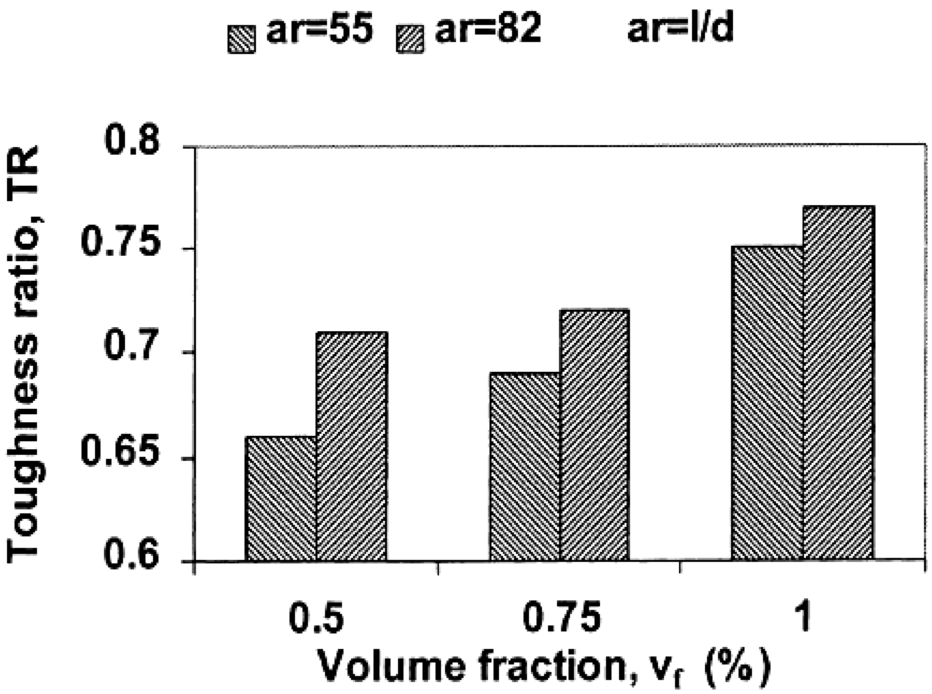


Fig 2.4: Modulus of toughness (Nataraja et al, 1999)

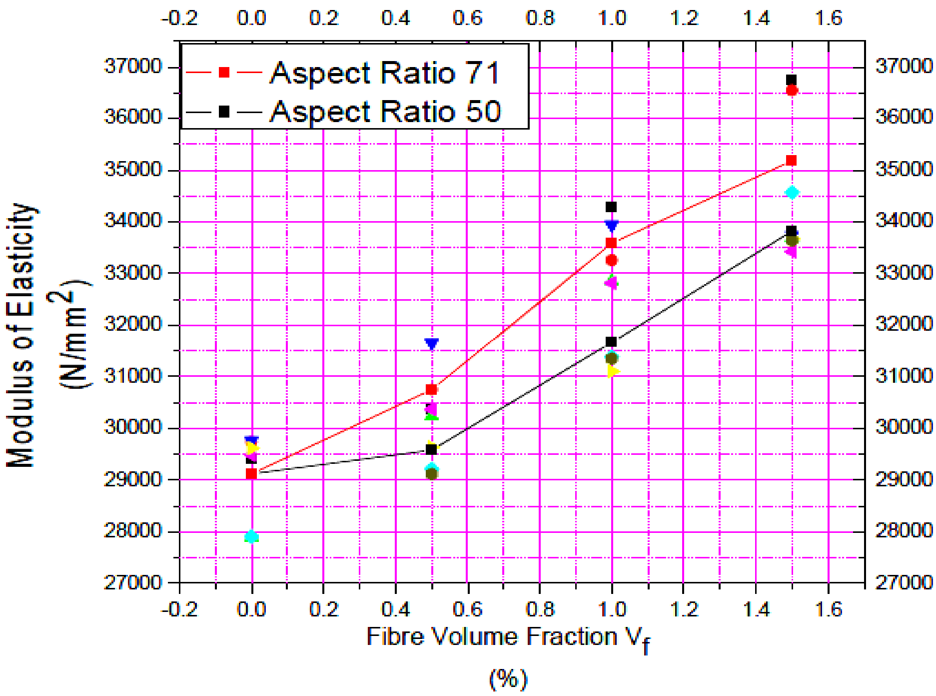


Fig 2.5: Modulus of elasticity of FRC (Misba Gul et al, 2014)

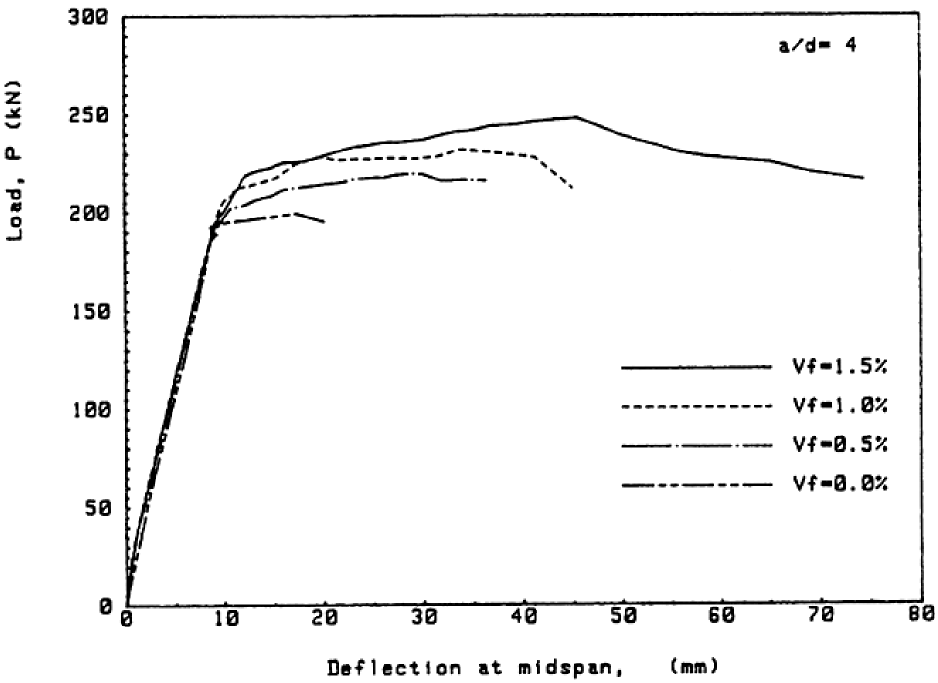


Fig 2.6: Load vs. deflection relationship of FRC (Wikipedia, 2014)

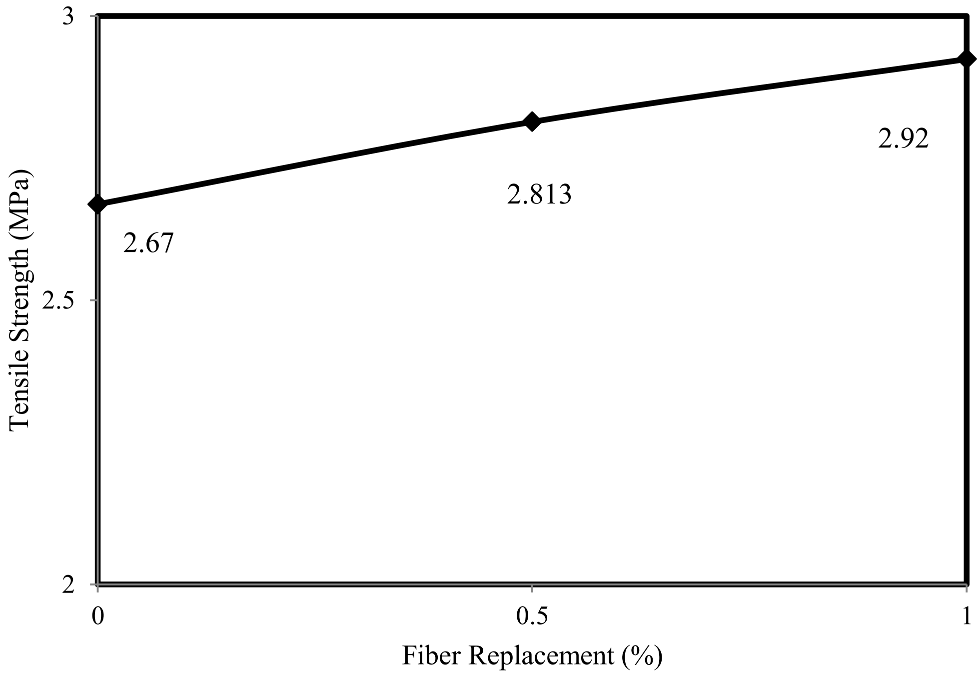


Fig 2.7: Tensile strength Vs fiber percentage of FRC (Wikipedia, 2014)

(f) Splitting Tensile Strength: The presence of 3 percent fiber by volume was reported to increase the splitting tensile strength of mortar about 2.5 times that of the unreinforced one. Figure 2.7 shows the tensile strength is increasing with the amount of fiber replacements.

(g) Impact Resistance: The impact strength for fibrous concrete is generally 5 to 10 times that of plain concrete depending on the volume of fiber

(h) Creep: Results don't show much difference.

(i) Fatigue Strength: The addition of fibers increases fatigue strength of about 90 percent and 70 percent of the static strength at 2 x 10^6 cycles for non-reverse and full reversal of loading, respectively.

(j) Shrinkage: 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.

(k) Corrosion of Steel Fibers: A 10-year exposure of steel fibrous mortar to outdoor weathering in an industrial atmosphere showed no adverse effect on the strength properties. Corrosion was found to be confined only to fibers actually exposed on the surface. Steel fibrous mortar continuously immerse in seawater for 10 years exhibited a 15 percent loss compared to 40 percent strength decrease of plain mortar.

2.6 Structural behavior of fiber reinforced concrete

Addition of fibers to concrete influences its structural properties which significantly depend on the type and percentage of fiber (Johnston C.D, 1974).

(a) Flexure: The use of fibers in reinforced concrete flexure members increases ductility, tensile strength, moment capacity, and stiffness. The fibers improve crack control and preserve post cracking structural integrity of members.

(b) Torsion: The use of fibers eliminates the sudden failure characteristic of plain concrete beams. It increases stiffness, torsional strength, ductility, rotational capacity, and the number of cracks with less crack width.

(c) Shear: Addition of fibers increases shear capacity of reinforced concrete beams up to 100percent. Addition of randomly distributed fibers increases shear-friction strength, the first crack strength, and ultimate strength.

(d) Column: The increase of fiber content slightly increases the ductility of axially loaded specimen. The use of fibers helps in reducing the explosive type failure for columns.

(e) High Strength Concrete: Fibers increase the ductility of high strength concrete. The use of high strength concrete and steel produces slender members. Fiber addition will help in controlling cracks and deflections.

(f) Cracking and Deflection: Tests shown that fiber reinforcement effectively controls cracking and deflection, in addition to strength improvement in the concrete. In conventionally reinforced concrete beams, fiber addition increases stiffness, and reduces deflection.

2.7 Types of fiber

Fibers are produced from different materials in various shapes and sizes. Typical fiber materials (Concrete society, 1973) are given below.

a) **Glass Fiber:** Straight diameter ranges from 0.005 to 0.015mm (maybe bonded together to form elements with diameter of 0.13 to 1.3 mm). Alkali resistant Glass-fiber is used in the manufacture of glass reinforced cement (GRC) products, which have wide ranges of application. Glass fiber has high tensile strength (2-4 GPa) and modulus of elasticity (70-80 GPa) but has brittle stress strain characteristics (2.5-4.8 % elongation at break) and low creep at room temperature. Claims have been made up to 5% glass fiber by volume has been used successfully in sand-cement mortar without balling. Figure 2.8 (a) shows the glass fiber.

b) **Synthetic Fiber:** These fibers are manmade fiber resulting from research and Development in the petrochemical and textile industries. Currently there are two different fiber volumes used in application namely low volume percentage (0.1-0.3% by volume) and high volume percentage (0.8-0.8% by volume). Fiber types that have been tried in the cement concrete matrices include acrylic, Aramid, carbon, nylon, polyester, polyethylene and polypropylene. Table 2.1 summarizes the ranges of physical properties of some synthetic fibers.

c) **Acrylic Fiber:** Acrylic fibers have been used to replace asbestos fiber in many fiber-reinforced concrete products shown in Figure 2.8 (f). In this process fibers are initially dispersed in dilute water and cement mixture. A composite thickness is built up in layers using a pressure forming process and vacuum dewatering. Acrylic fibers have also been added to conventional concrete at low volumes to reduce the effects of plastic-shrinkage cracking

d) **Aramid Fiber:** Aramid fibers are two and a half times as strong as glass fibers and five times as strong as steel fibers, per unit mass shown in Figure 2.8 (c). Due to the relatively high cost of these fibers, Aramid-fiber-reinforced concrete has been primarily used as an asbestos cement replacement in certain high-strength applications.

e) **Nylon:** Nylon is a generic name that identifies a family of polymers. Nylon fiber's properties are imparted by the base polymer type, addition of different levels of additive, manufacturing conditions and fiber dimensions. Currently only two types of nylon fiber are marketed for concrete. Nylon is heat stable, hydrophilic, relatively inert and resistant to a wide variety of materials. Nylon is particularly effective in imparting impact resistance and flexural toughness and sustaining and increasing the load carrying capacity of concrete following first crack.

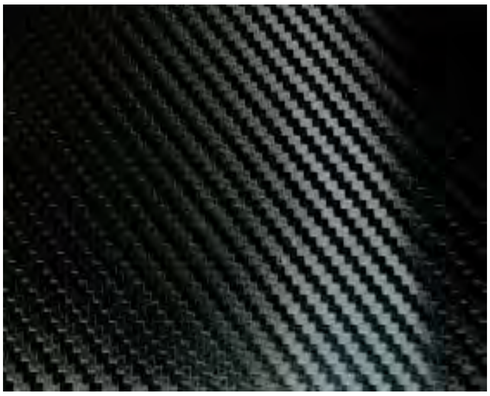
f) **Polyester:** Polyester fibers are available in monofilament form and belong to the thermoplastic polyester group. They are temperature sensitive and above normal service temperatures their properties may be altered. Polyester fibers are somewhat hydrophobic. Polyester fibers have been used at low contents (0.1% by volume) to control plastic-shrinkage cracking in concrete.

g) **Polyethylene:** Polyethylene has been produced for concrete in monofilament form with wart-like surface deformations shown in Figure 2.8 (e). Polyethylene in pulp form may be an alternate to asbestos fibers. Concrete reinforced with polyethylene fibers at contents between 2 and 4% by volume exhibits a linear flexural load deflection behavior up to first crack, followed by an apparent transfer of load to the fibers permitting an increase in load until the fibers break.

(a)

(b)

(c)



(d)

(e)

(f)

(g)

Fig 2.8: Different types of fiber (a) Glass fiber (b) Steel fiber (c) Aramid fiber (d) Carbon fiber (e) Polyethylene fiber (f) Acrylic (g) Galvanized iron fiber (Wikipedia, 2014)

mix. A satisfactory mix of chopped carbon fiber, cement and water is difficult to achieve because of the large surface area of the fiber. Figure 2.8 (d) shows carbon fiber.

i) **Steel fiber:** Steel fibers have been used in concrete since the early 1900s. The early fibers were round and smooth and the wire was cut to the required length. The modern fibers are either rough surfaces or hooked end or crimped or undulated through their length. Typically steel fiber has equivalent diameters of 0.15mm to 2 mm and length from 7mm to 75 mm. Aspect ratio ranges between 20-100. Carbon steels are most probably used to produce fibers. Steel fibers have high tensile strength (05-2 GPa) and modulus of elasticity 200 GPa, a ductile plastic stress strain characteristic and low creep. Typically content of steel fiber ranges from 0.25% to 2% by volume. Fiber contents of more than 2% volume result in poor workability and fiber distribution, But can be used successfully where the paste content of the mortar increased and aggregate size not more than 10 mm. concrete containing steel fibers have been shown to have substantially improved resistance to impact and greater ductility of failure in compression, flexure and torsion (Johnston C.D, 1974). Fatigue resistance of the concrete is reported to be increased by up to 70%. Here Properties of steel fiber having different shapes are being shown in the Table no 2.2. Figure 2.8 (b) shows the steel fiber. There are many different types and properties of natural and steel fiber have been shown above but no research studies have been found yet about Galvanized iron (G.I.) fiber reinforced concrete. G.I. fibers are readily available in Bangladesh. However, study of applicability and feasibility of G.I. fiber reinforced concrete in construction sectors of Bangladesh is not made available. Therefore, it is important to study the mechanical properties of G.I. fiber reinforced concrete. In addition, the study of feasibility and application of G.I. fiber concrete made with recycled brick aggregates is not made available in Bangladesh.

j) **Galvanized iron fiber:** Nowadays galvanized steel wire are using as the fiber reinforcement to boost up the strength of concrete. Galvanized steel wire is made of carbon steel zinc plated. The zinc coating offers corrosion resistance, allowing vary varied use for weaving of galvanized wire mesh, galvanized hardware cloth, welded iron wire mesh, chicken netting, etc. Galvanized steel wire with hot-dipped zinc coating is used in the seawater corrosion resistance alloy coated steel wire of 0.13-

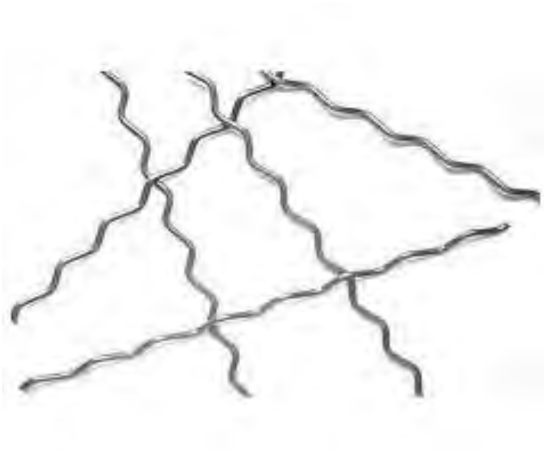
6.0 mm. The diameter of the wire generally varies 0.30 mm to 1.2 mm. Specific gravity of the G.I. wires are also ranges between 6000-7500 kg/m^3. Its ultimate tensile strength generally varies between 200-350MPa. Elastic modulus also ranges between 5-8 GPa. Its ultimate elongation varies between 2-3%. In Bangladesh it is very cheap and easily available in the local market. Figure 2.8 (g) shows the galvanized iron wire.

Table 2.2: Properties of different types of steel fiber (Kayat., Kassimi, 2014)

Fiber type	MO-S	MU-S	MI-MA		ST-PP		ST
Shape*	Straight monofilament	Kinked multifilament	Crimped	Tissue	Crimped	Multifilament	Hooked
Specific gravity	0.92	0.92	0.91	0.91	7.85	0.91	7.85
Length L_f, mm	40	50	50	20	42	5 to 15	30
Diameter d_f, mm	0.44	0.67	0.9	0.05	1.2	0.05	0.55
Aspect ratio L_f/d_f	90	74	84	400	47		55
Elastic modulus E_f, GPa	9.5	5	7.16	—	203	—	200
Tensile strength f_t', MPa	620	550 to 600	413	—	970 to 1240	Negligible	1100 to 1300

2.8 Shapes of the steel fiber

Typical fiber used in the fiber reinforced concrete (FRC) a) straight, smooth, drawn wire steel fiber b) deformed (crimped) wires steel fibers c) variable cross section steel fiber d) Glued bundles of steel fiber with crimped ends or hook end steel fiber (Soroushian and Bayasi, 1991). Steel fibers of different shapes are shown in Figure 2.9. However, hooked end steel fibers are mostly used in the steel fiber reinforced concrete due to it creates a good anchorage and interlock among the particles (Misba Gul et al, 2014).

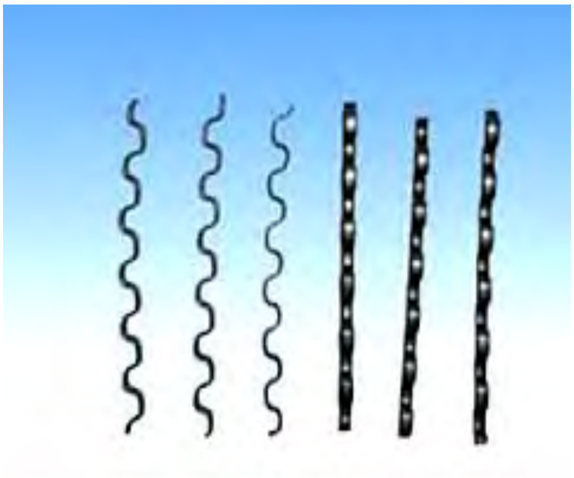


Crimped steel fiber

Paddled steel fiber

Deformed steel fiber

Hooked end steel fiber



Irregular steel fiber

Straight steel fiber

Fig 2.9: Different types of steel fiber (Wikipedia, 2014)

2.9 Research related to the steel fiber reinforced concrete

There are some research conducted over two decades on the mechanical behavior of fiber reinforced concrete, they are discussed below.

2.9.1 Stress-strain curves for steel-fiber reinforced concrete under compression, (Nataraja et al, 1999)

Steel fiber reinforced concrete is increasingly being used day by day as a structural material. The complete stress-strain curve of the material in compression is needed for the analysis and design of structures. In this experimental investigation, an attempt has been made to generate the complete stress-strain curve experimentally for steel fiber reinforced concrete for compressive strength ranging from 30 to 50 MPa. Round crimped fibers with three volume fractions of 0.5%, 0.75% and 1.0% (39, 59, and 78 kg/m3) and for two aspect ratios of 55 and 82 are considered. The effect of fiber addition to concrete on some of the major parameters namely peak stress, strain at peak stress, the toughness of concrete and the nature of the stress-strain curve is studied. A simple analytical model is proposed to generate both the ascending and descending portions of the stress-strain curve. There exists a good correlation between the experimental results and those calculated based on the analytical model. Equations are also proposed to quantify the effect of fiber on compressive strength, strain at peak stress and the toughness of concrete in terms of fiber reinforcing parameter.

2.9.2 Effect of aspect ratio and volume fraction of steel fiber on the mechanical properties of SFRC (Yazici et al, 2007)

Effects of aspect ratio (l/d) and volume fraction (Vf) of steel fiber on the compressive strength, split tensile strength, flexural strength and ultrasonic pulse velocity of steel fiber reinforced concrete (SFRC) were investigated. For this purpose, hooked-end bundled steel fibers with three different l/d ratios of 45, 65 and 80 were used. Three different fiber volumes were added to concrete mixes at0.5%, 1.0% and 1.5% by volume of concrete. Ten different concrete mixes were prepared. After 28 days of curing, compressive, split and flexural strength as well as ultrasonic pulse velocity were determined. It was found that, inclusion of steel fibers significantly affect the split tensile and flexural strength of concrete accordance with l/d ratio and V_f.

2.9.3 Experimental and numerical analysis on effect of fiber aspect ratio on mechanical properties of SRFC (Wang et al, 2010)

This research shows the effect of fiber aspect ratio (length-to-diameter) on mechanical characteristics of steel fiber reinforced concrete (SFRC). Analysis reveals that the aspect ratio has an optimal value for strengths in every concrete batch. Beyond this value, the addition of steel fibers into concrete may have an effect of increasing the ductility rather than the strengths. Subsequently, crater and perforation in two SFRC targets by a steel projectile are numerically simulated based on erosion algorithm. The effective stress and effective plastic strain are tabulated to model the softening behavior due to post-yield damage. Numerical results show that the hydrodynamic model is able to describe the responses of SFRC under impact loading. Besides, higher aspect ratio of fibers can absorb more energy, causing smaller craters in SFRC target and lower residual velocity of the projectile.

2.9.4 Compressive stress–strain behavior of steel fiber reinforced-recycled aggregate concrete (Jodilson et al, 2014)

In this work, an experimental investigation was carried out to investigate the influence of steel fiber reinforcement on the stress–strain behavior of concrete made with construction and demolition waste (CDW) aggregates. In addition, the flexural strength and splitting tensile strength of the mixtures were also determined. Natural coarse and fine aggregates were replaced by recycled coarse aggregate (RCA) and recycled fine aggregate (RFA) at two levels, 0% and 25%, by volume. Hooked end steel fibers with 35 mm of length and aspect ratio of 65 were used as reinforcement in a volume fraction of 0.75%. The research results show that the addition of steel fiber and recycled aggregate increased the mechanical strength and modified the fracture process relative to that of the reference concrete. The stress–strain behavior of recycled aggregate concrete was affected by the recycled aggregate and presented a more brittle behavior than the reference one. With the addition of steel fiber the toughness, measured by the slope of the descending branch of the stress–strain curve, of the recycled concretes was increased and their behavior under compression becomes similar to that of the fiber-reinforced natural aggregate concrete.

2.9.5 Assessment of concrete strength combining direct and NDT measures via Bayesian inference (Giannini et al, 2014)

Assessment of existing reinforced concrete structure entails a series of steps, among which the evaluation of the mechanical properties of concrete can be considered a corner-stone. To this end, direct compression tests on cores extracted directly from a structure provide the most reliable estimation of the strength. Unfortunately, the number of cores usually accepted is often limited because the method is expensive and invasive. For this reason, non-destructive (ND) methods are mostly used, whose results are usually calibrated using a limited number of destructive tests, to provide some preliminary information about the homogeneity of the investigated concrete and possibly to suggest zones where to extract other cores. In addition, non-destructive tests may be used to enlarge the database for the estimation of concrete strength. The main drawback in using this approach is that a correlation formula between the in situ measures and concrete strength is required. In many cases, such formula cannot be easily generalized and must be restricted every time based on pairs of indirect and direct measures of strength. Moreover, the use of different experimental techniques (destructive and non-destructive) provides information with different reliability, and the results are thus difficult to combine. For these reasons, in this paper, a technique based on Bayesian inference is proposed to combine in a rational manner the results of direct and indirect measures, providing the probabilistic distribution of the concrete strength and some significant properties such as the median and characteristic value.

2.9.6 Study of modulus of elasticity of steel fiber reinforced concrete (Misba Gul et al, 2014)

Plain, unreinforced concrete is a brittle material, with a low tensile strength, limited ductility and little resistance to cracking. In order to improve the inherent tensile strength of concrete there is a need of multidirectional and closely spaced reinforcement, which can be provided in the form of randomly distributed fibers. Steel fiber is one of the most commonly used fibers. Short, discrete steel fibers provide discontinuous three-dimensional reinforcement that picks up load and transfer stresses at micro-crack level. This reinforcement provides tensile capacity and crack control to the concrete section prior to the establishment of visible macro cracks, thereby promoting ductility or toughness. The modulus of elasticity of concrete is a very important parameter reflecting the ability of concrete to deform elastically. In addition, in order to make full use of the compressive strength potential, the structures using high strength concrete tend to be slimmer and require a higher elastic modulus so as to maintain its stiffness. Therefore, knowledge of the modulus of elasticity of high strength concrete is very important in avoiding excessive deformation, providing satisfactory serviceability, and avoiding the most cost-effective designs. The present experimental study considers the effect of steel fibers on the modulus of elasticity of concrete. Hook end steel fibers with aspect ratio of 50 and 71 at volume fraction of 0.5%, 1.0% and 1.5% were used. Study on effect of volume fraction and aspect ratio of fibers on the modulus of elasticity of concrete was also deemed as an important part of present experimental investigation. The results obtained show that the addition of steel fiber improves the modulus of elasticity of concrete. It was also analyzed that by increasing the fiber volume fraction from 0.5% to 1.5% and aspect ratio of fibers from 50 to 71, there was a healthy effect on modulus of elasticity of steel fiber reinforced concrete.

2.10 Cement

Cement is a cementing or binding material used in engineering construction. Bricklayer Joseph Aspdin of Leeds, England first made Portland cement early in the 19th century by burning powdered limestone and clay in his kitchen stove. By this crude method he laid the foundation for an industry which annually processes literally mountains of limestone, clay, cement rock, and other materials into a powder so fine it will pass through a sieve capable of holding water. Cement is so fine that one pound of cement contains 150 billion grains.

2.10.1 Cement Composition

Two different processes, "dry" and "wet," are used in the manufacture of Portland cement. When rock is the principal raw material, the first step after quarrying in both processes is the primary crushing. Mountains of rock are fed through crushers capable of handling pieces as large as an oil drum. The first crushing reduces the rock to a maximum size of about 6 inches. The rock then goes to secondary crushers or hammer mills for reduction to about 3 inches or smaller.

In the wet process, the raw materials, properly proportioned, are then ground with water, thoroughly mixed and fed into the kiln in the form of’ slurry" (containing enough water to make it fluid). In the dry process, raw materials are ground, mixed and fed to the kiln in a dry state. In other respects, the two processes are essentially alike.

The raw material is heated to about 2,700 degrees F in huge cylindrical steel rotary kilns lined with special firebrick. Kilns are frequently as much as 12 feet in diameter large enough to accommodate an automobile and longer in many instances than the height of a 40-story building. Kilns are mounted with the axis inclined slightly from the horizontal. The finely ground raw material or the slurry is fed into the higher end. At the lower end is a roaring blast of flame, produced by precisely controlled burning of powdered coal, oil or gas under forced draft. As the material moves through the kiln, certain elements are driven off in the form of gases. The remaining elements unite to form a new substance with new physical and chemical characteristics. The new substance, called clinker, is formed in pieces about the size of marbles. Clinker is discharged red-hot from the lower end of the kiln and generally is brought down to handling temperature in various types of coolers. The heated air from the coolers is returned to the kilns, a process that saves fuel and increases burning efficiency. There are four chief minerals present in a Portland cement grain: tricalcium silicate (Ca_3SiO_5), dicalcium silicate (Ca_2SiO_4), tricalcium aluminate ($Ca_3Al_2O_5$) and calcium aluminoferrite ($Ca_4Al_nFe_{2-n}O_7$). The formula of each of these minerals can be broken down into the basic calcium, silicon, aluminum and iron oxides (Table 1). Cement chemists use abbreviated nomenclature based on oxides of various elements to indicate chemical formulae of relevant species, i.e., C = CaO, S = SiO_2, A = Al_2O_3, F = Fe_2O_3. Hence, traditional cement nomenclature abbreviates each oxide as shown in Table 2.3. The composition of cement is varied depending on the application. A typical example of cement contains 50–70% C3S, 15–30% C2S, 5–10% C3A, 5–15% C4AF, and 3–8% other additives or minerals (such as oxides of calcium and magnesium). It is the hydration of the calcium silicate, aluminate, and aluminoferrite minerals that causes the hardening, or setting, of cement. The ratio of C3S to C2S helps to determine how fast the cement will set, with faster setting occurring with higher C3S contents. Lower C3A content promotes resistance to sulfates. Higher amounts of ferrite lead to slower hydration. The ferrite phase causes the brownish gray color in cements, so that “white cements” (i.e., those that are low in C4AF) are often used for aesthetic purposes. Figure 2.10 shows the standard chemical requirements of cement.

Table 2.3 Chemical formulae for major constituents of Portland cement (Wikipedia, 2014)

Mineral	Chemical formula	Oxide composition	Abbreviation
Tricalcium silicate (alite)	Ca_3SiO_5	$3CaO.SiO_2$	C3S
Dicalcium silicate (belite)	Ca_2SiO_4	$2CaO.SiO_2$	C2S
Tricalcium aluminate	$Ca_3Al_2O_4$	$3CaO.Al_2O_3$	C3A
Tetracalcium aluminoferrite	$Ca_3Al_2O_4$	$4CaO.Al_nFe_{2-n}O_3$	C4AF
Abbreviation notation: C = CaO, S = SiO_2, A = Al_2O_3, F = Fe_2O_3.			

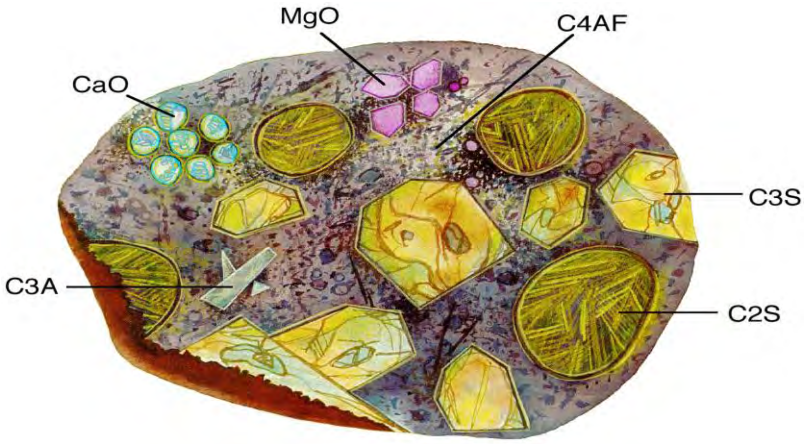


Fig 2.10 Standard chemical requirements of Cement (Wikipedia, 2014)

2.10.2 Composition of Portland composite cement (PCC)

Portland composite cement is a hydraulic binder. It is produced by grinding clinker and a certain amount of gypsum, fly ash, slag and limestone. Figure 2.11 shows the components.

Fig 2.11 Component of PCC (Wikipedia, 2014)

2.10.2.1 Active ingredient

Portland clinker is active ingredient. Clinkers are formed by the heat processing of cement elements in a kiln. Limestone, clay, bauxite and iron ore sand in specific proportions are heated in a rotating kiln at 2770˚F (1400˚C) unit they being to form cinder lumps, which are also known as cement clinkers.

2.10.2.2 Mineral Component

Mineral Component of PCC are given below

a) Fly ash – Pozzolan component.
b) Blast furnace Slag – hydraulic component.
c) Limestone – inert component.
d) Gypsum – Retarding agent to control setting time.

Properties of different types of mineral components in cement are given below

(a) Fly ash: Fly ash is a byproduct of coal after burning for different purposes and subsequently crushed to powder level to be used for the manufacture of cement. It has more fineness it increases long age strength. Due to Pozzolanic and latent hydraulic properties, Portland Composite Cement (PCC) gives high long term concrete strength. In general, strength gains up to 90 days. Figure 2.12 shows the microscopic view of fly ash.

(b) Blast furnace Slag: Slag is a byproduct of smelting ore to separate the metal from the unwanted materials. It can usually be considered to be a mixture of metal oxides and silicon dioxide. The most common sources of slag are manufacture of pig iron. Advantage of slag on cement is mainly is higher compressive and flexural strength and also it gives high resistance to sulfate & chloride attack. Figure 2.13 shows the Microscopic view of slag.

(c) Limestone: It is sedimentary rock composed largely of the minerals calcite and aragonite, which are different crystal forms of calcium carbonate ($CaCO_3$). Limestone's has very pleasant appearance, can be polished to a smooth shiny surface and work filler.

(d) Gypsum: Gypsum is a mineral and hydrated calcium sulfate in chemical form. Gypsum plays a very important role in controlling the rate of hardening of the cement (European standard, EN197-1, 2000). Table 2.4 shows composition of all kinds of cement.

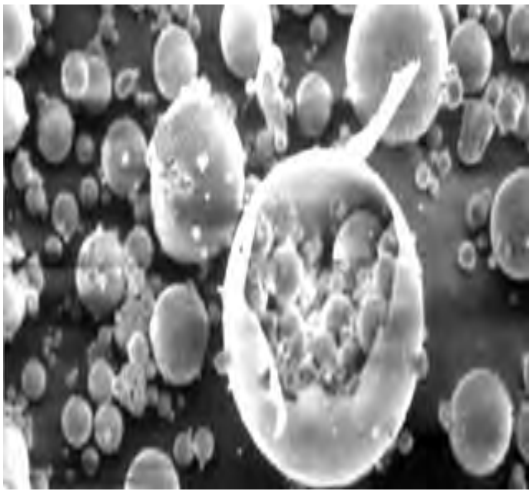


Fig 2.12: Microscopic view of fly ash (Wikipedia, 2014)

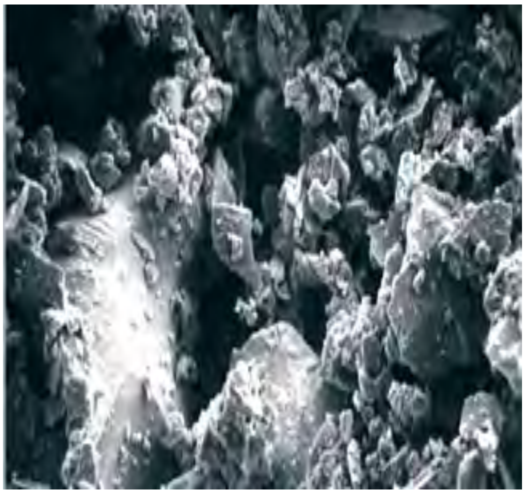


Fig 2.13: Microscopic view of slag (Wikipedia, 2014)

Table 2.4 Constituents of PCC (BS EN 197-1, 2011)

Main types	Notation of the 27 products (types of common cement)		Composition (percentage by mass [a])										
			Main constituents										Minor additional constituents
			Clinker	Blast-furnace slag	Silica fume	Pozzolana		Fly ash		Burnt shale	Limestone		
						natural	natural calcined	siliceous	calca-reous				
			K	S	D [b]	P	Q	V	W	T	L	LL	
CEM I	Portland cement	CEM I	95-100	–	–	–	–	–	–	–	–	–	0-5
CEM II	Portland-slag cement	CEM II/A-S	80-94	6-20	–	–	–	–	–	–	–	–	0-5
		CEM II/B-S	65-79	21-35	–	–	–	–	–	–	–	–	0-5
	Portland-silica fume cement	CEM II/A-D	90-94	–	6-10	–	–	–	–	–	–	–	0-5
	Portland-pozzolana cement	CEM II/A-P	80-94	–	–	6-20	–	–	–	–	–	–	0-5
		CEM II/B-P	65-79	–	–	21-35	–	–	–	–	–	–	0-5
		CEM II/A-Q	80-94	–	–	–	6-20	–	–	–	–	–	0-5
		CEM II/B-Q	65-79	–	–	–	21-35	–	–	–	–	–	0-5
	Portland-fly ash cement	CEM II/A-V	80-94	–	–	–	–	6-20	–	–	–	–	0-5
		CEM II/B-V	65-79	–	–	–	–	21-35	–	–	–	–	0-5
		CEM II/A-W	80-94	–	–	–	–	–	6-20	–	–	–	0-5
		CEM II/B-W	65-79	–	–	–	–	–	21-35	–	–	–	0-5
	Portland-burnt shale cement	CEM II/A-T	80-94	–	–	–	–	–	–	6-20	–	–	0-5
		CEM II/B-T	65-79	–	–	–	–	–	–	21-35	–	–	0-5
	Portland-limestone cement	CEM II/A-L	80-94	–	–	–	–	–	–	–	6-20	–	0-5
		CEM II/B-L	65-79	–	–	–	–	–	–	–	21-35	–	0-5
		CEM II/A-LL	80-94	–	–	–	–	–	–	–	–	6-20	0-5
		CEM II/B-LL	65-79	–	–	–	–	–	–	–	–	21-35	0-5
	Portland-composite cement [c]	CEM II/A-M	80-94	<------------ 6-20 ------------>									0-5
		CEM II/B-M	65-79	<------------ 21-35 ------------>									0-5
CEM III	Blastfurnace cement	CEM III/A	35-64	36-65	–	–	–	–	–	–	–	–	0-5
		CEM III/B	20-34	66-80	–	–	–	–	–	–	–	–	0-5
		CEM III/C	5-19	81-95	–	–	–	–	–	–	–	–	0-5
CEM IV	Pozzolanic cement [c]	CEM IV/A	65-89	–	<------ 11-35 ------>					–	–	–	0-5
		CEM IV/B	45-64	–	<------ 36-55 ------>					–	–	–	0-5
CEM V	Composite cement [c]	CEM V/A	40-64	18-30	–	<---- 18-30 ---->			–	–	–	–	0-5
		CEM V/B	20-38	31-50	–	<---- 31-50 ---->			–	–	–	–	0-5

a The values in the table refer to the sum of the main and minor additional constituents.
b The proportion of silica fume is limited to 10 %.
c In Portland-composite cements CEM II/A-M and CEM II/B-M, in pozzolanic cements CEM IV/A and CEM IV/B and in composite cements CEM V/A and CEM V/B the main constituents other than clinker shall be declared by designation of the cement (for example see clause 8).

2.11 Aggregates

Aggregates are inert granular materials such as sand, gravel, or crushed stone or bricks that, along with water and Portland cement, are an essential ingredient in concrete. For a good concrete mix, aggregates need to be clean, hard, strong particles free of absorbed chemicals or coatings of clay and other fine materials that could cause the deterioration of concrete. Aggregates, which account for 60 to 75 percent of the total volume of concrete, are divided into two distinct categories-fines and coarse. Fine aggregates generally consist of natural sand or crushed stone with most particles passing through a 3/8-inch (9.5-mm) sieve. Coarse aggregates are any particles greater than 0.19 inch (4.75 mm), but generally range between 3/8 and 1.5 inches (9.5 mm to 37.5 mm) in diameter. Gravels constitute the majority of coarse aggregate used in concrete with crushed stone making up most of the remainder.

2.11.1 Classification of aggregates

According to particle size and source, aggregates can be divided into the following different categories

(a) Coarse aggregate: Aggregate mainly retained on a 5.0 mm BS test sieve and containing no more finer material than is permitted in BS 882: 1992 (BS 882:1992).

(b) Fine aggregate (sand): Aggregates mainly passing 5.0 mm BS test sieve and containing no more coarser material than is permitted for the various grading in BS 882:1992.

2.11.2 Physical Properties of aggregates

Properties of the aggregates which influence the properties of both the fresh and the hardened concretes are mainly the particle size distribution, the maximum size of the particles and the shape and surface texture of the particles. Furthermore, the density and the porosity together with water absorption and moisture content have to be considered when the concrete is proportioned. Properties of the aggregates which are relevant to this investigation are described in the following sections.

2.11.2. 1 Particle shape

The shape of aggregate can be divided as rounded, flaky, irregular, angular, elongated and flaky and elongated.

2.11.2.2 Surface texture

The surface texture of aggregates is classified as glassy, smooth, granular, rough, crystalline and honeycombed. Smooth aggregates need less water to achieve the same workability as rough aggregates. Nevertheless, rough surface of aggregates is responsible for better mechanical bond in the hardened concrete, so strength is comparatively higher (if concrete with the same w/c is compared).

2.11.2.3 Moisture content

The moisture condition of aggregates consists of accumulation of water in the pores and on the surface of aggregates.

2.11.2.4 Gradation of Aggregates

a) Gradation is the proportion of the different sizes of particles making up the aggregate
b) Suitable gradation is required to ensure strength, workability and economy of concrete.
c) Principle of Gradation: Smaller size particles fill up the voids left in large size particles
d) Sieve analysis is the method to determine grading of aggregates
e) For same size particles**:** void is more
f) For different size particles**:** void is less

2.11.2.5 Specific Gravity (Relative density)

Absolute: the ratio of the weight of the solid to the weight of an equal volume of water (both at a stated temperature)

(a) Refers to volume of the material excluding all pores. Apparent: ratio of the weight of the aggregate (dried in an oven at 212- 230ºF for 24 hours) to the weight of water occupying a volume equal to that of the solid including the impermeable pores.

(b) Volume of solid includes impermeable pores (but not capillary pores). Used for calculating yield of concrete or the quantity of aggregate required for a given volume of concrete.

2.11.2.6 Unit Weight (Unit mass or bulk density)

The weight of the aggregate required to fill a container of a specified unit volume. Table 2.5 shows different Bulk density that can be used for the concrete.

(a) Volume is occupied by both the aggregates and the voids between the aggregate particles.

(b) Depends on size distribution and shape of particles and how densely the aggregate is packed

(c) Loose bulk density

(d) Rodded or compact bulk density

Table 2.5 Normal-weight concrete: Bulk density of aggregate is approximately 75-110 lb cft (Uddin, 2011)

Weight	Examples of Aggregates Used	Uses for the Concrete
ultra-lightweight	vermiculite, ceramic	Can be sawed or nailed, also used for its insulating properties.
Light weight	expanded clay, shale or slate, crushed brick	Used primarily for making lightweight concrete for structures, also used for its insulating properties.
Normal weight	crushed limestone, sand, river gravel, crushed recycled concrete	Used for normal concrete projects.
Heavy weight	steel or iron shot; steel or iron pellets	Used for making high density concrete for shielding against nuclear radiation.

2.11.2.7 Moisture Conditions of Aggregates

Different moisture conditions of aggregates shown in Figure 2.14

a) Oven dry- fully absorbent.

b) Air dry- dry at the particle surface but containing some interior moisture

c) Saturated surface dry (SSD)–neither absorbing water nor contributing water to the concrete mixture.

d) Wet or moist-containing an excess of moisture on the surface.

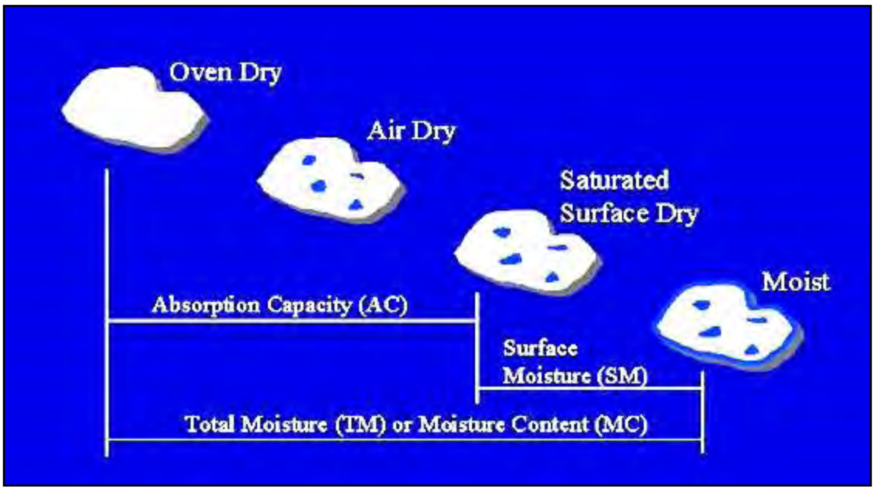


Fig 2.14: Moisture Conditions of Aggregates (Wikipedia, 2014)

2.11.3 Brick aggregate

Aggregate acts as a filler material in the concrete. In Bangladesh, crushed brick is generally used as coarse aggregate. Brick aggregate produced from 1st class well burnt brick though it is artificial but it acts as a hard material like stone. High grade concrete can easily be produced by using brick aggregate. Although this concrete has a lower value of modulus of elasticity it's tensile strength is higher than that of normal weight of concrete (Akhtaruzzaman and Hasnat, 1983)

2.11.3.1 Properties of brick aggregate

Concrete is produced by mixing cement, sand, coarse aggregate and water to produce a material that can be molded into almost any shape. The major volume of concrete is filled with aggregate. Aggregate inclusion in concrete reduces its drying shrinkage and improves many other properties. Akhtaruzzaman and Hasnat (1983) investigated that splitting tensile strength of brick aggregate is, in general about 12% greater than that of normal weight concrete. Aggregate is also the least expensive per weight unit, put it makes the most amount of the weight. It is costly to transport so local sources are needed, but due to geographical constraint this is not available at all places, therefore it necessitates finding other sources and alternatives from local sources. In eastern and north eastern states of India and Bangladesh where natural rock deposits are scarce, burnt clay bricks are used as an alternative source of coarse aggregate. In these places of India brick aggregate are traditionally used as coarse aggregate. The use and performance of concrete made with broken brick as coarse aggregate are quite extensive and satisfactory for ordinary concrete. Clay and silt along with appropriate quantity of sand can be burnt in its natural form as is done in brick-making and the product may be a source of coarse aggregate for concrete. Also in brick-making, a large number of bricks are rejected due to nonconformity with the required specifications. One such major nonconformity is the distorted form of brick produced due to the uneven temperature control in the kiln. These rejected bricks can also be a potential source of coarse aggregate (Rashida et al, 2009). Akhtaruzzaman and Hasnat (1983) investigated the various engineering properties of concrete using crushed brick as coarse aggregate (Khaloo, 1994) studied the properties of concrete using crushed clinker brick as coarse aggregate. In both the above-mentioned studies, investigations were also done by comparing the properties of brick aggregate concrete with those for stone aggregate concrete. Rashid et al, (2009) investigated the properties of higher strength concrete with brick aggregate. On the other hand, studies were done by Mansur et al, (1999) comparing the properties of stone aggregate concrete with those of equivalent brick aggregate concrete obtained by replacing stone with an equal volume of crushed brick, everything else remaining the same. Cachim (2009) studied the mechanical properties brick aggregate concrete by partial replacement of natural stone aggregate by brick aggregate and it was found that up to 15% replacement there is no reduction of strength. Debieb and Kenai (2008) showed that it is possible to produce concrete containing crushed bricks (coarse and fine) with characteristics similar to those of natural aggregate concrete provided that the percentage of brick aggregates is limited to 25 and 50% for the coarse and fine aggregate respectively. Apart from strength parameter in ambient temperature studied the thermal properties of brick aggregate concrete and it was found that brick aggregate concrete perform similar and even better than granite aggregate concrete in elevated temperature (Khalaf and DeVenny, 2004).

2.11.4 Recycled brick aggregate

Aggregates may be Natural, Man-made. Recycled from material previously used in construction can be used as aggregates. The multiple use of a product represents another way to conserve natural resources and avoid waste. This process usually termed as recycling. Recycled concrete contains some previously hardened concrete in the form of aggregate particularly coarse aggregate. Then the building rubble could be transformed into use full recycled aggregate through proper processing (Uddin et al, 2013).

2.11.4.1 Properties of recycled brick aggregate

Properties of recycled aggregate (Uddin , 2011) are given below.

a) Specific gravity of recycled coarse aggregate will be 5% to 10% lower than that of the virgin aggregates in old concrete. This is due to the existence of large amount of old mortar and cement paste adhering to RC. Typical values of recycled coarse aggregate (RCA) range between 2 and 2.5 in the SSD condition.
b) The water absorption of RCA is much higher than that of the virgin aggregates in old concrete due to the attachment of mortar in RCA. Absorption values typically range from 6% to 20% for coarse aggregates.
c) Typical abrasion losses for recycled aggregates range from 20% to 48%. The upper limit for pavement aggregates is 50%.
d) RCA is a more porous aggregate than natural aggregate (NA). RCA provides an extra amount of mortar to the RC which in turn leads to an increase in porosity and thus to the possibility of increased strain. Porosity increases considerably when NA is replaced by RCA in recycled concrete (RC).
e) The internal friction between the recycled aggregate is also higher due to the higher surface roughness of the recycled aggregate

2.11.4.2 Advantages of using recycled brick aggregate

There are some advantages of using recycling brick over the brick aggregate (Uddin, 2011). The advantages are given below.

a) Save energy when recycling is done on site.
b) Save natural resources.

c) RCA that originated as concrete with rounded aggregate yields a new product with particles having fractured angular shapes for increased paste bond.
d) RCA when used in the base and sub-base material performs better than virgin aggregate.
e) Using RCA in the Detroit metropolitan region is more advantageous than in rural areas, since sources of old concrete are readily available and virgin aggregate sources are not as plentiful.
f) Substitution of virgin aggregate by RCA can provide a reduction in the final cost of the project.
g) Saving cost of disposal of demolished concrete.
h) Create additional business opportunities.

2.11.4.3 Disadvantages of using recycled brick aggregate

a) The use of RCA in new concrete initially created problems with mix workability. The problem was associated with the absorbency of the aggregate and the difficulty maintaining a consistent and uniform saturated surface dry condition of RCA aggregate
b) Excessive working of the RCA base will segregate the base materials. Minimum shaping of the RCA base material should occur
c) Compaction of the RCA base should be in a saturated state to aid in the migration of fines throughout the mix.
d) Research has identified an increase in creep and shrinkage when RCA is incorporated into new concrete. This can be a major issue when RCA is used in structural concrete
e) Benefits could only be realized where there is an adequate supply of quality RCA
f) Recycled coarse aggregate has a much higher thermal coefficient than virgin aggregate due to the attached old mortar.

2.11.5 Fine aggregate (sand)

Sand is an engineering material in concrete work. It is usually termed as fine aggregate. Sand is a form of silica (quartz) and may be of argillaceous siliceous or calcareous according to its composition.

(a) More or less 75 % volume of concrete is aggregate. So, good quality of aggregates should be used.

(b) Aggregates act as a filler material in concrete

(c) We need good quality aggregate for making good quality concrete.

(d) Sand should be free from dust (clay + silt) and sand

(e) Sand should be free from reactive silica or carbonate and organic matter

(f) Sand should be well graded.

(g) Washing of sand is necessary to remove dust

(h) Dust: which passes through the # 100 sieve? (Dust = Clay + Silt)

2.11.5.1 Classification of Sand

Sand can be classified according to source, shape and size. Classifications are briefly presented below.

According to Source:

(a) Pit Sand

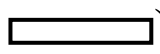
(b) River Sand

(c) Sea Sand

According to Shape:

(a) Angular ()

(b) Round (○)

(c) Flaky ()

According to Size:

(a) Coarse Sand (3/8"), FM: 2.6

(b) Medium Sand (1/8"), FM: 2.2

(c) Fine Sand (1/16"), FM: 1.8 ~ 2.0

2.11.5.2 Test for Sand

(i) Test for silt and clay: Determined by the percentage loss in weight of a sample after washing the same with clean water.

$$\text{Silt} = \frac{M_{\text{before wash}} - M_{\text{after wash}}}{M_{\text{after wash}}}$$

(ii) Organic Matter: A sample of sand is mixed with NaOH in a closed bottle. The sample is left 24 hours. If any organic matter is exist. The solution will become brown. The amount organic matter is determined from the intensity of brown color.

2.11.5.3 Bulking of Sand

This is the increase in the volume of a given weight of sand due to the presence of moisture, For up to about 5 ~ 8% of moisture by weight of sand there is a steady increase in volume to about 20 ~ 30 % (Aziz, 2012).

The bulking of sand for small moisture content is due to the formation of thin film of water around the sand grains and interlocking the air in between the sand grains and the film of water. Figure 2.15 shows Bulking of different types of sand.

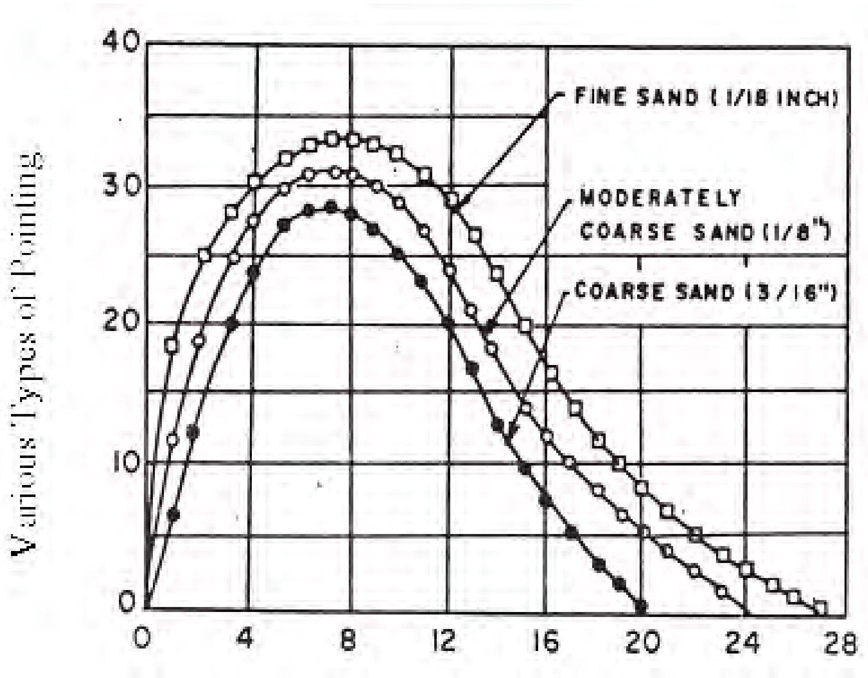


Fig: 2.15 Bulking of Different Types of Sand (Wikipedia, 2014)

2.11.6 Mixing water of concrete

Water plays two roles in the production of concrete, which are as mixing water and curing water. The mixing water is the free water present in freshly mixed concrete. It has three main functions: (1) it reacts with the cement powder, thus producing hydration; (2) it acts as a lubricant, contributing to the workability of the fresh mixture; and (3) it secures the necessary space in the paste for the development of hydration products. The amount of water needed for adequate workability is practically always greater than that needed for complete hydration of the cement. Usually, if water is potable, then it is also suitable in making the concrete. Mixing water in mortar includes batch water added when ingredients are batched into a mixer, ice, water added by the driver, free moisture on aggregates and water introduced in any significant quantity when admixtures are used.

Chapter 3
TESTING OF G.I. FIBER REINFORCED CONCRETE

3.1 Introduction

Concrete containing cement, water, fine, coarse aggregate, and incorporating discrete discontinuous galvanized iron fibers is called G.I. fiber reinforced concrete. Fibers of various shapes and sizes can be produced from galvanized iron wires. The main objective of this study is to assess compressive strength, tensile strength, modulus of elasticity and stress-strain behavior of plain and G.I. fiber reinforced concrete. In addition, a comparison between plain concrete (0% G.I. fiber replacement) and G.I. fiber reinforced concrete (0.5% and 1%) is to be conducted. Plain concrete is relatively brittle and the tensile strength is one tenth of its compressive strength. Moreover, it has no post cracking ductility (Bentur, A. and Mindess, 1990). Therefore, it is important to know the mechanical properties of G.I. fiber reinforced concrete.

3.2 Experimental Program

Extensive laboratory testing have been carried out to evaluate the properties of brick aggregate, recycled brick aggregate, fine aggregate, cement, G.I. fiber and water. There are 6 cases and 2 types of aggregates have been considered in the present study to understand the effect of aggregate types on the mechanical strength of concrete. Plain concrete (control case) which is 0 % fiber replacements and G.I. fiber reinforced concrete (0.5% and 1% fiber) made with brick aggregate (B) and recycled brick aggregate (RB) are the total 6 cases are being considered to understand the effect of G.I. fiber replacement on the mechanical strength of concrete. A trial mix design is made to check the compatibility before making the final mix design. Water cement ratio(w/c) =0.44, sand to aggregate ratio (s/a) =0.44, cement content 390 $kg/m^3$are used without any chemical admixture for both the types of aggregate (B & RB) concrete. All cases of specimen have been tested at the age of 7, 14, and 28 days to understand the effect of age on the mechanical strength of both plain and G.I. fiber reinforced concrete.

3.2.1 Specimen designation and legends

This is a sample of specimen legends which is followed in all tests as shown in Figure 3.1

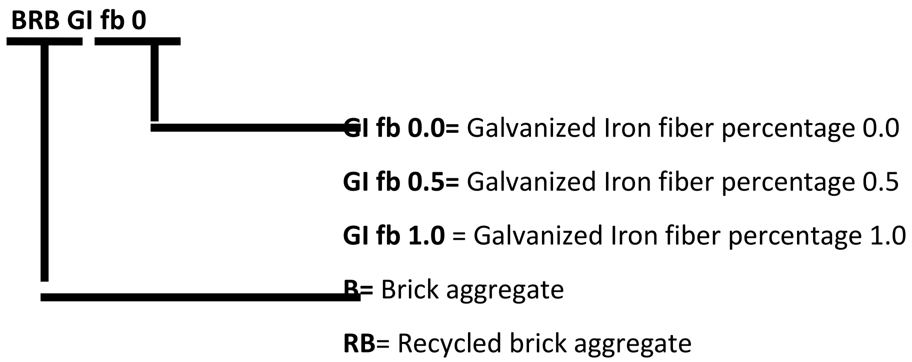


Fig 3.1: Typical legends used for different types of cylinder specimen

3.3 Materials

Two types of coarse aggregate, fresh brick and recycled brick aggregate as coarse aggregate, Sylhet sand as fine aggregate, Portland composite cement (CEM II/B-M), portable water and Hooked end G.I. fiber are being used as the materials for concrete specimens.

3.3.1 Brick Aggregate (B)

Crushed brick is commonly used in Bangladesh as coarse aggregate. Collected brick samples were broken into pieces manually having a size of 19 mm downgraded. The brick aggregates were then sieved to control a standard grading according to standard ASTM C33-93. A fineness modulus of the brick aggregate was obtained 5.91 and a gradation of aggregates used in the concrete mix is shown in figure 3.2.After sieving the aggregate, these were washed properly to avoid dusts and were dried in the laboratory to maintain the saturated surface dry (SSD) condition. The oven dry (OD) and SSD unit weight and void content were calculated according to the ASTM standard requirements of specification C29. Rodding method was used to calculate the unit weight. Specific gravity and absorption capacity of the brick aggregate was determined according to the ASTM standard requirements of specification C127. Table 3.1presents the properties of aggregates that have been tested in the laboratory and figure 3.3 shows the testing procedure of brick aggregates.

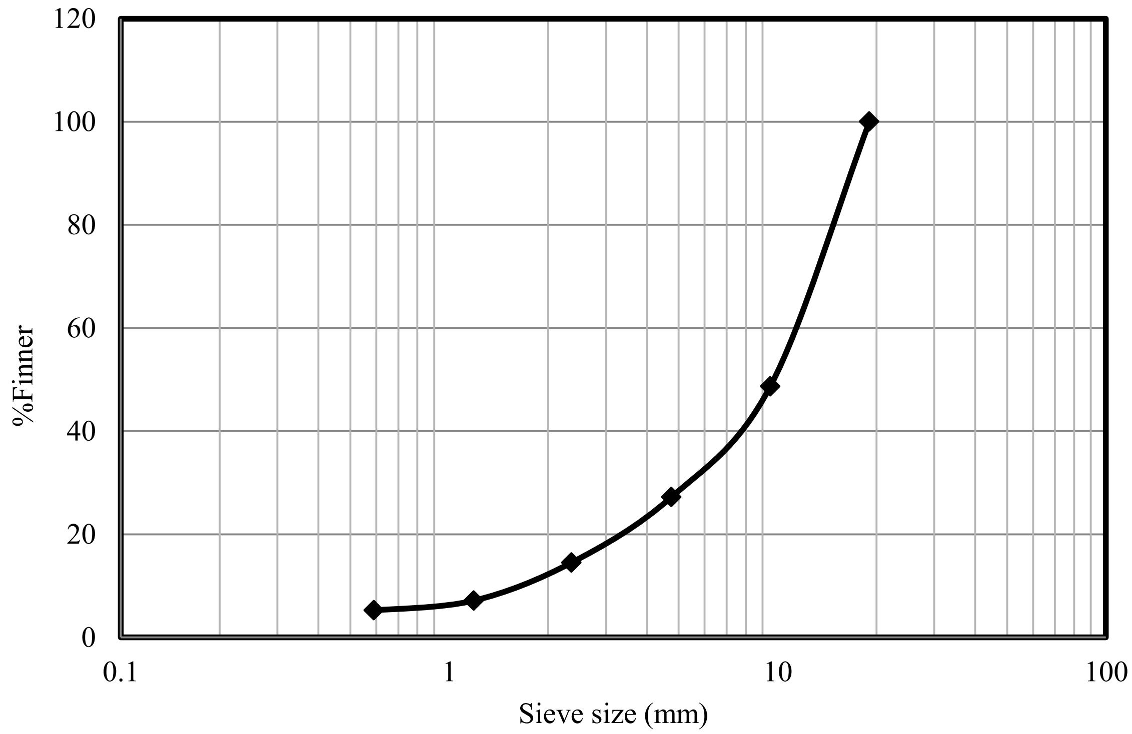


Fig 3.2: Sieve analysis of brick aggregate

Table 3.1: Properties of brick aggregate

SL No.	Name of the test	value
1.	Bulk Specific Gravity (OD)	1.83
2.	Bulk Specific Gravity (SSD)	2.10
3.	Apparent Specific Gravity	2.34
4.	Unit Weight (OD) (kg/m^3)	1000
5.	Unit Weight (SSD) (kg/m^3)	1120
6.	Absorption Capacity (%)	12
7.	Void Content (%)	4

(a) (b)

(c) (d)

Fig 3.3: Physical properties testing of brick aggregates

(a)Size (b)Unit weight (c) Specific gravity (d) Weight calculation for FM

3.3.2 Recycled brick Aggregate (RB)

Demolished concrete blocks were collected from the structural members (beams, columns, slabs) of a 5 storied demolished residential building of 30 years old. Demolished buildings and blocks are shown in figure 3.4 (a) & (b) respectively. The collected concrete samples were broken into pieces manually to have a size of 19 mm downgraded. The aggregates were then sieved to have a standard grading according to ASTM C33-93. The fineness modulus of the recycled brick aggregate was obtained 6.61 and sieve analysis results of this aggregates is presented in figure 3.5. To maintain the SSD condition, aggregates were washed properly to avoid the dust and were dried in the laboratory. The oven dry(OD) basis unit weight and saturated surface dry (SSD) basis unit weight as well as void content were determined according to the ASTMC29. Rodding method was used to calculate the unit weight. Specific gravity and absorption capacity of the recycled brick aggregate were determined according to the ASTM standard C127. Table 3.2 shows the properties of recycled aggregates that have been tested in the laboratory and figure 3.6 shows the testing procedure of recycled brick aggregates.

(a) (b)

Fig 3.4: Demolished concrete (a) building (b) blocks

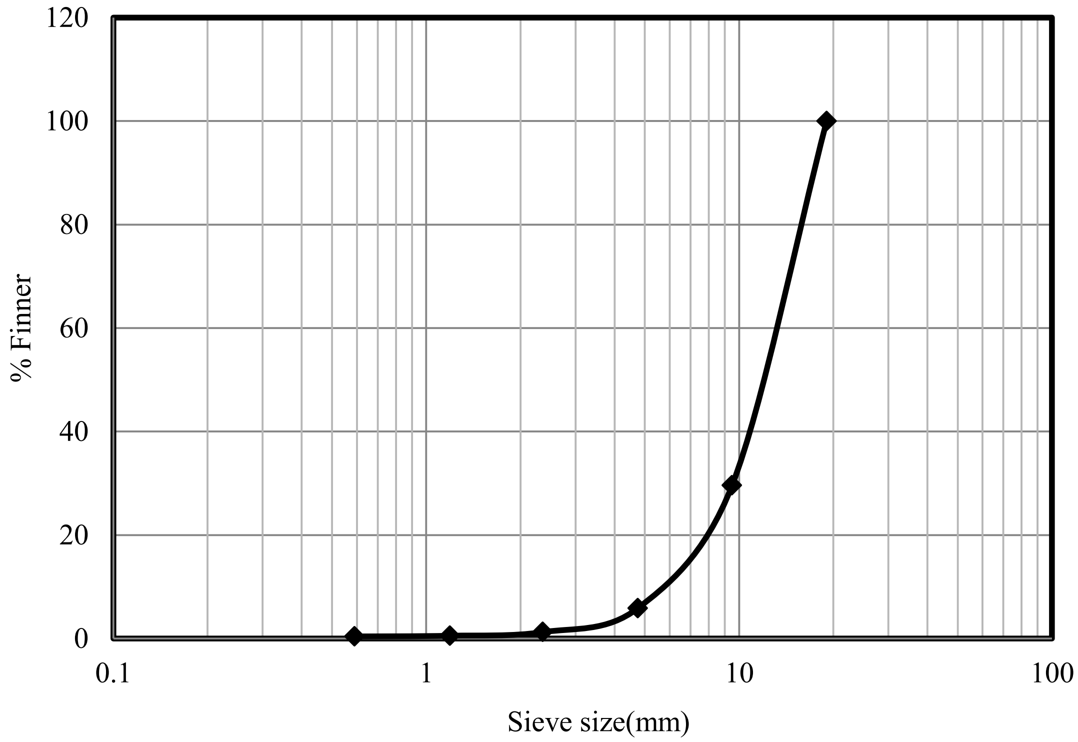


Fig 3.5: Sieve Analysis of recycled brick aggregate

Table 3.2: Properties of recycled brick aggregate

Sl. No.	Name of the test	Value
1.	Bulk Specific Gravity (OD)	1.78
2.	Bulk Specific Gravity (SSD)	2.02
3.	Apparent Specific Gravity	2.36
4.	Unit Weight (OD) (kg/m^3)	1096
5.	Unit Weight (SSD) (kg/m^3)	1245
6.	Absorption Capacity (%)	14
7.	Void Content (%)	40

Fig 3.6: Physical Properties testing of recycled brick aggregate

(a)Size (b)Sieve analysis (c) Unit weight (d) appearing to absorption capacity

3.3.3 Fine aggregate

Sand which was collected from the rivers in Sylhet district of Bangladesh is called "Sylhet Sand". It was collected from the local market in Dhaka city. Sand as a fine aggregate was sieving through No 4. ASTM sieve to ensure that no big particle or no rubbish were present into the samples. It is conducted according to ASTM C33-93, hence the fineness modulus of fine aggregate was obtained 3.0 and a gradation chart is shown in figure 3.7. The unit weights (OD& SSD) and void content were calculated according to the ASTMC29. Rodding method was used to calculate the unit weight. Specific gravity and absorption capacity of the fine aggregate was determined according to the ASTM C127. Table 3.3 shows the properties of fine aggregates that have been tested in the laboratory and figure 3.8 show the testing procedure of fine aggregates. After washing the sand, it had been dried in the laboratory and then SSD sand was prepared. Sand had been putted into the plum and then pressed, while it tends to congregate, then it was assumed that sand was in SSD condition. After preparation of SSD sand, it had been putted into air tied bags to avoid any moisture content losses.

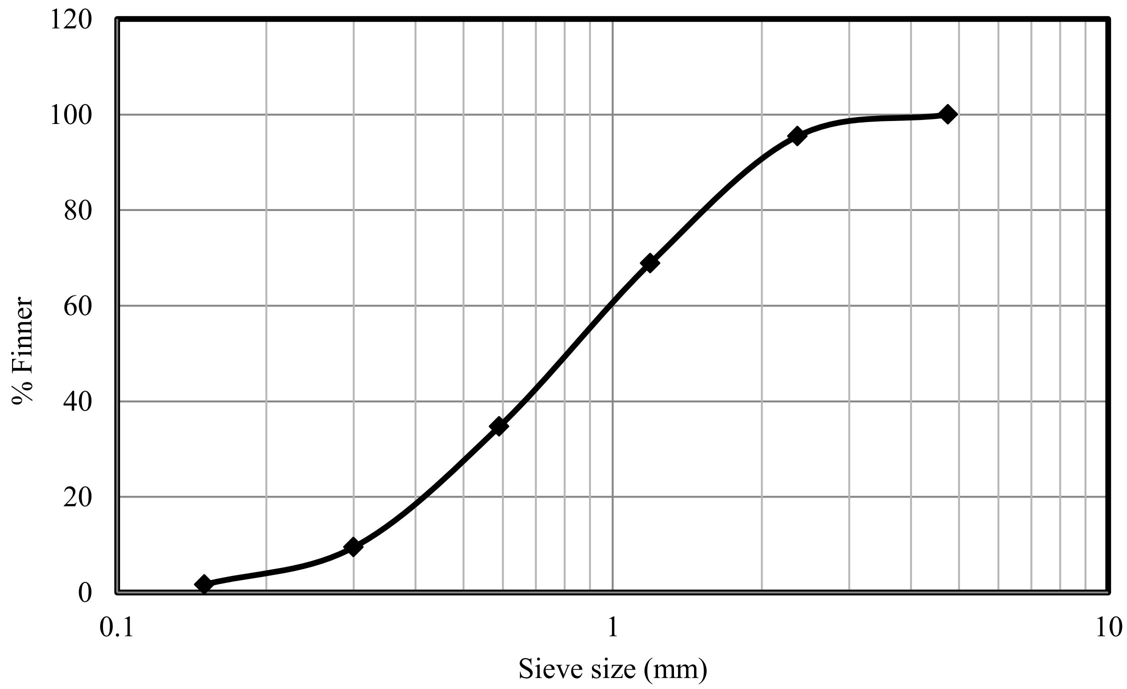


Fig 3.7: Sieve analysis of fine aggregates

Table 3.3: Properties of fine aggregate

Sl. No.	Name of the test	Value
1.	Bulk Specific Gravity (OD)	2.26
2.	Bulk Specific Gravity (SSD)	2.40
3.	Apparent Specific Gravity	2.53
4.	Unit Weight (OD) (kg/m^3)	1573
5.	Unit Weight (SSD) (kg/m^3)	1666
6.	Absorption Capacity (%)	5.86
7.	Void Content (%)	26.28

(a) (b)

Fig 3.8: Physical properties of fine aggregates(a) Specific gravity (b) sand in SSD condition

3.3.4 Cement

Cement was collected from the local market in Dhaka city and its initial setting time and final setting time were determined according to the ASTM standard C191.The normal consistency was measured as per ASTM standard C187. The unit weight of the cement was 3000 kg/m^{3}and it was an approximation. The cement was Portland composite cement (PCC) which contains 70-79% clinker, 21-25% fly ash, slag, limestone and 0-5% gypsum. Before using the cement in the concrete mixing, it was tested to determine its properties. A number of tests of cement that have been conducted in the laboratory are presented in table 3.4.

Table 3.4: Properties of cement

Sl. No.	Properties of Cement	Value
1.	Initial Setting Time (min)	110
2.	Final Setting Time(min)	290
3.	Normal Consistency (%)	28.25
4.	Compressive strength-28 day (MPa)	31

3.3.5 G.I. fiber

GI Fiber was collected from the local market in Dhaka city. Hooked end steel fiber is used in this present study to assess the effect of fiber on both the strength and ductility of concrete.

3.3.5.1 G.I. fiber properties

G.I. fiber having different sizes of diameter is generally found in Bangladesh. However, in this study length and diameter of the fiber was 50 mm and 0.9 mm respectively with an aspect ratio (l/d) was 55.56. Figure 3.9 shows the tensile strength test procedure and Table 3.5 shows the properties of fibers that have been tested in the laboratory.

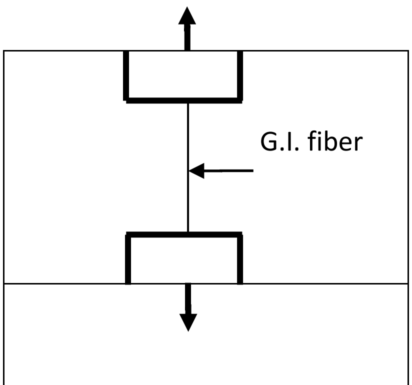


Fig 3.9: Tensile strength testing of fiber

Table 3.5: Properties of G.I. fiber

Sl. No.	Name of Properties	Value
1.	Length L(mm)	50
2.	Diameter D(mm)	0.9
3.	Aspect Ratio (L/D)	55.56
4.	Specific Gravity	6.0
5.	Unit Weight (kg/m^3)	6000
6.	Tensile Strength (MPa)	220

3.3.5.2 Preparation of G.I. fiber samples

In general, it is simple and easier to make different shapes of G.I. fiber but it takes more time to prepare as there is no mechanical setup. After collecting the G.I. fiber from local market, a heavy cutter was used to cut the whole bundle of wires manually. Fiber wire straightening was accomplished after cutting the bundle wires. The fiber was then cut into small pieces as the required length and it was pressed between two spikes sited on a wooden frame to make two bends at angle of 120^0. Finally, the length was checked to obtain the desired sample size of 50 mm. The whole working procedure is shown in figure 3.11. The diameter and aspect ratio (l/d) of the fiber was obtained 0.90 mm and 55.56 respectively. A number of researches have shown that the diameter and length of fibers can be varied (Jodilson, 2014., Parviz Soroushian., Ziad Bayasi, 1991). Hooked ends were bended at 120 degree to provide a good anchorage and interlock among the fibers. Figure 3.10 shows the size and geometry of the fiber used in the present study.

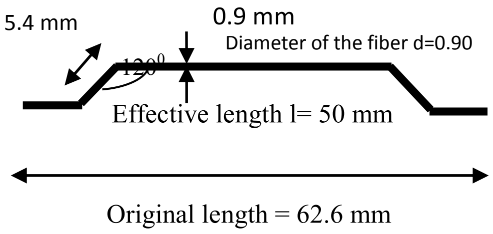


Fig 3.10: Size & geometry of fiber

Fig 3.11: G.I. fiber making procedure

(a) Rolled G.I. fiber (b) Making noodles (c) Cutting (d) Bending (e) Fiber matrices (f) Size (g) Fresh fiber

3.4 Types of concrete used in the present study

In this study, two types of coarse aggregate are considered: brick aggregate (B) and recycled brick aggregate (RB).To understand the effect of G.I. fiber on both the B and RB aggregates, concrete with three different fiber additions are being considered as 0% (control case), 0.5% and 1%. Therefore, a total number of cases are 6. A total of 5 types of tests were being conducted. Crushing strength of concrete (f′c), concrete compressive strength using Rebound Hammer (RH), Tensile strength (f_t), Young's Modulus (YM) and the stress-strain (σ- ε) behavior of concrete. Table 3.6 shows the test plan of this present study.

Table 3.6: Types of concrete considered

Sl No.	Case	Full name of the cases	Conducted Tests				
			f'_c	RH	f_t	Y.M	σ- ε
1.	B GI fb 0% (Control case)	Brick aggregate G.I. fiber reinforced concrete made with 0% fiber	f'_c	RH	f_t	Y.M	σ- ε
2.	B GI fb 0.5%	Brick aggregate G.I. fiber reinforced concrete made with 0.5% fiber	f'_c	RH	f_t	Y.M	σ- ε
3.	B GI fb 1%	Brick aggregate G.I. fiber reinforced concrete made with 1% fiber	f'_c	RH	f_t	Y.M	σ- ε
4.	RB GI fb 0% (Control case)	Recycled Brick aggregate G.I. fiber reinforced concrete made with 0% fiber	f'_c	RH	f_t	Y.M	σ- ε
5.	RB GI fb 0. 5%	Recycled Brick aggregate G.I. fiber reinforced concrete made with 0.5% fiber	f'_c	RH	f_t	Y.M	σ- ε
6.	RB GI fb 1%	Recycled Brick aggregate G.I. fiber reinforced concrete made with 1% fiber	f'_c	RH	f_t	Y.M	σ- ε

3.5 Mixture proportion

The unit contents of ingredients of concrete, such as water, cement, coarse aggregate and fine aggregate can be determined by solving equation (3.1)

$$\frac{A}{G_A\gamma_w}+\frac{S}{G_S\gamma_w}+\frac{C}{G_w\gamma_w}+\frac{Air(\%)}{100}=\mathbf{1}\text{..................................... (3.1)}$$

To solving the above equation, the following relationships are used:

(1) Sand to total aggregate volume ratio

$$\frac{\frac{S}{G_S\gamma_S}}{\frac{A}{G_A\gamma_A}+\frac{S}{G_S\gamma_S}}=\mathbf{0.44}\text{.. (3.2)}$$

Here, sand to total aggregate volume ratio is assumed to be o.44for both B and RB aggregates.

(2) Water to cement ratio

W/C = **0.44** for both the cases (B and RB)................................ (3.3)

(3) Unit content of cement

C = **390** kg/m^3 .... (3.4)

In general, the air percent of the mix design was assumed as 2%.Mix design for the B and RB aggregates concrete of different cases in weight basis are shown in the table 3.7.G.I. fibers will be mixed depending on its unit weight. In this study, 1% fibers by volume produced unit weight of 60 kg/m^3.

Table 3.7: Weight based mix proportion for 1 m^{3}G.I. fiber reinforced concrete

Sl. No.	Cases	Cement (kg/m^3)	Sand (kg/m^3)	B (kg/m^3)	RB (kg/m^3)	Water (kg/m^3)	G.I. fiber (kg/m^3)
1	B GI fb 0%	390	716.4	798	-	171.6	0
2	B GI fb 0.5%	390	716.4	798	-	171.6	30
3	B GI fb 1%	390	716.4	798	-	171.6	60
4	RB GI fb 0%	390	716.4	-	768	171.6	0
5	RB GI fb 0. 5%	390	716.4	-	768	171.6	30
6	RB GI fb 1%	390	716.4	-	768	171.6	60

3.6 Sample preparation

In this study, concrete cylinder with a dimension of 4″ x 8″ is made as specimen. A total of 6 sets of concrete cylinders are casted. Figure 3.12 shows the typical dimension of the concrete specimen.

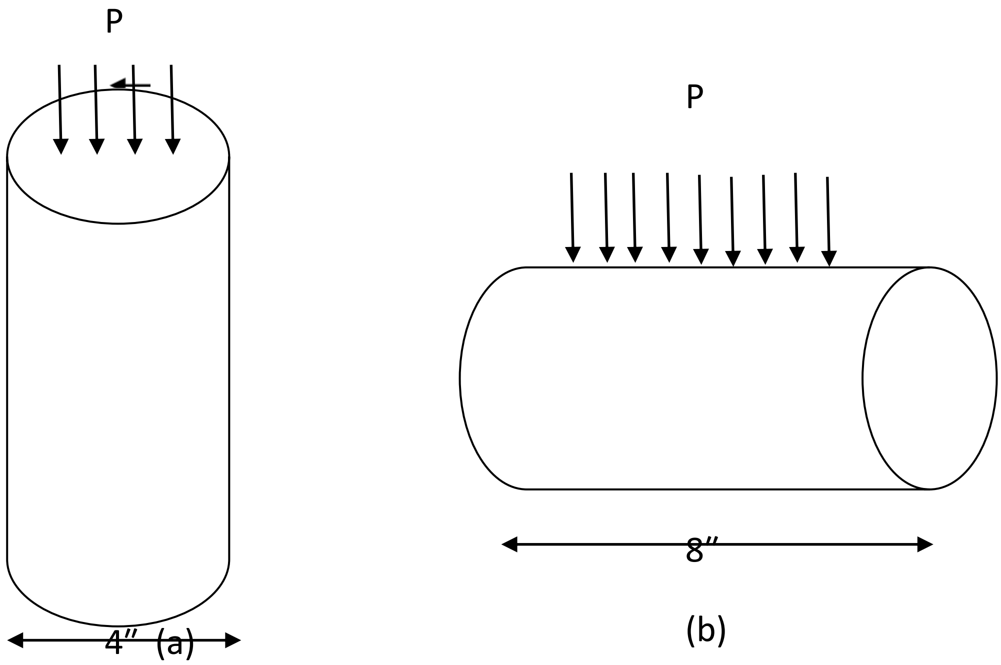


Fig 3.12: Typical dimension of cylinder specimen (a) compressive strength test and (b) tensile strength test

3.6.1 Mold preparation

The cylindrical molds are prepared properly before putting the fresh concrete into these specimens. Molds are being lubricated inside before casting of concrete specimens. Figure 3.13 shows the mold preparation before casting of concrete.

(a) (b)

Fig 3.13:Mold preparation for casting(a) Tightening (b)Lubricating

3.6.2 Concrete mixing and casting of specimens

Automated mixture machine is used for mixing concrete. Speed of the machine is 30-35 revolutions per minute Trial mix is prepared for every case mentioned earlier before the final mix. To ensure the quality strength in the matrix, the following format is followed sequentially for mixing concrete:

(i) Addition of the coarse aggregate;

(ii) addition of 70% of the water;

(iii) addition of cement;

(iv) addition of the remaining portion of water

(v) addition of the fine aggregate.

A mixing time of 8-10 min was used to guarantee the homogeneity of the concrete (Nataraja et al, 1999).When fibers are used, they are dispersed manually during this period of mixing ingredients of concrete. Figure 4.14shows the mixing procedure.

3.6.2.1 Measurement of workability

To measure the workability of freshly mixed concrete, two methods are commonly used (i) Indirect method- Slump test (ii) Laboratory test -Vebe test. In this study, slump test was conducted to measure the workability. Slump cone was filled by 3 layers with 25 times temping on each layer. Diameter of the temping rod was 5/8 inch. Figure 14 (b) shows the workability measurement.

(a)

(b) (c)

Fig 3.14: Concrete casting(a) Concrete Mixing (b) Slump test (c) Fresh concrete with G.I. fiber after mixing

3.6.2.2 Compaction of the concrete

Concrete specimens have been properly compacted following the specification of ASTM C 1435-99. Each and every cylindrical specimen is compacted by the vibrator as shown in figure3.15. After compaction of these specimens, scaling and hammering have been made to get a void free surface of the specimens.

3.6.2.3 Curing of the specimens

Curing of the specimens is completely ensured after the casting. Normal tape water is used for the curing. In this study, under water curing method is applied to ensure adequate moisture and temperature as requirements of specification by ASTM C192/C192M-02. Figure 3.16 shows the underwater curing of the concrete specimens.

Fig 3.15: Compaction using vibrator machine

Fig 3.16: Under water curing of specimens

3.7 Testing of hardened concrete

Four types of tests are conducted for evaluating hardened concrete properties. A non-destructive test by using Rebound Hammer is used to determine the concrete compressive strength. Details of non destructive test have been discussed and presented in separate chapter 5 of this thesis. Crushing strength of concrete, tensile strength and stress-strain behavior of concrete are the other tests which have been carried out in this study.

3.7.1 Concrete compressive strength test by destructive method

Compressive strength of concrete are measured at 7, 14 and 28 days by using Universal Testing Machine (UTM) shown in figure 3.17.Loading rate is 4 kN/sec by the UTM over the specimens. Failure surfaces of concrete are checked carefully after crushing of the concrete cylinders. Compressive strength of the cylinder is determined as per ASTM C39M-03. Figure 3.18 shows the compressive strength test of the specimen. The test is conducted in a 1000 kN compression testing machine with a rate of loading controller. The cylinder is capped with a hard plastic on the cast face to ensure parallel loading surfaces of the test specimens and constant height for all cylinders.

3.7.2 Tensile Strength test

In this study, indirect tensile strength test is carried out to determine the tensile strength of both plain and G.I. fiber reinforced concrete. Testing is done at 7, 14 and 28 days by using Universal Testing Machine (UTM).Loading rate was 4 kN/sec by the UTM over the specimens. Failure surfaces of concrete have been also observed after crushing of the specimens. Tensile strength of concrete is determined as per ASTM C496M-04. Figure 3.19 shows the tensile strength test of the specimen. The equation used to calculate the tensile strength is given below.

$$\text{Stress} = \mathbf{2P/\pi DL} \qquad \text{(3.5)}$$

Where, P= applied force, D= diameter of the specimen, L= length of the specimen

3.7.3 Stress–strain measurement of concrete

The relationship between stress and strain of concrete specimen under uniaxial loading has been proposed by Desayi and Krishnan (1964), Domingo and Chu (1985) for stone aggregate concrete based on the experimental data. This relationship depends on the water to cement relationship, cement content, characteristics of coarse aggregate and many other properties of concrete. In this study, stress–strain of concrete is measured for 7, 14 and 28 days for all cases. A strain gauge is used to measure the strain of specimen under a uniform loading rate. The gauge length is 3 inch and it is placed very carefully. Figure 3.20 shows the stress-strain measurement of the specimen. The test is conducted in a 1000kN compression testing machine with a rate of loading controller. The cylinder specimen is capped with a hard plastic on the cast face to ensure parallel loading faces of the test specimens and constant height for all cylinders. A compressometer equipped with a dial-

Fig 3.17: Universal testing machine

Fig 3.18: Compressive strength test

Fig 3.19: Tensile strength test

Fig 3.20: Measurement of Stress-strain

gauges available in the laboratory is used to record the deformation over the middle half of the cylinder as shown in Figure 3.21. In the present study, many trial tests have been conducted initially to have control on operation of the machine. The load is applied at a very slow rate and an initial load of about 50kNis applied and released. The testing head is lowered slowly to bring it in contact with the specimen. At this stage, the dial gauges are set to zero. Load is increased slowly by adjusting the lever and controlling the oil flow simultaneously. Deformations have been measured approximately at an every 50 kN load increment (Nataraja et al., 1999). The testing is performed with the help of technical assistants to control the whole process. No difficulty in recording the load and deformation readings are observed. Load indicating needle of the machine gauge is moving slowly during the loading stage (ascending).However, the movement is rather faster in the unloading (descending) stage. Efforts have been made to take as many readings as possible, to get a considerable length of post-peak portion of the stress-strain curve of concrete. In the descending portion, readings have been taken at random intervals. Strains and corresponding stresses are calculated and the average readings are reported in the present study.

Fig 3.21: Strain measuring gauge

3.7.4 Determination of Young's modulus of concrete

Young's modulus of concrete is evaluated for 7, 14 and 28 days for all cases at the strain level of 0.0005 based on plain concrete (Nilson et al., 2003).In general, at low stresses, up to about $f'_c/2$, the concrete is seen to behave nearly elastically, i.e., stresses and strains are quite closely proportional; the straight line *d* represents this range of behavior with little error for both rates of loading. For the given concrete, the range extends to a strain of about 0.0005.Figure 3.21 shows the typical stress-strain diagram of concrete.

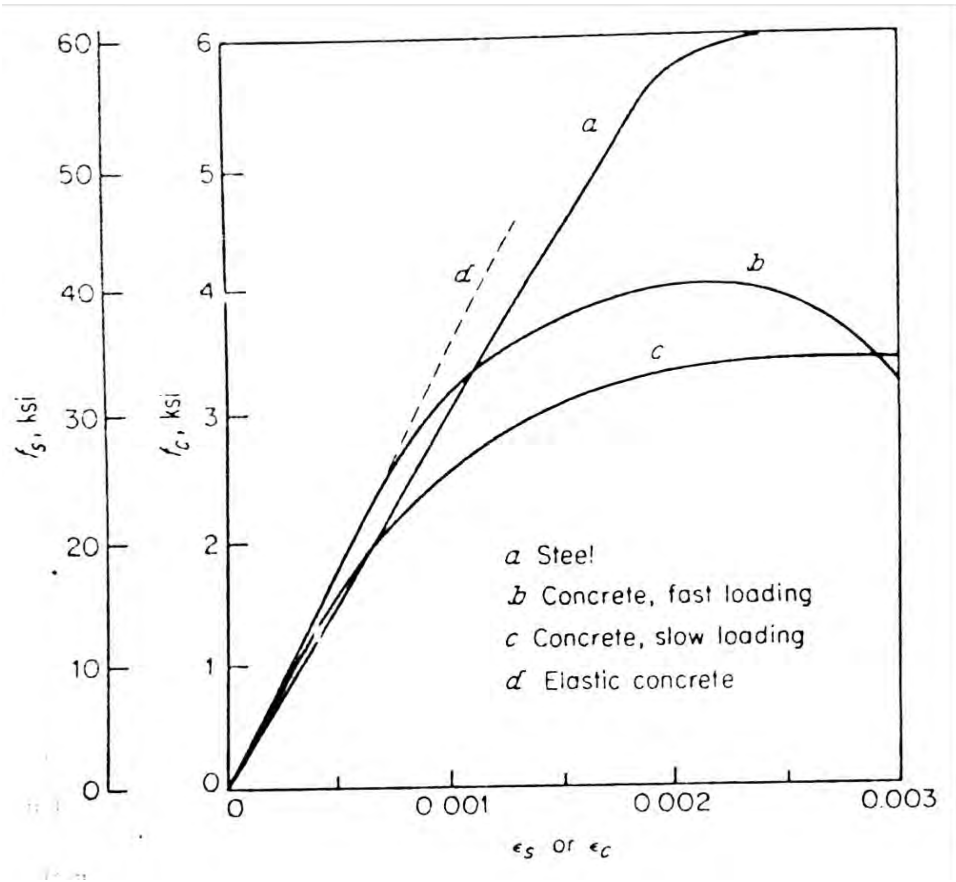


Fig 3.22: Stress-strain diagram of concrete (Nilson et al., 2003)

Chapter 4
EXPERIMENTAL RESULTS AND DISCUSSIONS

4.1 General

Different properties of brick aggregate, recycled brick aggregate, fine aggregate and cement are presented in previous chapter. In addition, properties of G.I. fiber and the preparation process of fiber is also presented. Two different cases such as concrete with brick aggregate and recycled brick aggregates are studied in this thesis. A total of six types of concrete with different G.I. fiber additions as well as two types of aggregates have been addressed. Different properties of fresh concrete as well as hardened concrete are evaluated. This chapter discusses the results of experimental investigation of different cases and types of concrete.

4.2 Results of fresh concrete properties

A number of tests are available to evaluate fresh concrete properties such as initial & final setting time, heat of hydration, workability etc. Fresh concrete properties are determined before casting the cylinder specimens. In the present study, workability as a property of fresh concrete is determined. Slump cone having a dimension of 12 inch in height, 4 inch diameter in top and 8 inch diameter in bottom, is filled with 3 layers and on each layers 25 times temping with a 5/8″ diameter rod having a weight of 930 gm, are accomplished. Therefore, a total temping of 75 times for three layers are carried out, following ASTM C143.

4.2.1 Workability measurement

In this study, workability of fresh concrete is evaluated. From the experimental results, it can be said that workability of concrete decreases with the increase of percentage of fiber replacement. It is also observed that workability is reduced when recycled brick (RB) is used as coarse aggregates in comparison to that of brick aggregates (B). Figures 4.1 and 4.2 shows the effect of G.I. fiber additions and aggregate types on the workability of concrete, respectively.

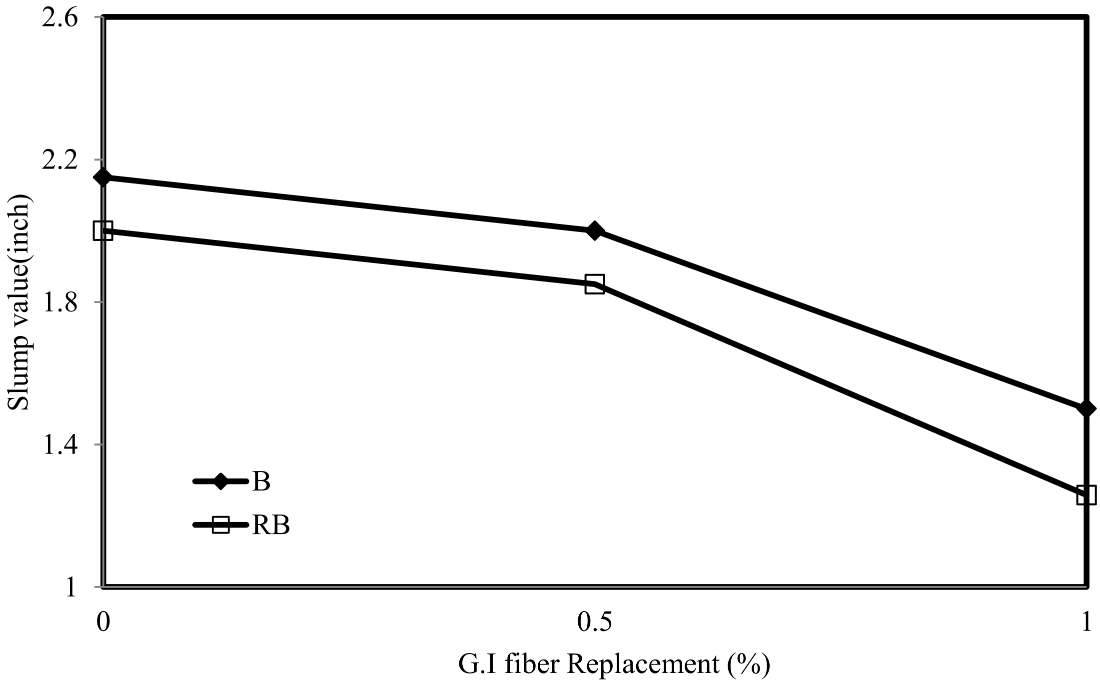


Fig 4.1: Effect of G.I. fiber Replacement on workability of concrete

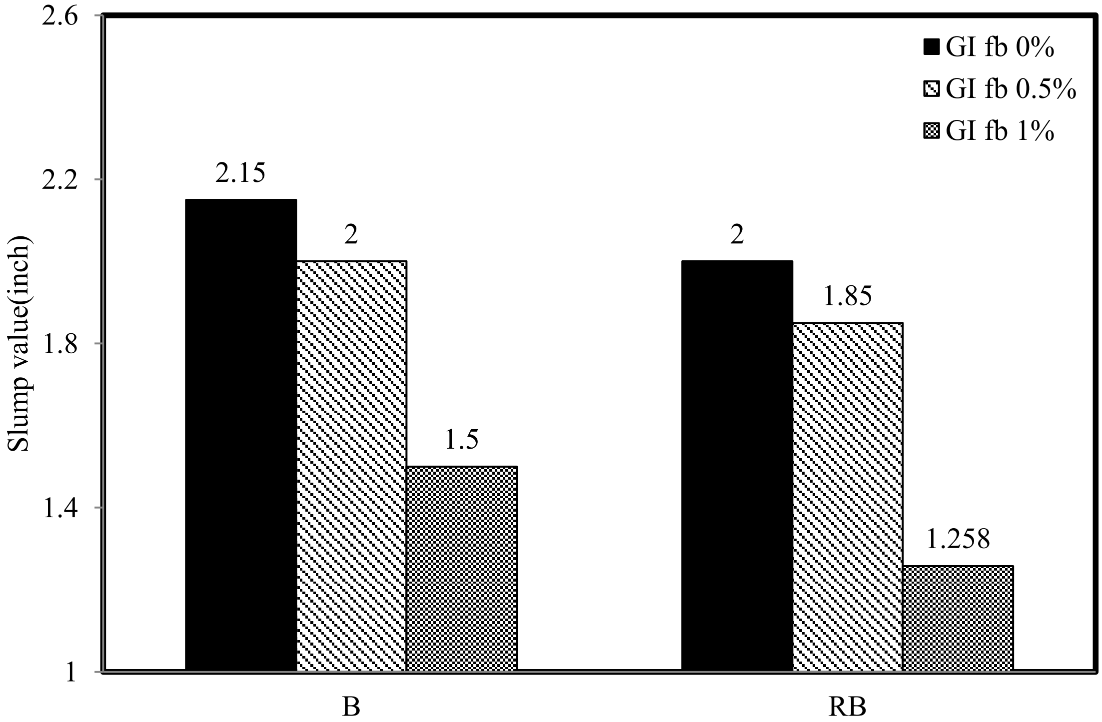


Fig 4.2: Effect of aggregate type on workability of concrete

4.3 Results of hardened concrete properties

Mechanical properties such as compressive strength by destructive and non-destructive tests, tensile strength, stress-strain behavior, and Young's modulus of hardened concrete have been studied in this research. Results of experimental studies are presented below.

4.3.1 Effect of G.I. fiber additions on concrete made with fresh brick (B) aggregates

G.I. fiber plays a vital role on the mechanical properties of hardened concrete. In this study, two different G.I. fiber additions are considered with 0.5% and 1.0%, respectively. Details of G.I. fiber replacement are given in article 3.3 of Chapter 3. Crushed bricks are commonly used as coarse aggregates in Bangladesh and locally available. Mechanical properties such as compressive strength, tensile strength, Young's modulus, stress-strain behavior are investigated at two different G.I. fiber additions in the concrete mix.

4.3.1.1 Concrete compressive strength

Effect of G.I. fiber addition on compressive strength of brick aggregate concrete is tested at 7 days, 14 days, and 28 days as shown in Figure 4.3, Figure 4.4, and Figure 4.5, respectively. No significant improvement is observed in compressive strength with the increase of G.I. fiber percentage for all tested ages. A value of 5% increase in 28 days compressive strength is observed for 0.5% G.I. fiber compared to control case (0% G.I. fiber replacement). For 1% G.I. fiber addition, 8% increase in compressive strength is obtained.

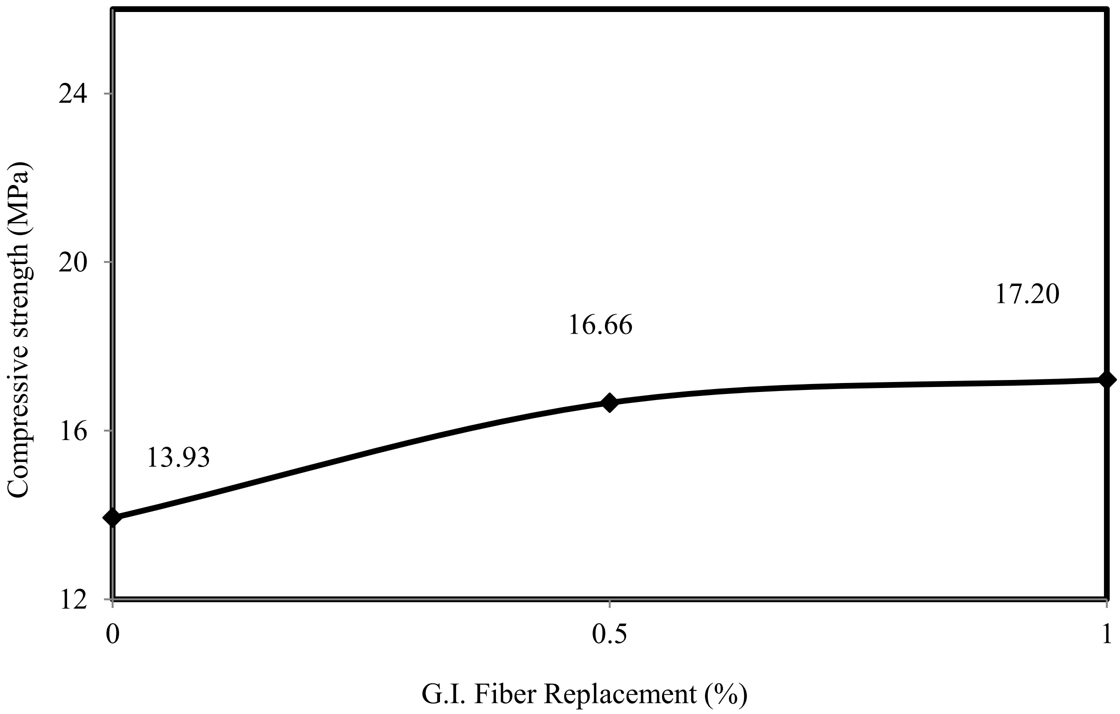


Fig 4.3: Concrete compressive strength with brick aggregates at 7 day

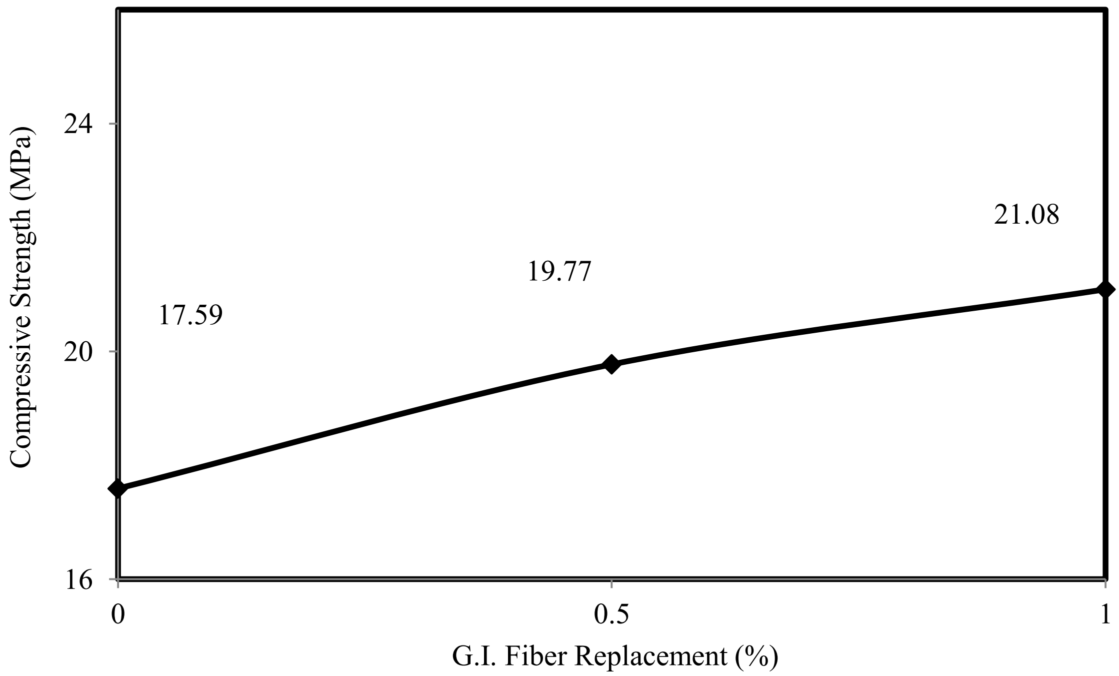


Fig 4.4: Concrete compressive strength with brick aggregates at 14 day

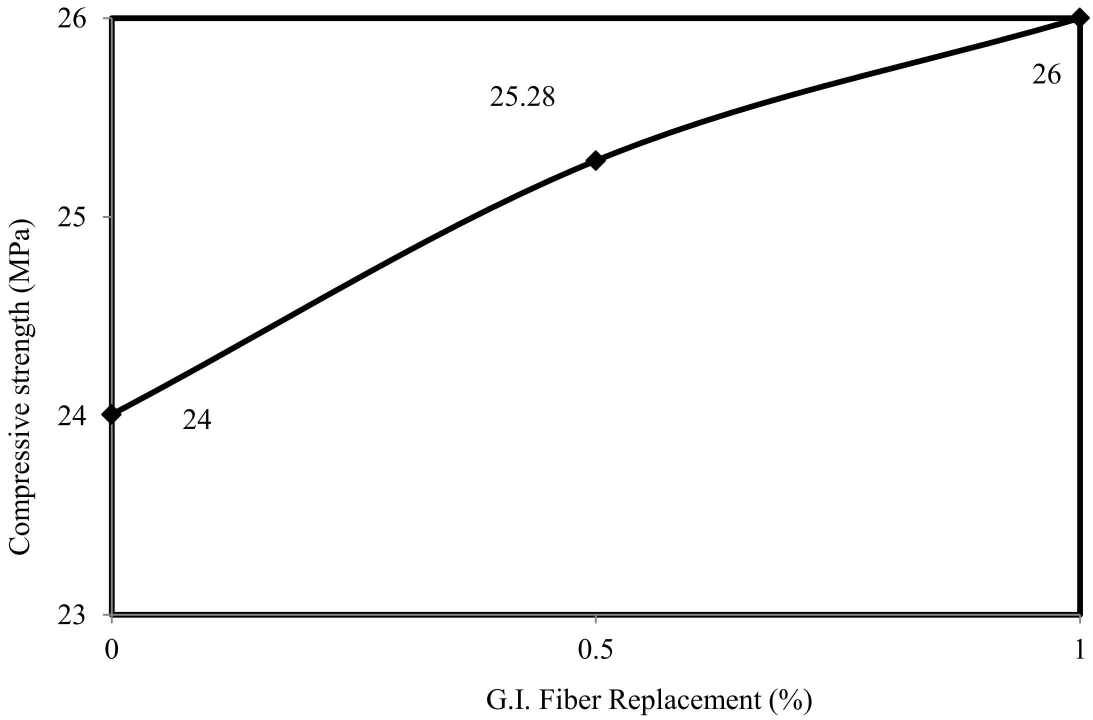


Fig 4.5: Concrete compressive strength with brick aggregates at 28 day

4.3.1.2 Tensile strength

Effect of G.I. fiber additions on tensile strength of concrete with brick aggregate is obtained for 7 days, 14 days, and 28 days and is shown in Figures 4.6, 4.7, and 4.8, respectively. Tensile strength of brick aggregate concrete is significantly improved for concrete with G.I. fiber addition. A value of 29% increase in 7 days tensile strength is observed for 0.5% G.I. fiber addition compared to control case (0% G.I. fiber replacement). For 1% G.I. fiber addition, 43% increase in tensile strength is observed. However, for 28 days test, this improvement is shown insignificant.

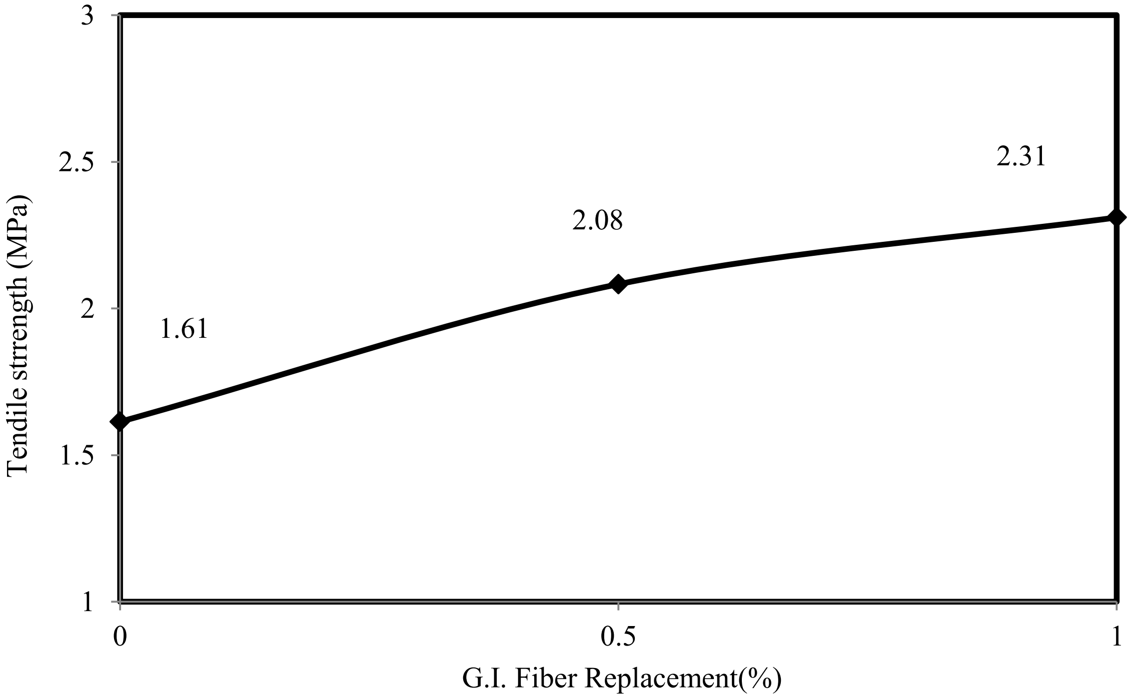


Fig 4.6: Tensile strength concrete with brick aggregates at 7days

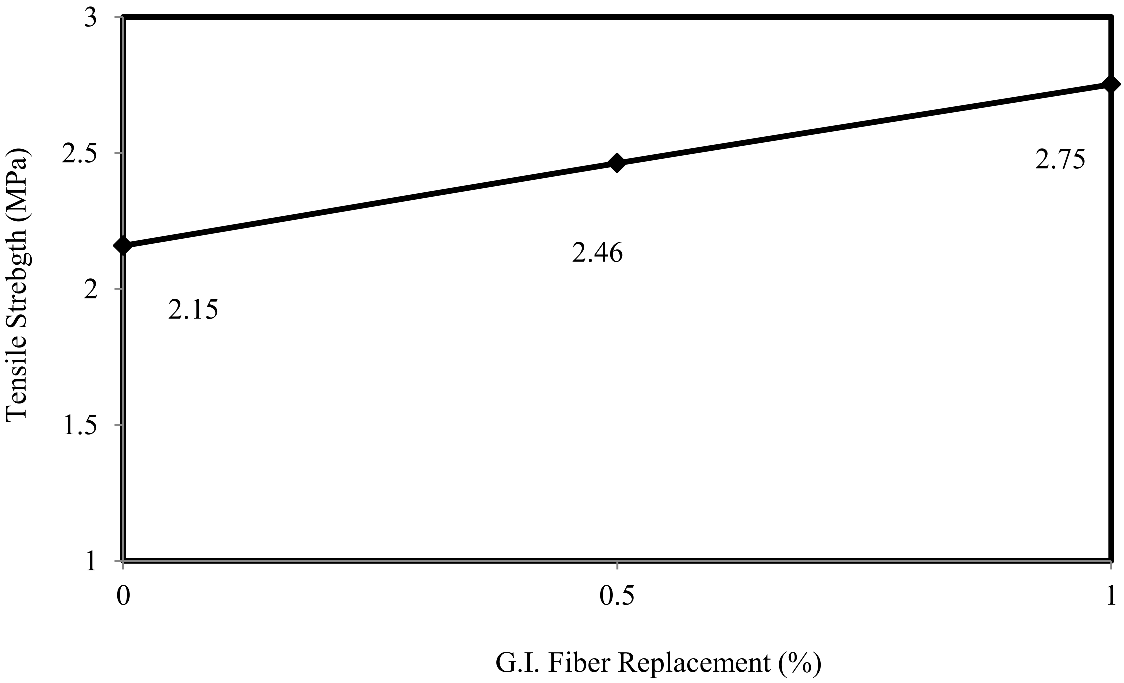


Fig 4.7: Tensile strength concrete with brick aggregates at 14 days

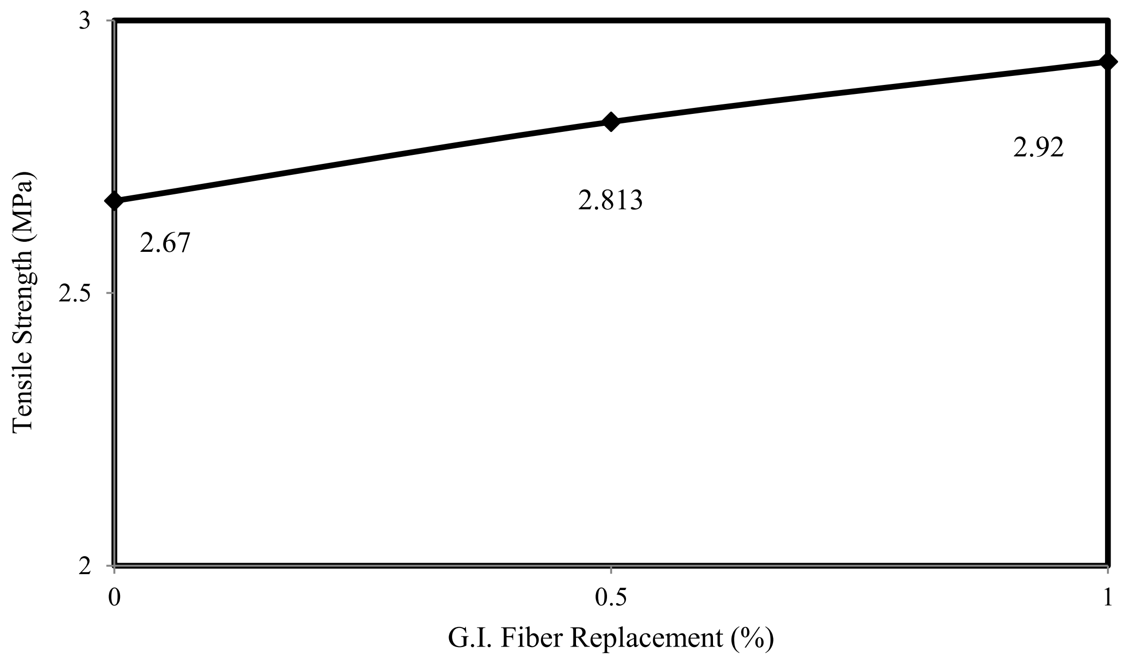


Fig 4.8: Tensile strength concrete with brick aggregates at 28 days

4.3.1.3 Modulus of elasticity of concrete

Effect of G.I. fiber additions on Modulus of elasticity of concrete with brick aggregate are observed for 7 days, 14 days, and 28 days as shown in Figures 4.9, 4.10, and 4.11, respectively. It is seen that modulus of elasticity of brick aggregate concrete is significantly improved for concrete with G.I. fiber additions. An amount of 23% increase in 7 days Young's modulus is observed for 1% G.I. fiber compared to control case (0% G.I. fiber replacement). For 1% G.I. fiber addition, 30% increase in Young's modulus is observed in 14 days. However, this improvement is not significant for concrete with 28 days.

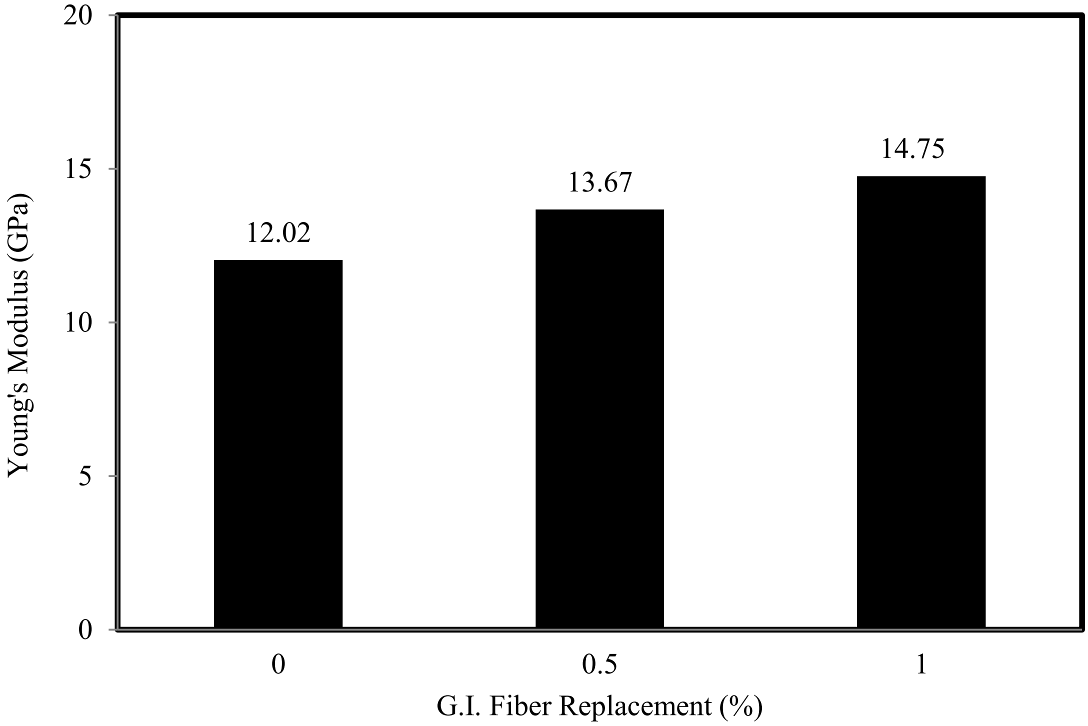


Fig 4.9: Young’s modulus of concrete with brick aggregates at 7days

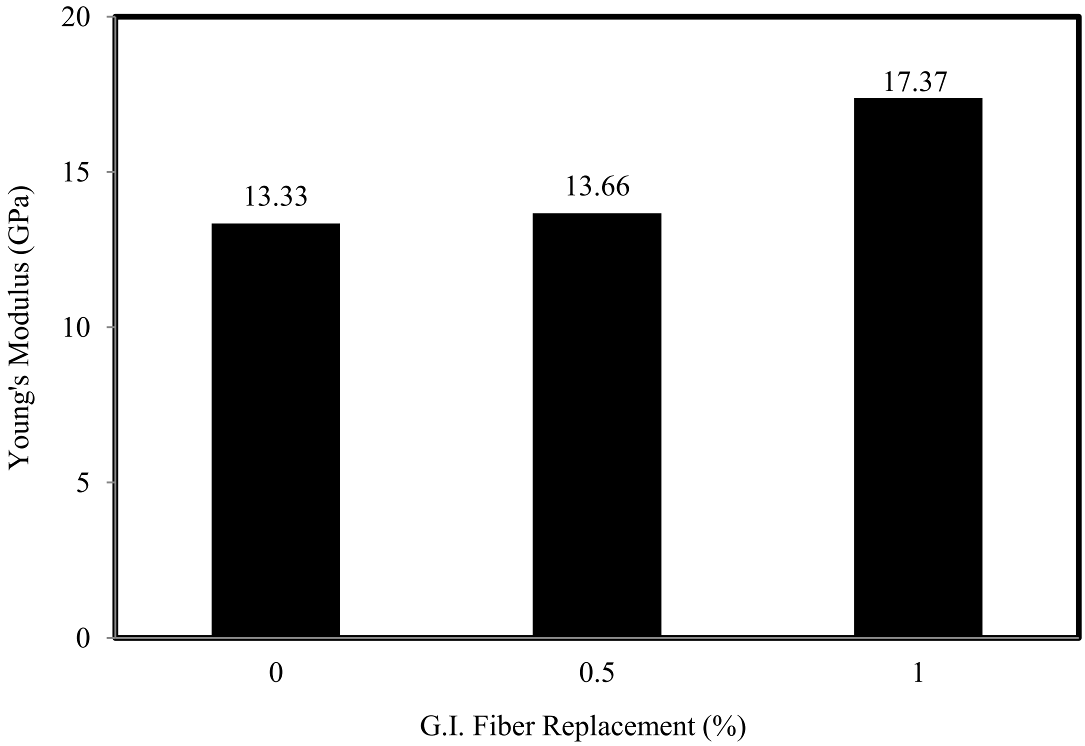


Fig 4.10: Young’s modulus of concrete with brick aggregates at 14 days

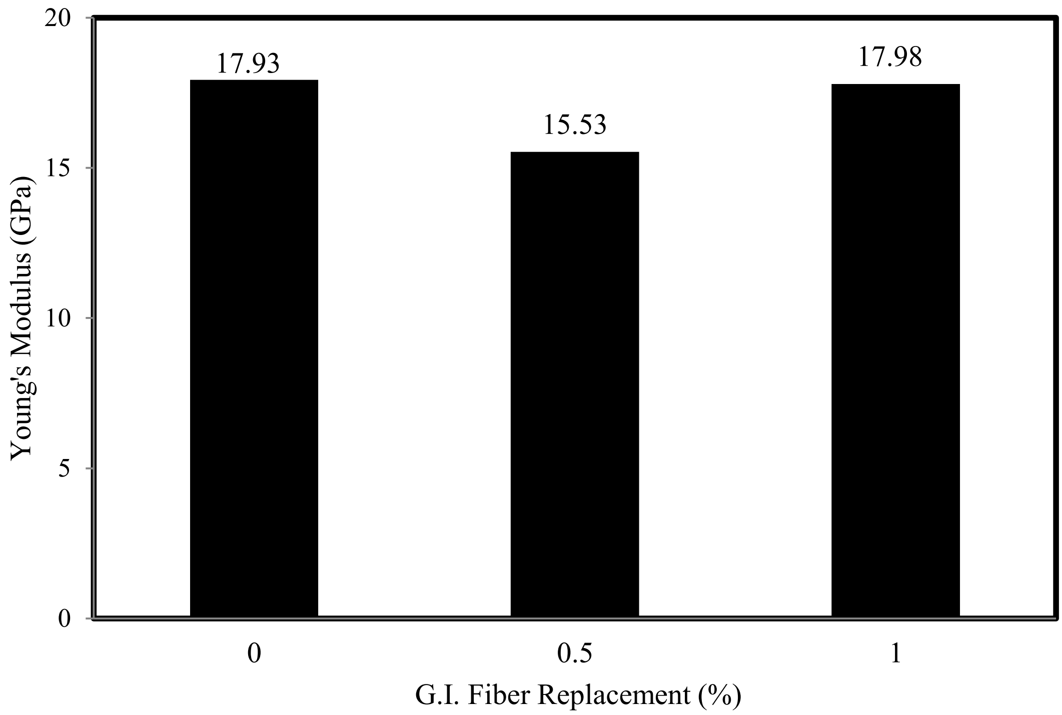


Fig 4.11: Young’s modulus of concrete with brick aggregates at 28 days

4.3.1.4 Stress-strain behavior of concrete

Effect of G.I. fiber additions on the behavior of stress-strain behavior of concrete made with brick aggregates are observed for 7 days, 14 days, and 28 days and presented in Figures 4.12, 4.13, and 4.14, respectively. It is shown that strain taken capacity of brick aggregate concrete is significantly enhanced for concrete made with G.I. fiber. Approximately 26% increase in 7 days strain capacity is observed for 0.5% G.I. fiber addition compared to control case with 0% G.I. fiber replacement. For concrete with 1% G.I. fiber, 58% increase in strain taken capacity is also obtained in 7 days. Similar trend is observed for concrete with an age of 14 days. However, a huge enhancement of 80% in strain taken capacity for 1% G.I. fiber addition in 28 days of concrete is observed.

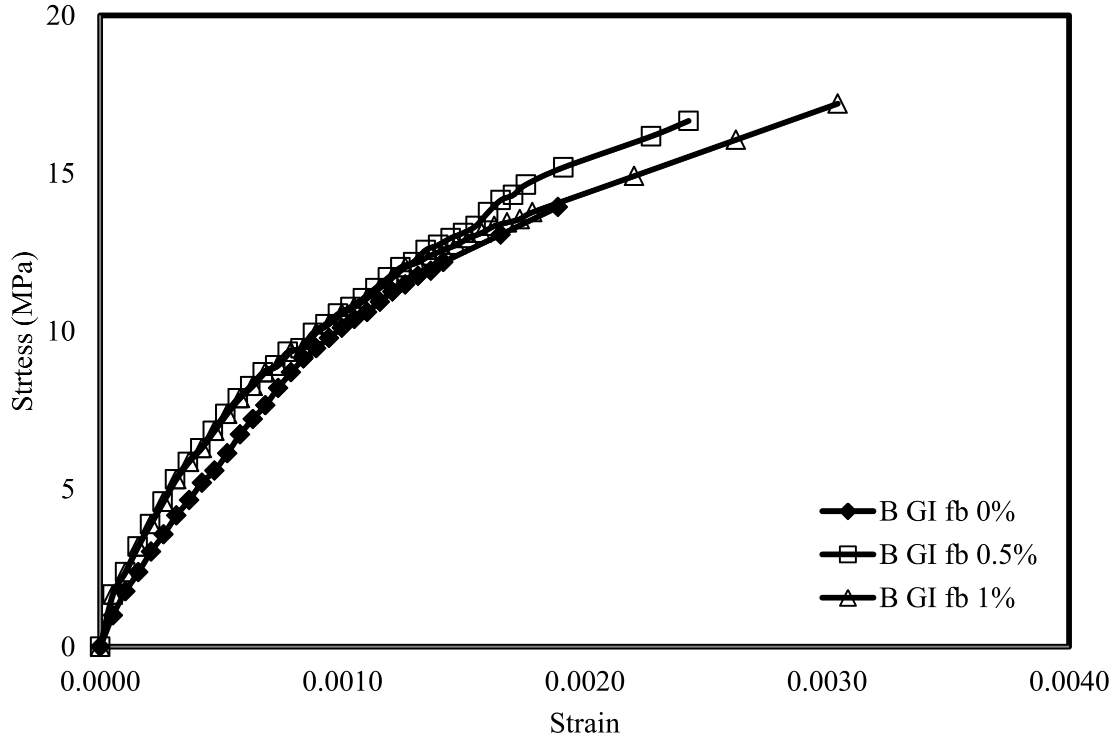


Fig 4.12: Stress-strain behavior of concrete with brick aggregates at 7days

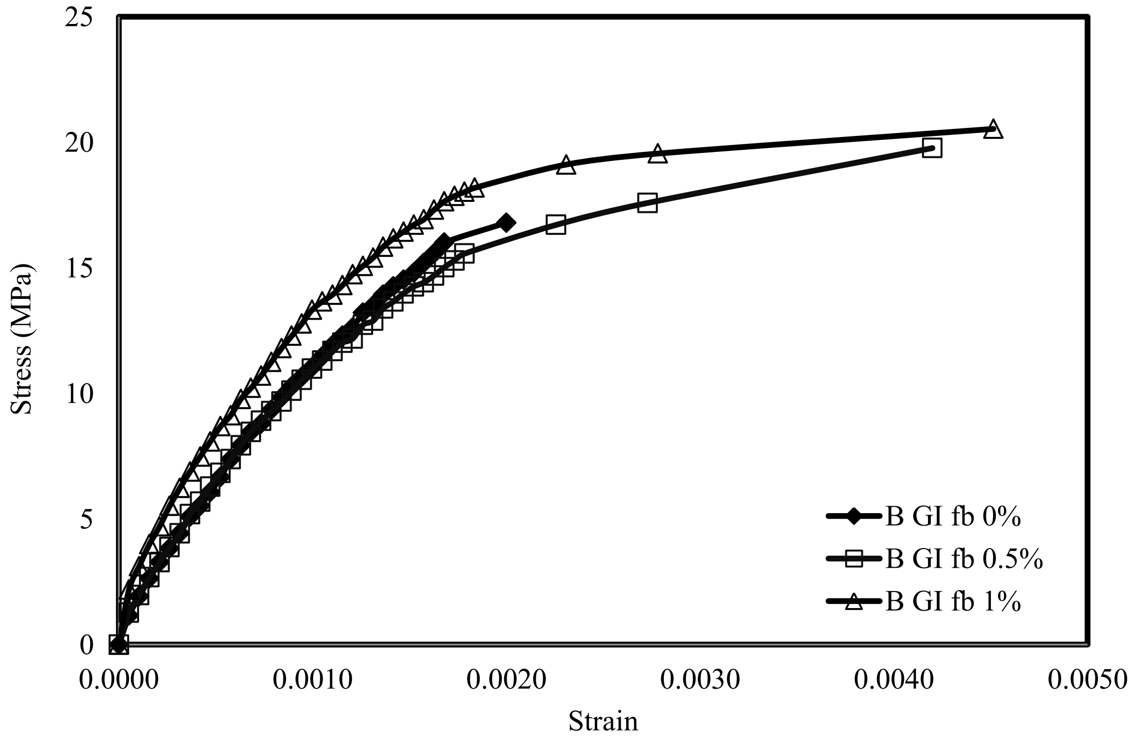


Fig 4.13: Stress-strain behavior of concrete with brick aggregates at 14 days

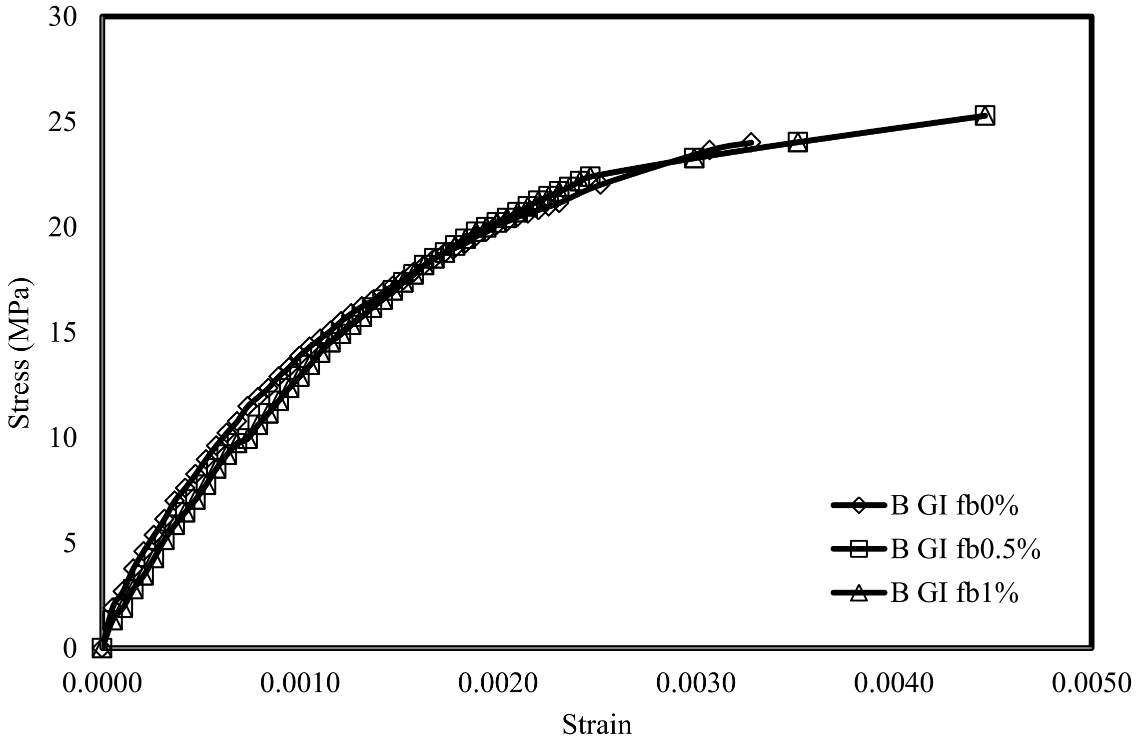


Fig 4.14: Stress-strain behavior of concrete with brick aggregates at 28 days

4.3.2 Effect of G.I. fiber additions on concrete made with recycled brick (RB) aggregates

Crushed demolished block may be used as coarse aggregates in concrete in Bangladesh context. Mechanical properties such as compressive strength, splitting tensile strength, Young's modulus, stress-strain behavior are investigated for concrete made with recycled brick aggregates having two different G.I. fiber additions. Results of experimental study are presented following subsections.

4.3.2.1 Compressive strength of concrete

Effect of G.I. fiber additions on compressive strength of recycled brick aggregate concrete is assessed at 7 days, 14 days, and 28 days and are shown in Figures 4.15, 4.16, and 4.17, respectively. No significant improvement on compressive strength of concrete is observed with the increase of G.I. fiber additions for all tested ages. An increase in 11% at 28 days concrete compressive strength is observed for 0.5% G.I. fiber addition compared to control case with 0% G.I. fiber replacement. For 1% G.I. fiber addition, 13% increase in compressive strength is obtained.

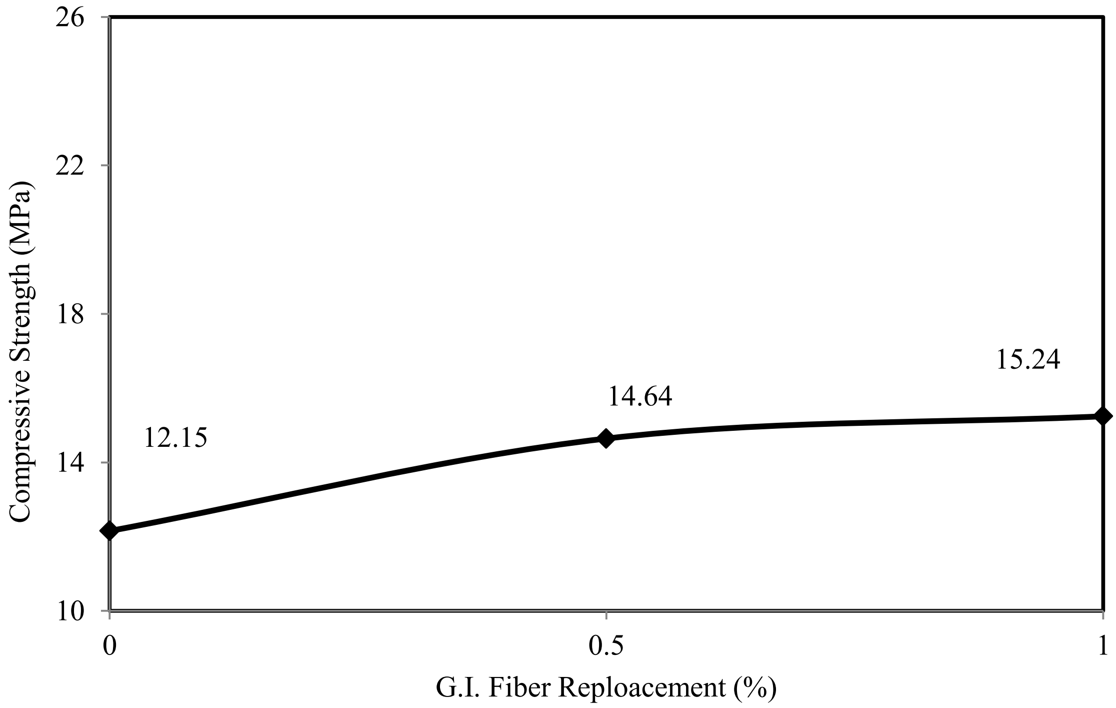


Fig 4.15: Compressive strength of concrete with recycled brick aggregates at 7 days

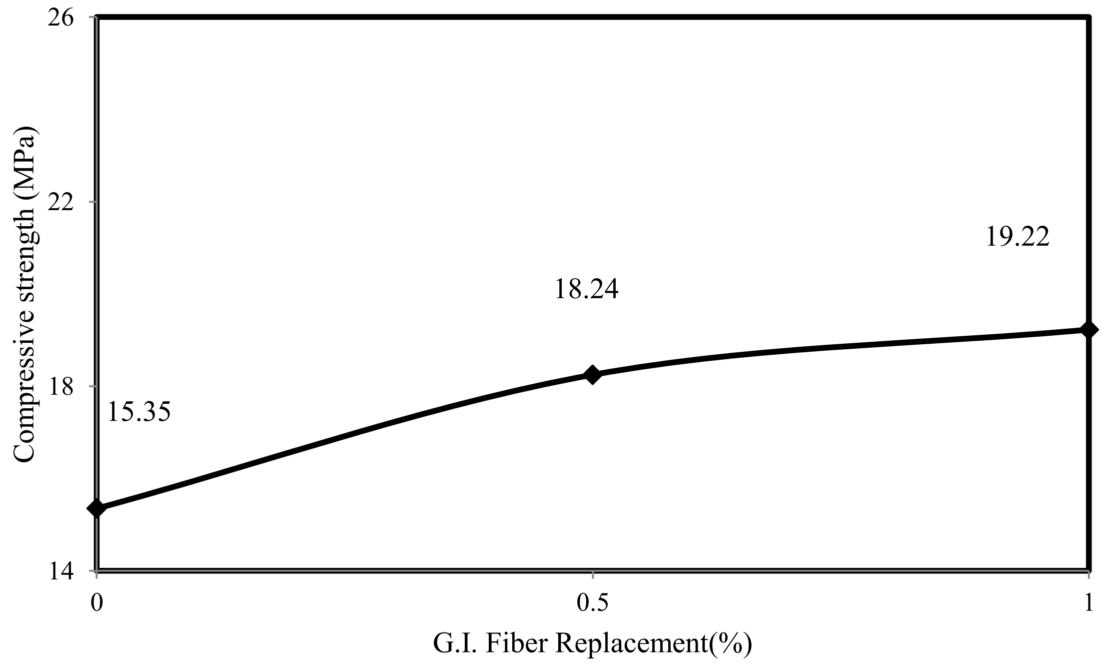


Fig 4.16: Compressive strength of concrete with recycled brick aggregates at 14 days

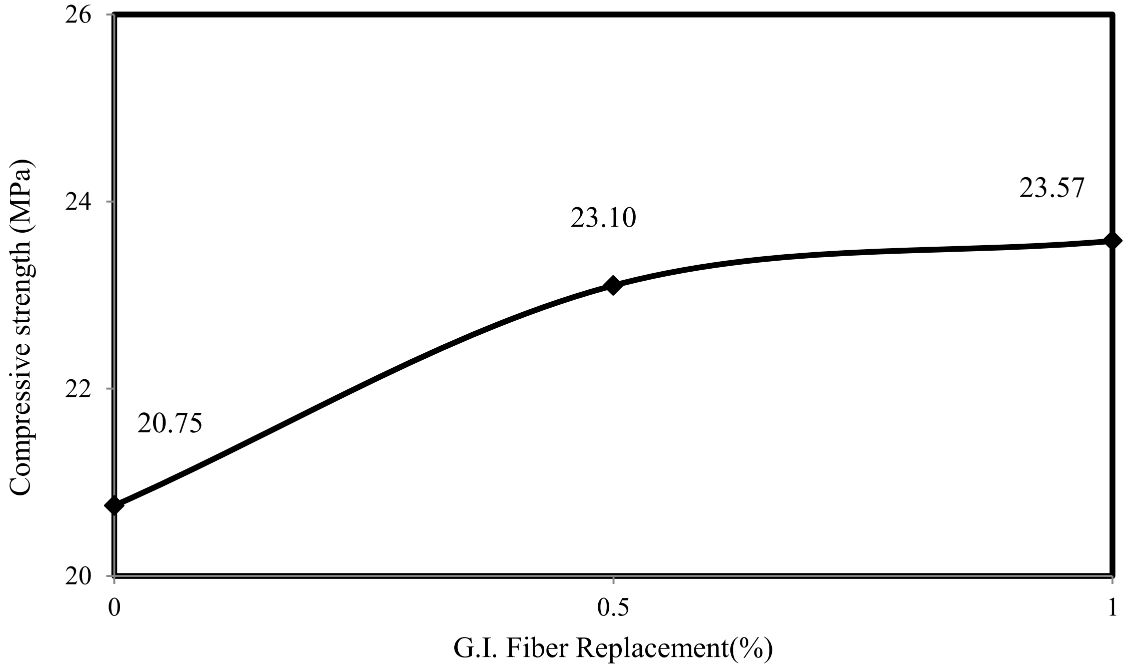


Fig 4.17: Compressive strength of concrete with recycled brick aggregates at 28 days

4.3.2.2 Tensile strength of concrete

Effect of G.I. fiber additions on tensile strength of recycled brick aggregate concrete is evaluated at 7 days, 14 days, and 28 days and is presented in Figures 4.18, 4.19, and 4.20, respectively. Tensile strength of recycled brick aggregate concrete is significantly improved for concrete with G.I. fiber addition. A37% increase in 7 days tensile strength is observed for 0.5% G.I. fiber addition compared to control case with 0% G.I. fiber replacement. For 1% G.I. fiber addition, 63% increase in tensile strength is observed. Similar trend is not observed for both the cases in 14 days. However, concrete at 28 days, this improvement in tensile strength is also insignificant.

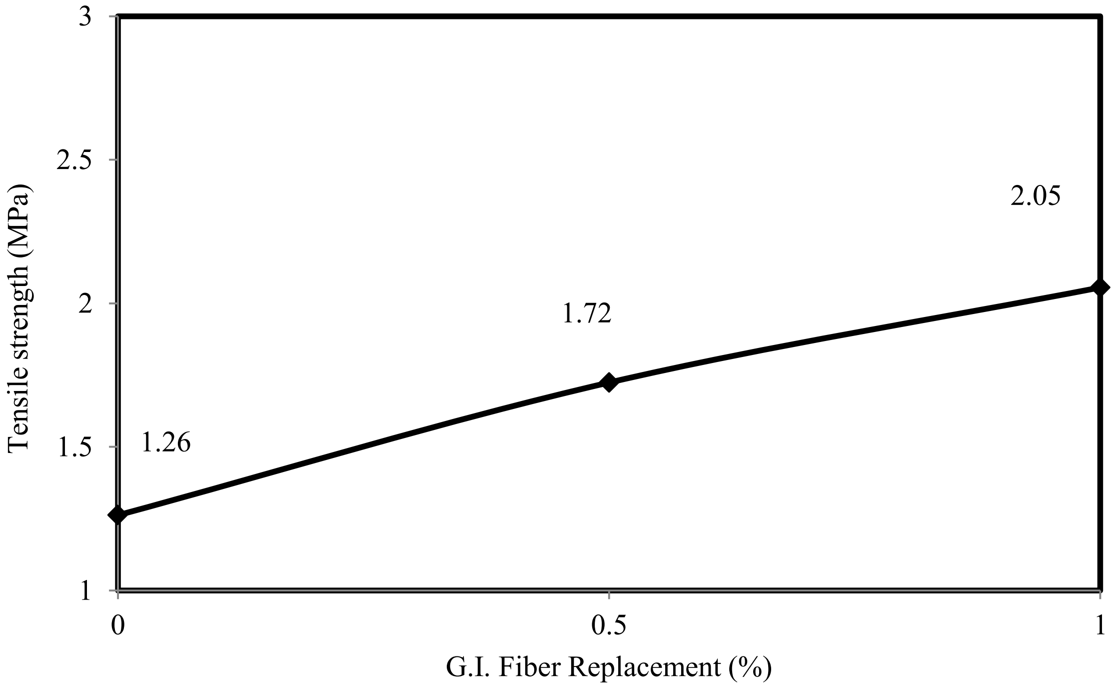


Fig 4.18: Tensile strength of concrete with recycled brick aggregates at7 days

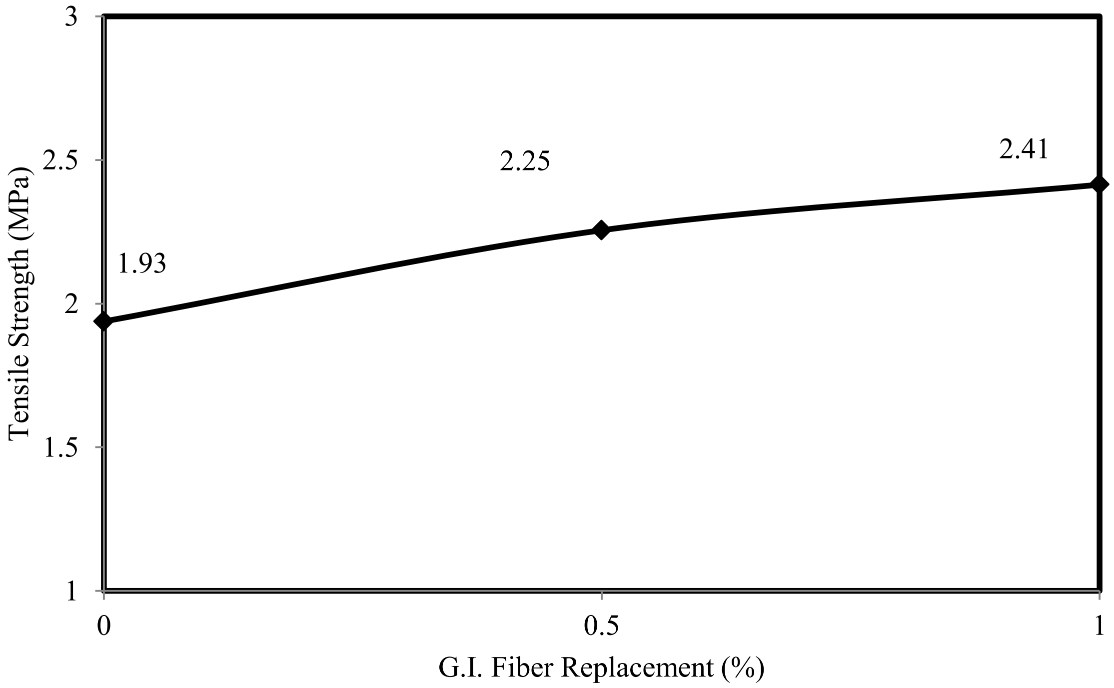


Fig 4.19: Tensile strength of concrete with recycled brick aggregates at 14 days

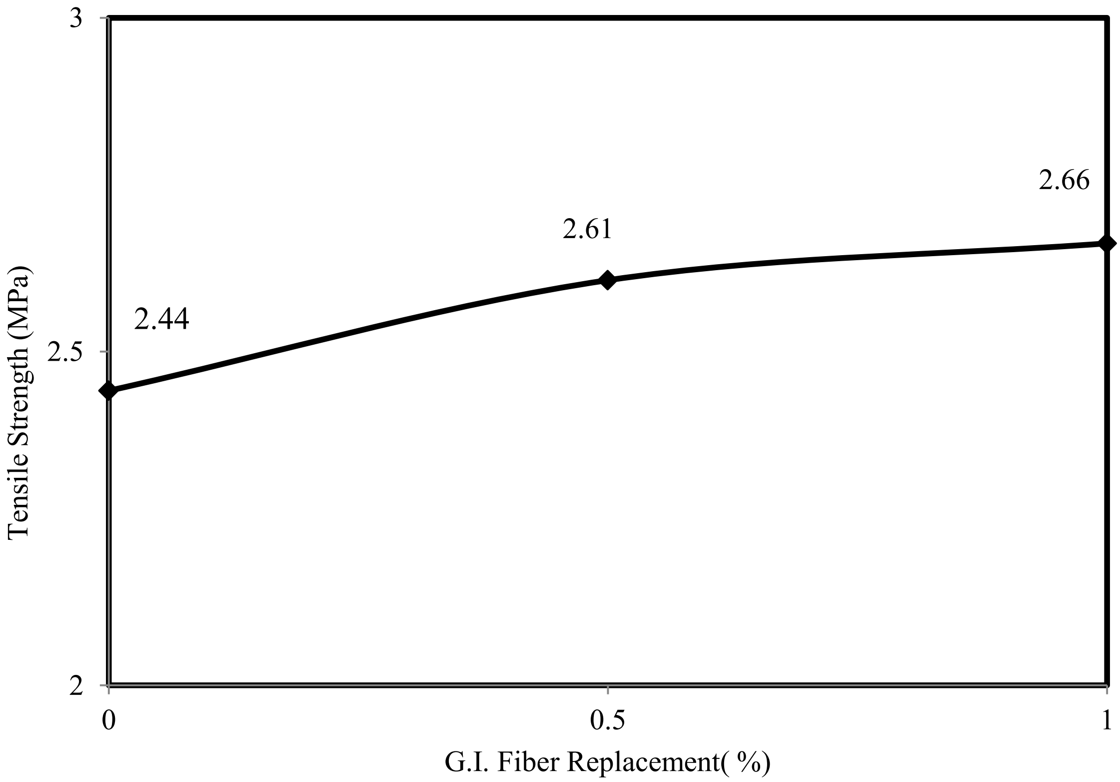


Fig 4.20: Tensile strength of concrete with recycled brick aggregates at 28 days

4.3.2.3 Modulus of elasticity of concrete

Effect of G.I. fiber additions on Modulus of Elasticity of concrete made with recycled brick aggregate is evaluated for 7 days, 14 days, and 28 days and presented in Figures 4.21,4.22, and 4.23, respectively. It is seen that modulus of elasticity of recycled brick aggregate concrete is significantly improved for concrete with G.I. fiber additions. Around 26% increase in Young's modulus of concrete at 28 days is observed for 0.5% G.I. fiber addition compared to control case with 0% G.I. fiber replacement. For 1% G.I. fiber addition, an increase of 38% in Young's Modulus is observed for a 28 days concrete.

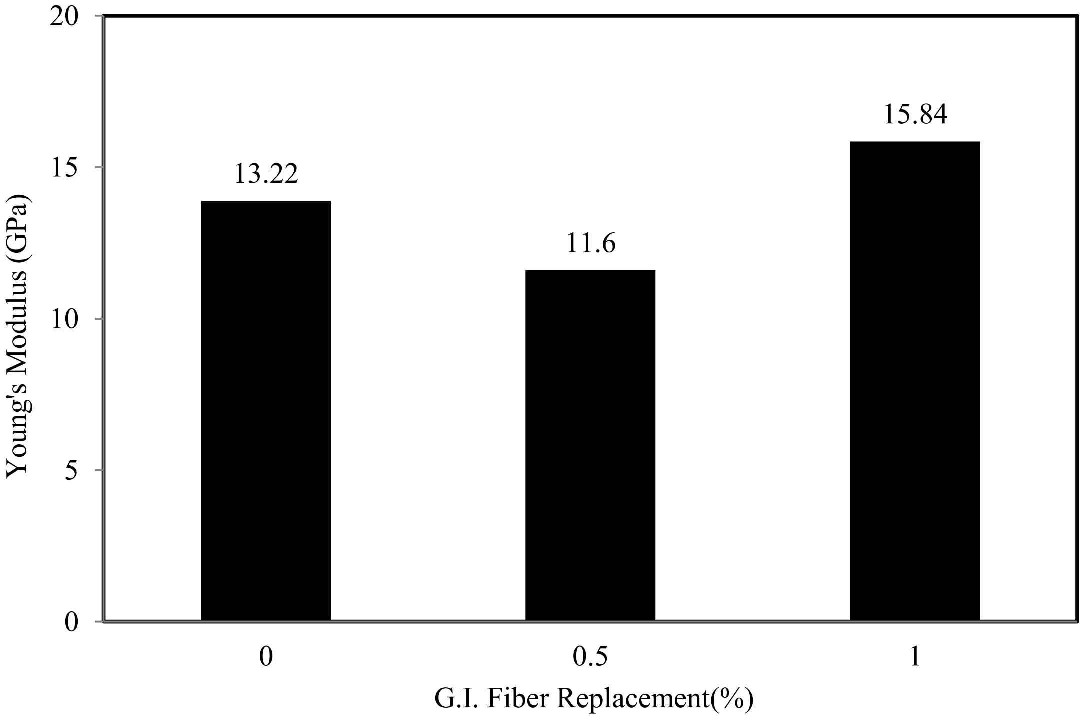


Fig 4.21: Modulus of elasticity of concrete made with recycled bricks at 7 days

Fig 4.22: Modulus of elasticity of concrete made with recycled bricks at 14 days

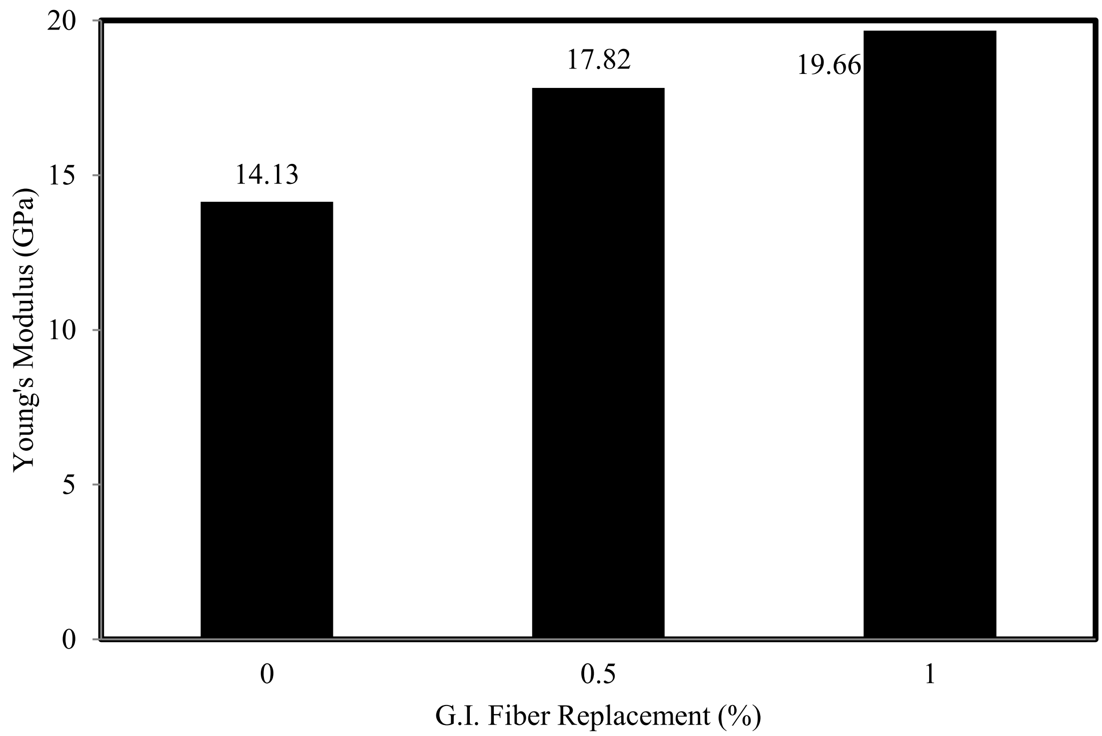


Fig 4.23: Modulus of elasticity of concrete made with recycled bricks at 28 days

4.3.2.4 Stress-strain behavior of concrete

Effect of G.I. fiber additions on the stress-strain behavior of recycled brick aggregate concrete is observed for 7 days, 14 days, and 28 days and is shown in Figures 4.24, 4.25, and4.26, respectively. It is seen that strain taken capacity of recycled brick aggregate concrete is significantly improved for concrete with G.I. fiber additions. Almost twice the capacity in 7 days concrete is observed for 0.5% and 1% G.I. fiber additions in comparison to control case with 0% G.I. fiber replacement. There is a huge enhancement in capacity is also observed for concrete at 14 days for both the cases. There is no significant improvement is observed for 0.5% G.I. fiber addition at 28 days. However, about 82% increase in strain taken capacity for 1% G.I. fiber additions in 28 days is observed.

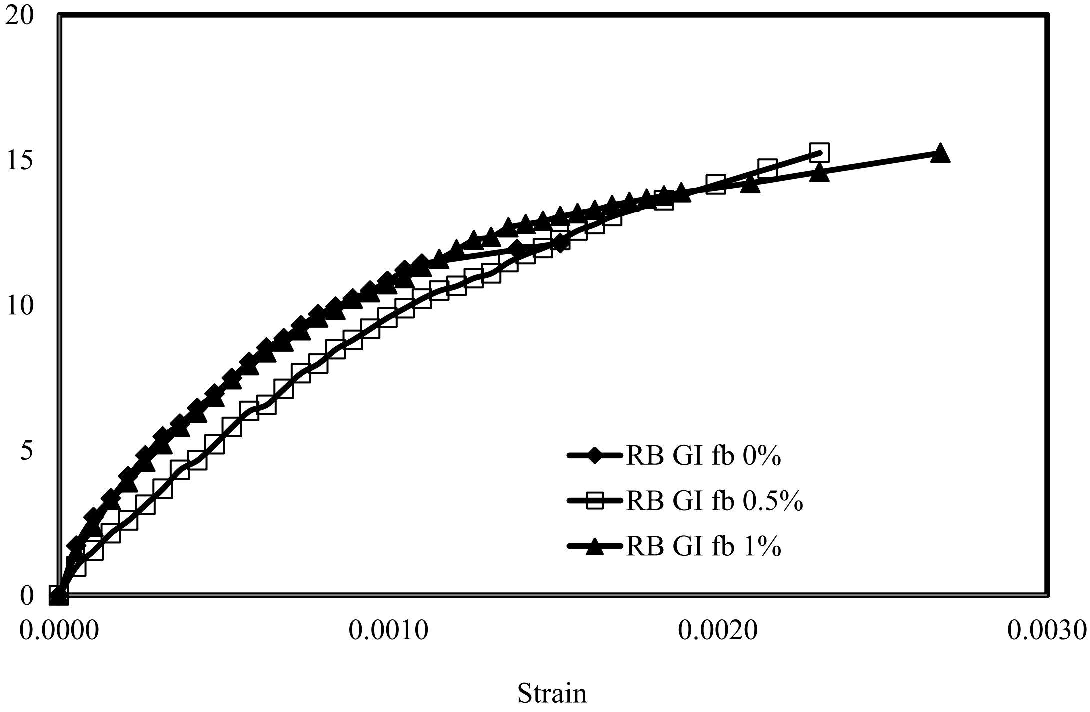


Fig 4.24: Stress-strain behavior of concrete made with recycled aggregates at 7 days

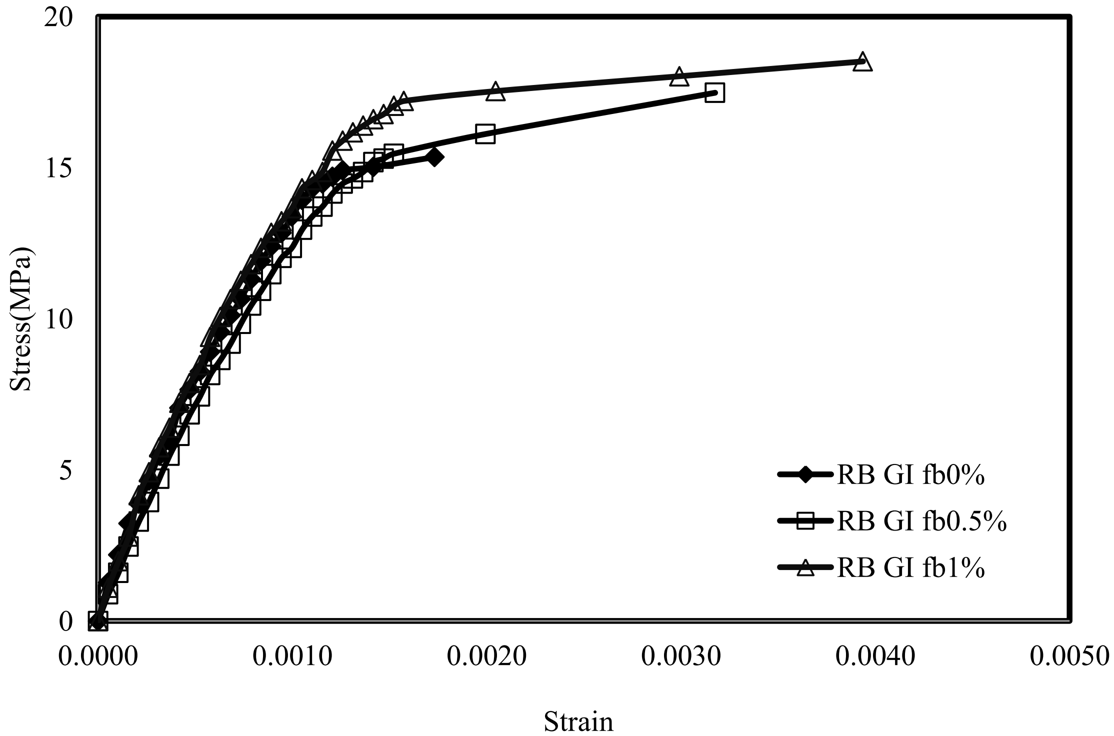


Fig 4.25: Stress-strain behavior of concrete made with recycled aggregates at 14 days

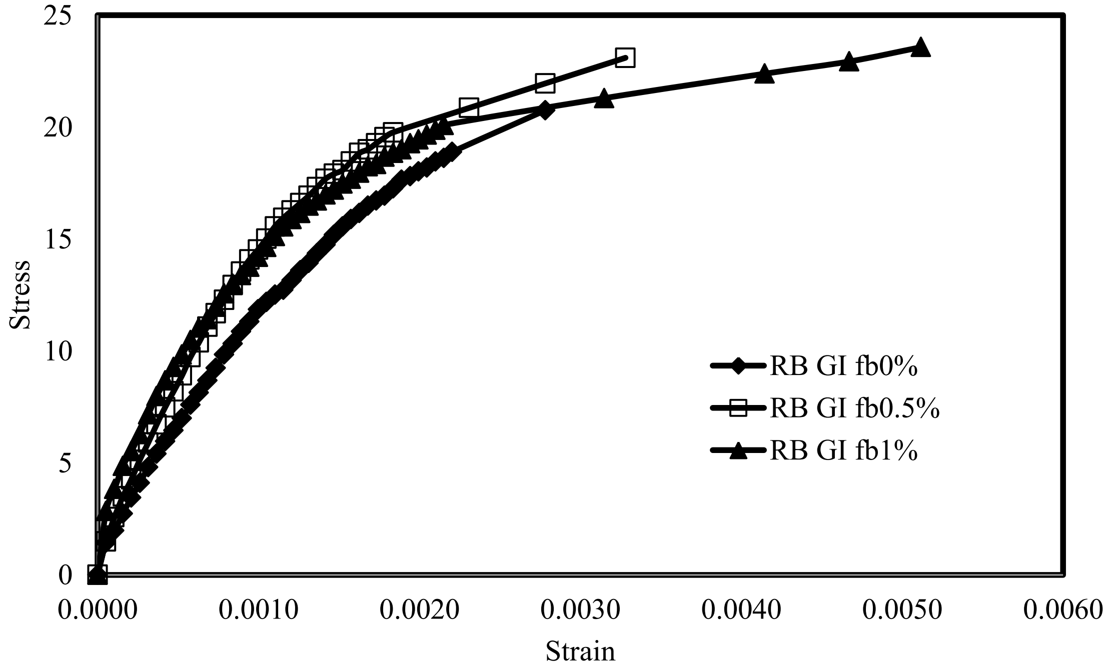


Fig 4.26: Stress-strain behavior of concrete made with recycled aggregates at 28 days

4.3.3 Effect of aggregate type on Plain and G.I fiber reinforced concrete

To understand the effect G.I. fiber additions, two types of coarse aggregates are used in this study: fresh brick aggregate and recycled brick aggregate. Details of aggregate type are given in sections 3.2.1 and 3.2.2 of Chapter 3.To understand the effect of aggregate type, same W/C=0.4, same S/A=0.44 and the same cement content=390 kg/m^{3}are used for both the aggregate types (B&RB). Mechanical properties (compressive strength, tensile strength, Young's modulus, stress-strain behavior) are investigated at different G.I. fiber additions.

4.3.3.1 Compressive strength

Effect of aggregate type on the compressive strength of plain and G.I. fiber reinforced concrete are tested at 7 days, 14 days, and 28 days and the results are shown in Figures 4.27, 4.28, and 4.29, respectively. No significant improvement is observed in compressive strength with the increase of G.I. fiber percentage for all the tested ages. About 14% increase in 7 days compressive strength of concrete with fresh brick aggregates (B) is observed for 0.5% G.I. fiber addition compared to that of recycled brick aggregates (RB).

For 1% G.I. fiber addition, 13% increase in compressive strength is found. Similar trend for the concrete strength is observed for the both the 14 and 28 days concrete.

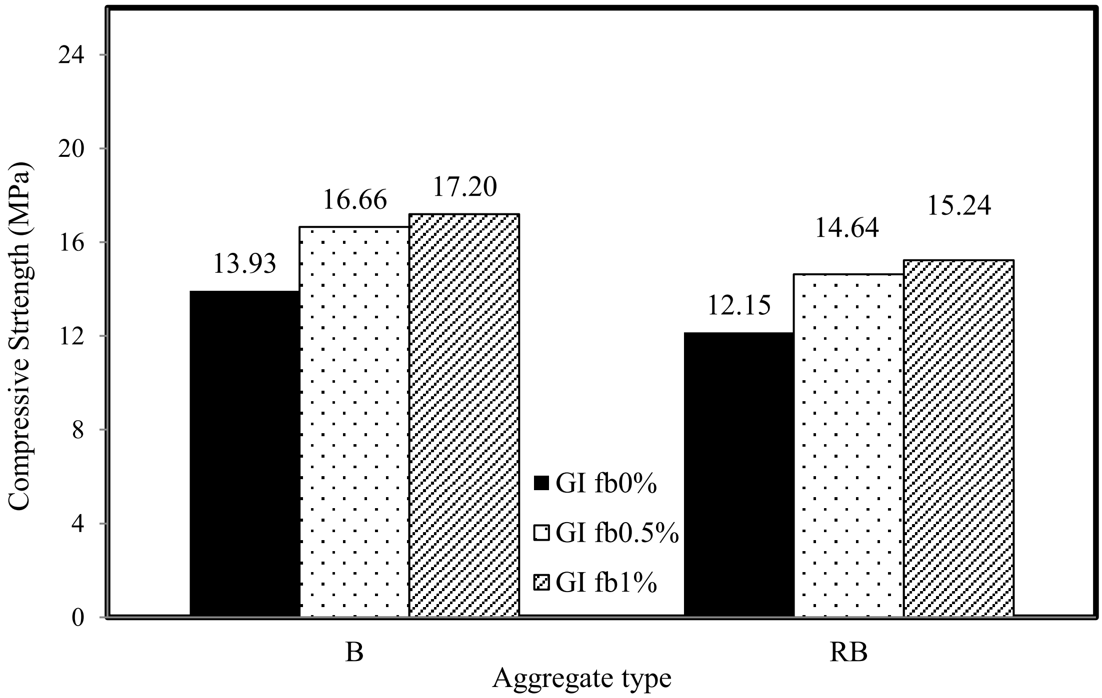


Fig 4.27: Compressive strength of concrete with B& RB at 7 days

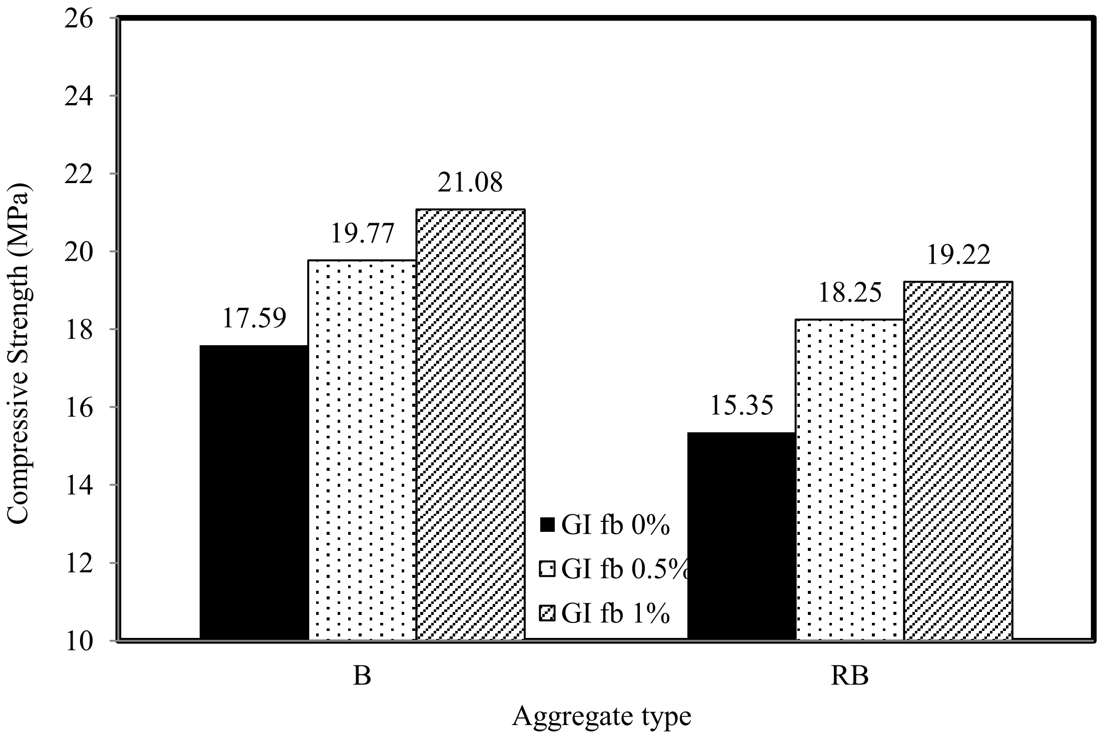


Fig 4.28: Compressive strength of concrete with B & RB at 14 days

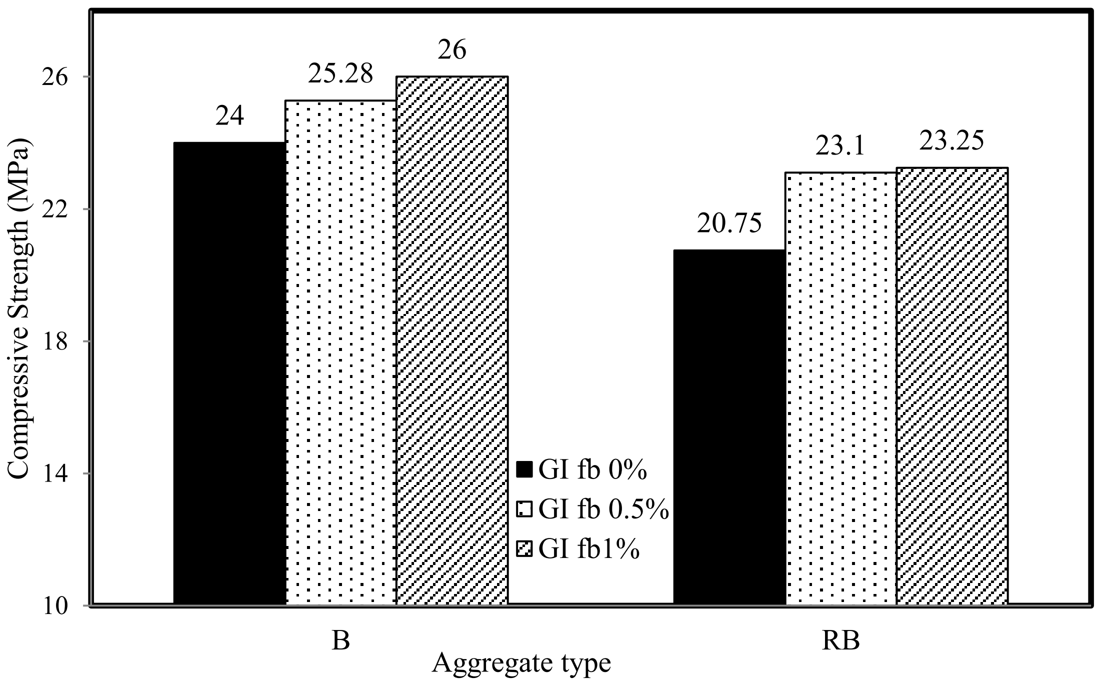


Fig 4.29: Compressive strength of concrete with B & RB at 28 days

4.3.3.2 Tensile strength

Effect of aggregate type on tensile strength of G.I. fiber reinforced concrete is investigated at 7 days, 14 days, and 28 days and the results are presented in Figures 4.30, 4.31, and 4.32, respectively. It is seen that tensile strength of brick aggregate concrete is increased almost 8% compared to recycled brick aggregate concrete for 0.5% G.I. fiber additions in 28 days. It is also observed that the trend is similar for 1% G.I. fiber addition.

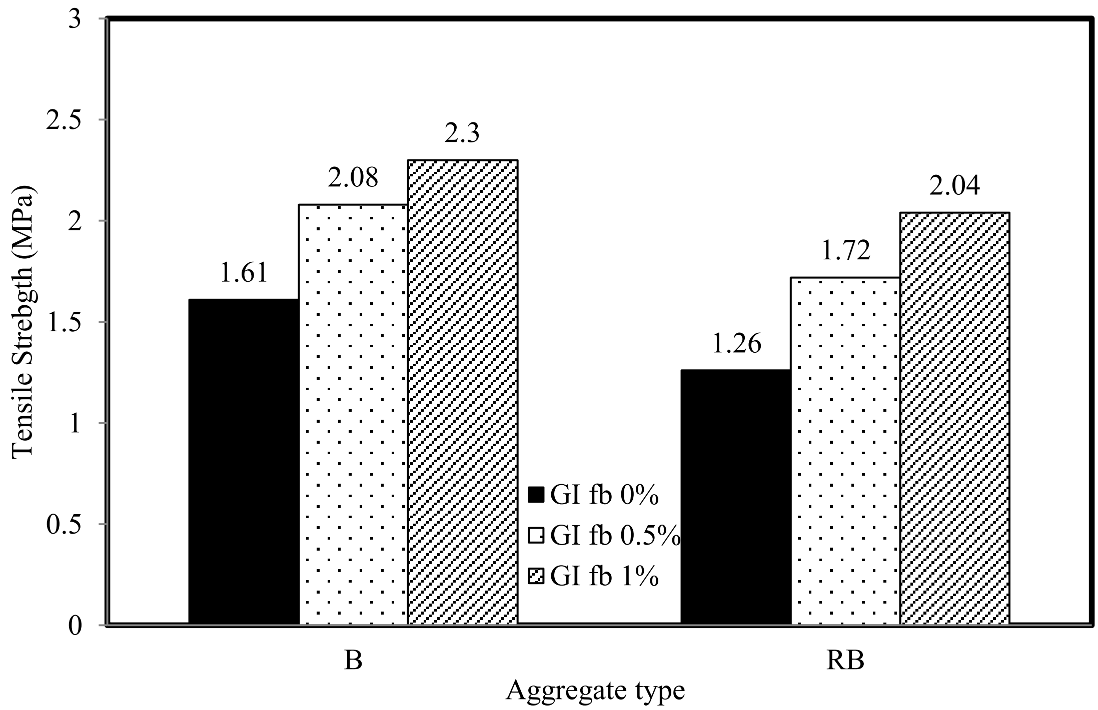


Fig 4.30: Compressive strength of concrete with B & RB aggregates at 7 days

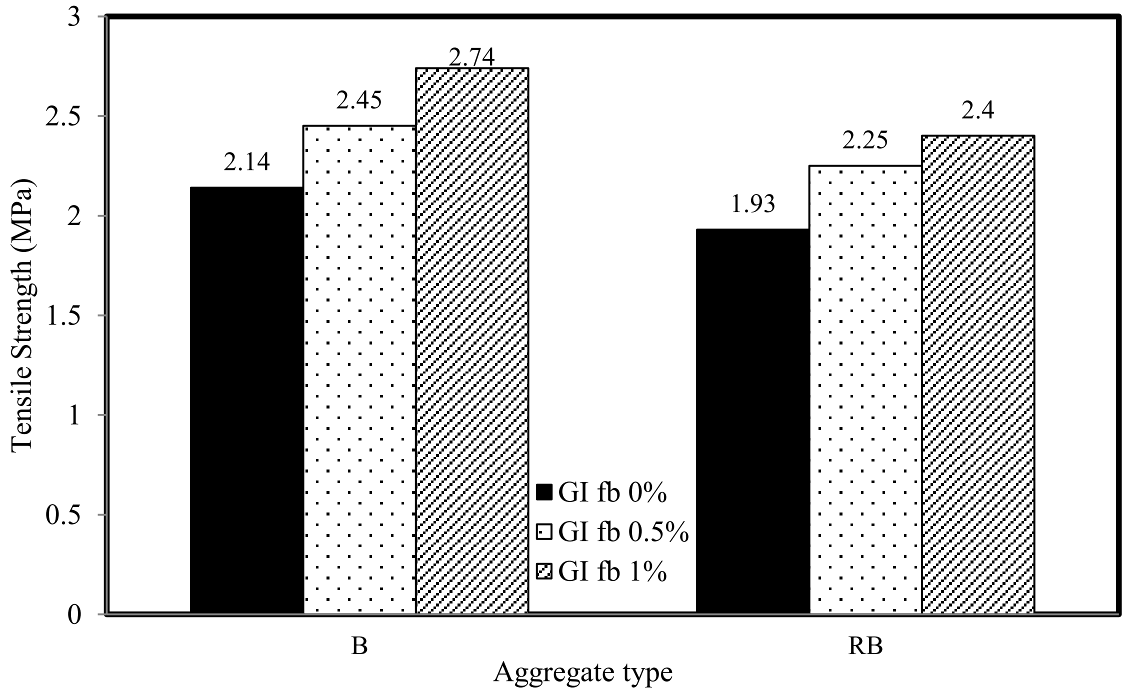


Fig 4.31: Compressive strength of concrete with B & RB aggregates at 14 days

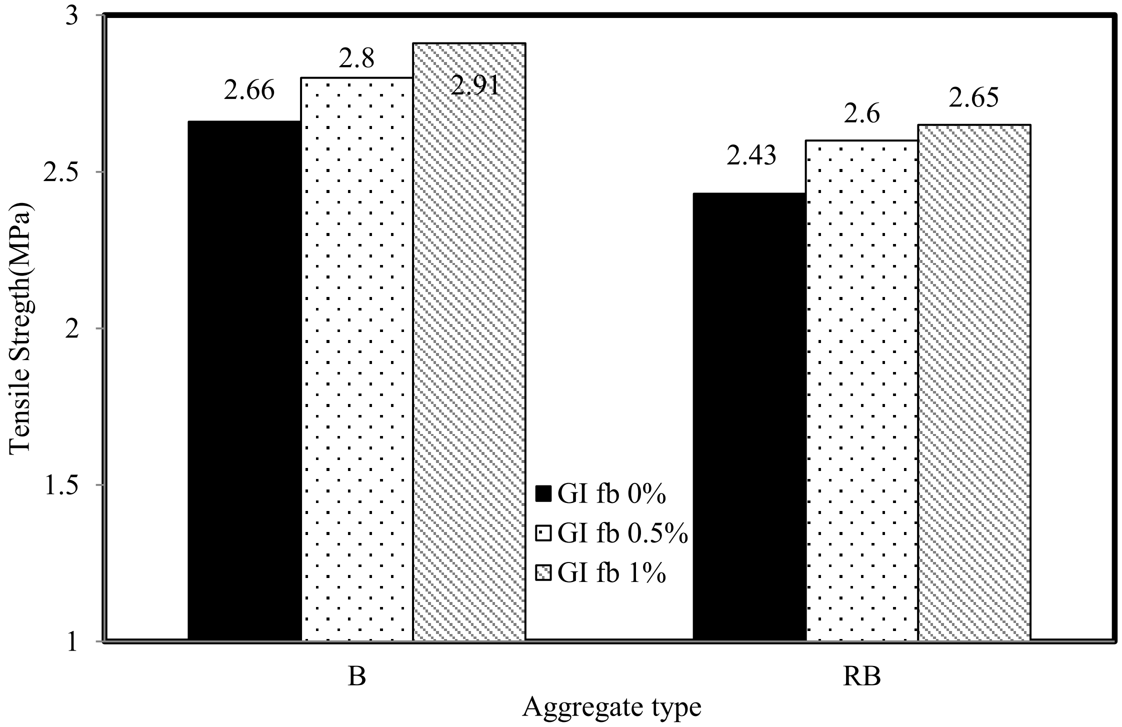


Fig 4.32: Compressive strength of concrete with B & RB aggregates at 28 days

4.3.3.3 Modulus of elasticity

Effect of aggregate type on Modulus of Elasticity of G.I. fiber reinforced concrete are assessed for 7 days, 14 days, and 28 days and the results are shown in Figures 4.33, 4.34, and 4.35, respectively. No Significant improvement has been shown for the Modulus of Elasticity of concrete with fresh brick aggregates in comparison to that of recycled brick aggregates. Only 2% increase in Young's Modulus of concrete at 14 days is observed for 1% G.I. fiber addition compared to that of recycled brick aggregates. The result does not show any specific trend of enhancement.

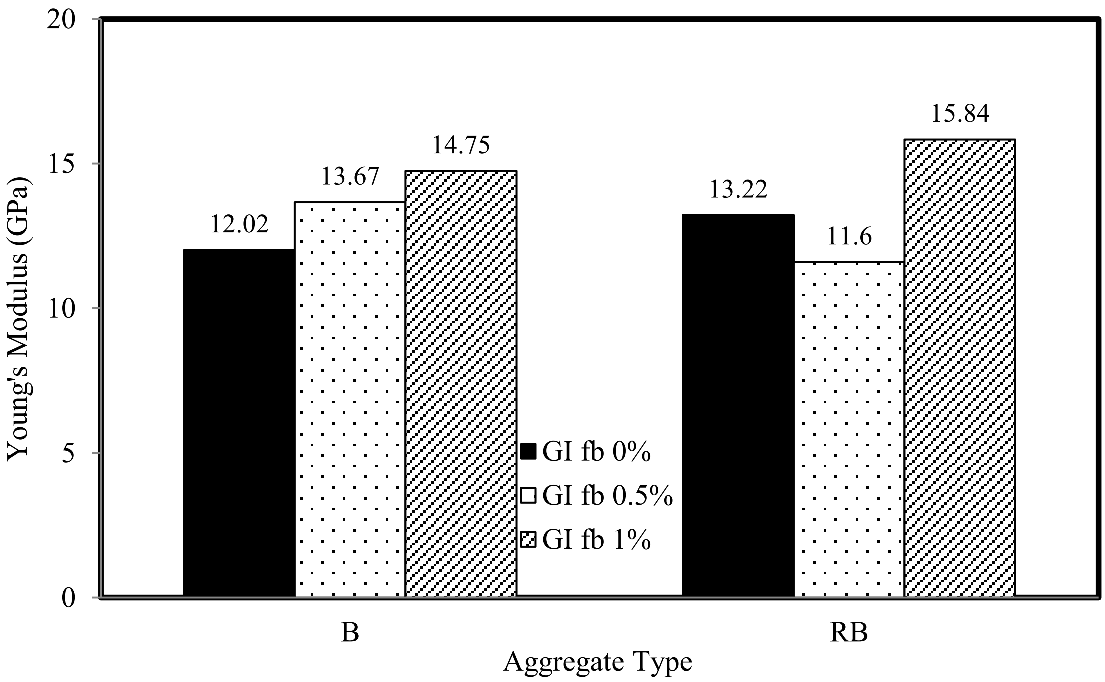


Fig 4.33: Modulus of elasticity of concrete with B & RB aggregates at 7 day

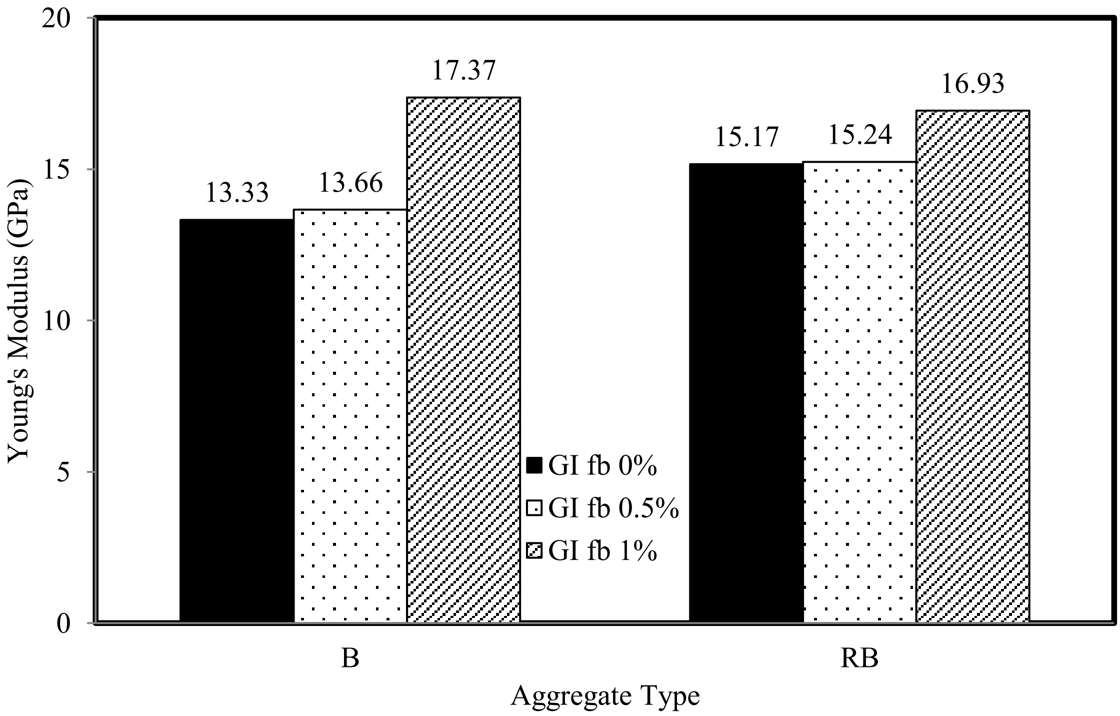


Fig 4.34: Modulus of elasticity of concrete with B & RB aggregates at 14 day

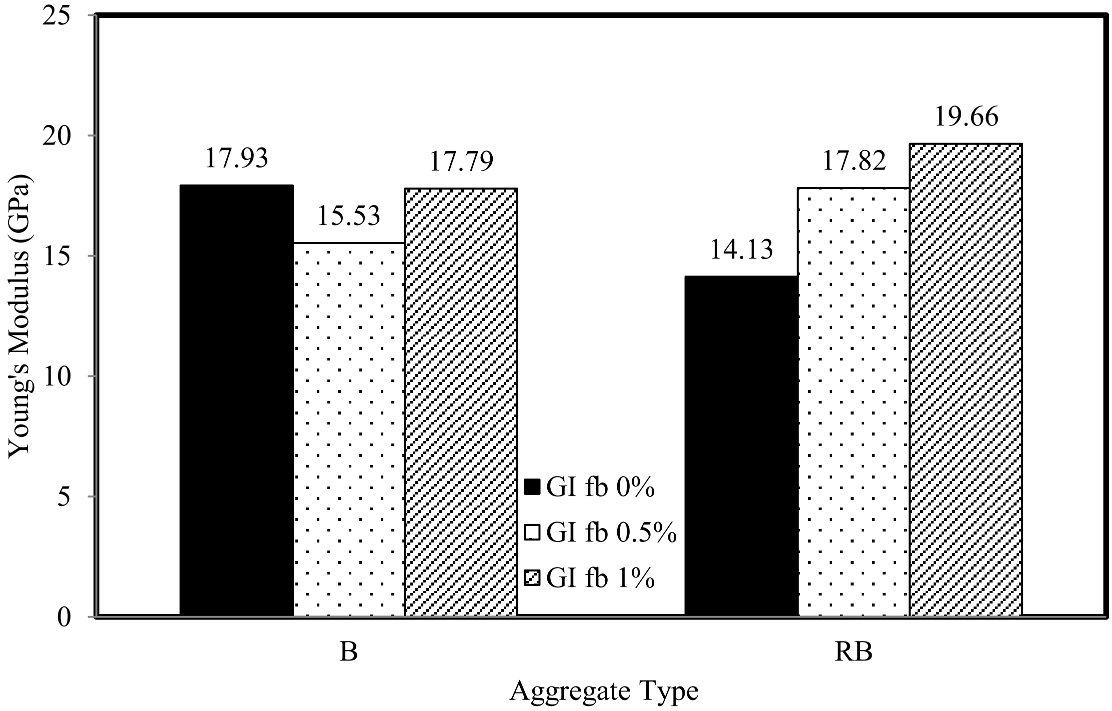


Fig 4.35: Modulus of elasticity of concrete with B & RB aggregates at 28 day

4.3.3.4 Stress-strain behavior

Effect of aggregate type on the stress-strain behavior of G.I. fiber reinforced concrete is investigated for 7 days, 14 days, and 28 days. Figures 4.36, 4.37 & 4.38 show the results for stress-strain behavior of concrete with control case (0% fiber addition), 0.5% G.I. fiber addition, and 1% G.I. fiber additions, respectively for concrete of 7 days. Stress-strain behavior of concrete for 14 days and 28 days is shown in Figures 4.39, 4.40 & 4.41 and Figures 4.42, 4.43 & 4.44, respectively. It is observed that strain taken capacity of concrete with fresh brick aggregates (B) is significantly improved for concrete with G.I. fiber additions. About 37% increase in 28 days strain taken capacity is observed for 0.5% G.I. fiber addition compared to RB concrete (0.5% G.I. fiber addition). However, it shows a little improvement (about 15%) in strain taken capacity for 1% G.I. fiber addition in 28 days.

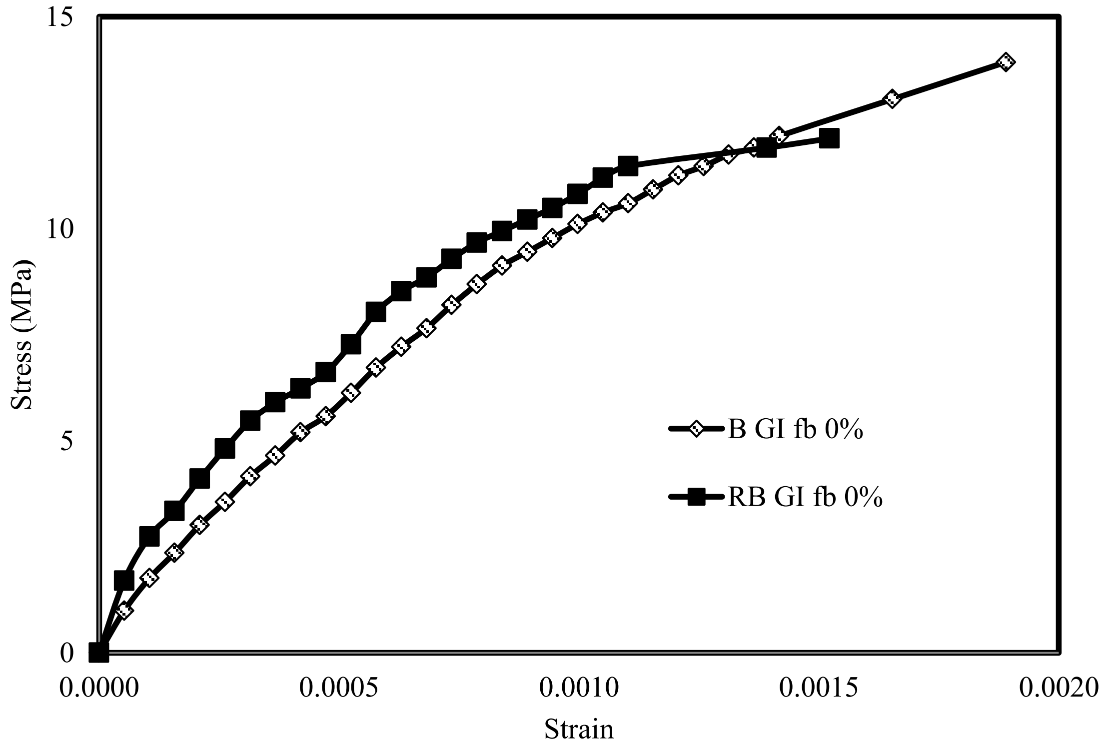


Fig 4.36: Stress-strain behavior of concrete B and RB aggregates with GI fb 0% at 7 days

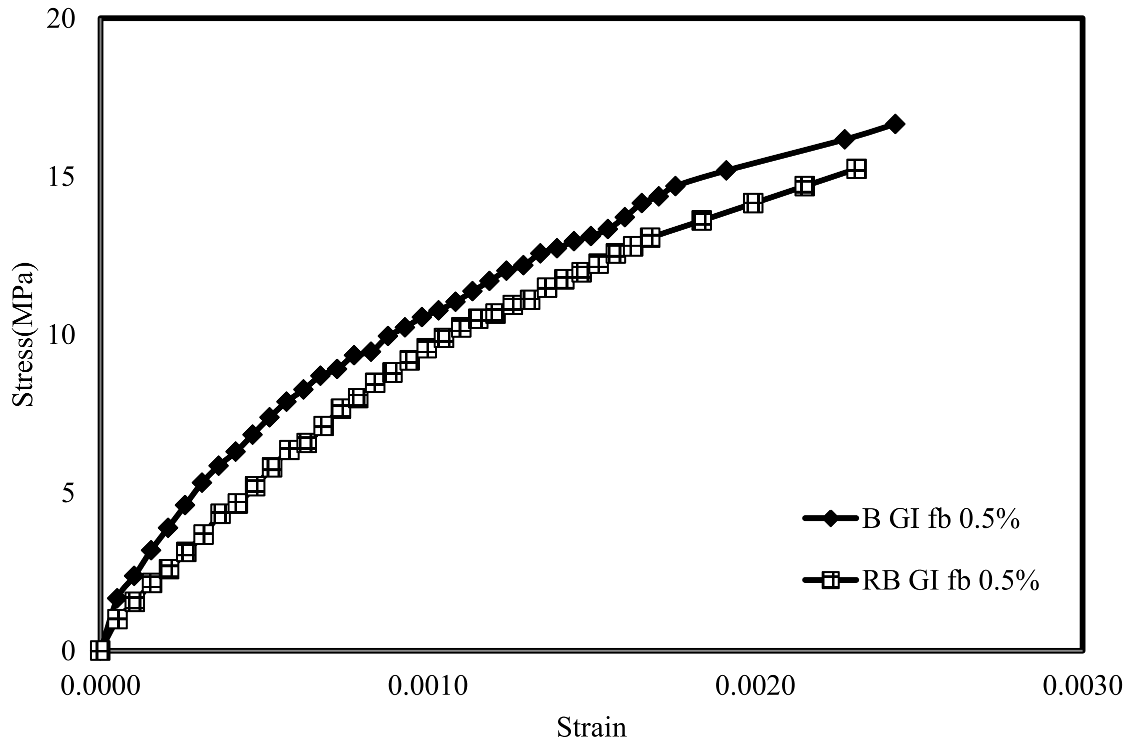


Fig 4.37: Stress-strain behavior of concrete B and RB aggregates with GI fb 0.5% at 7 days

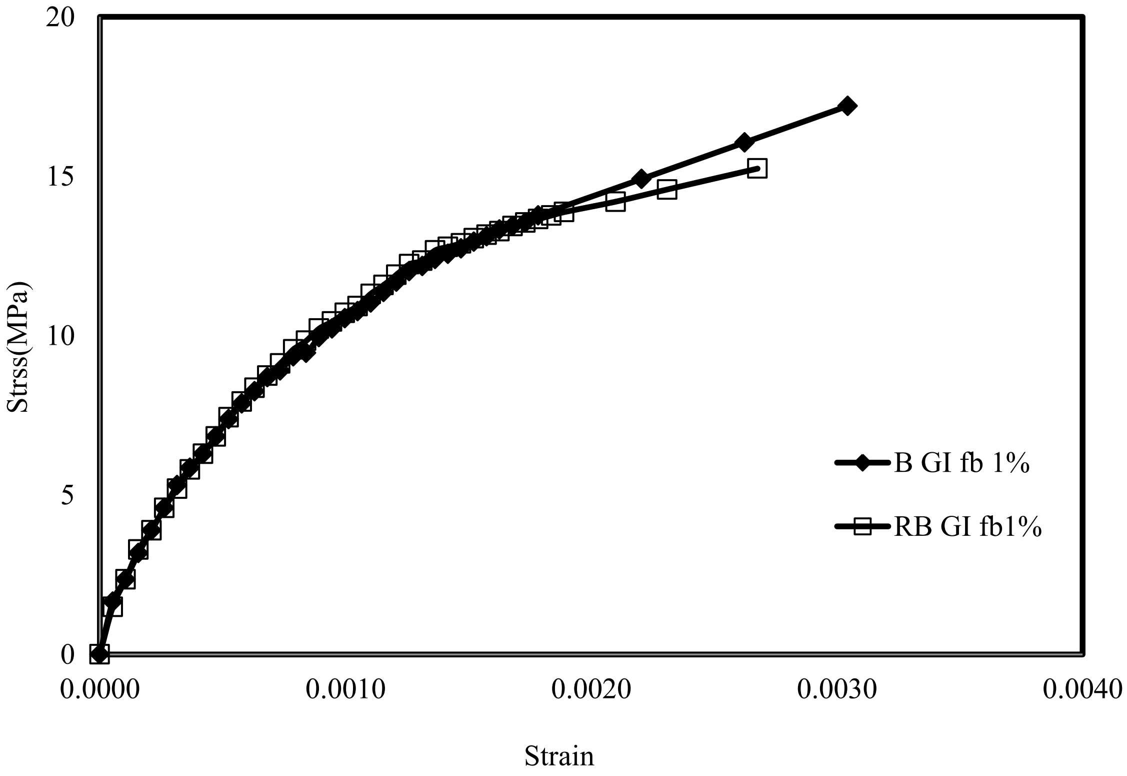


Fig 4.38: Stress-strain behavior of concrete B and RB aggregates with GI fb 1% at 7 days

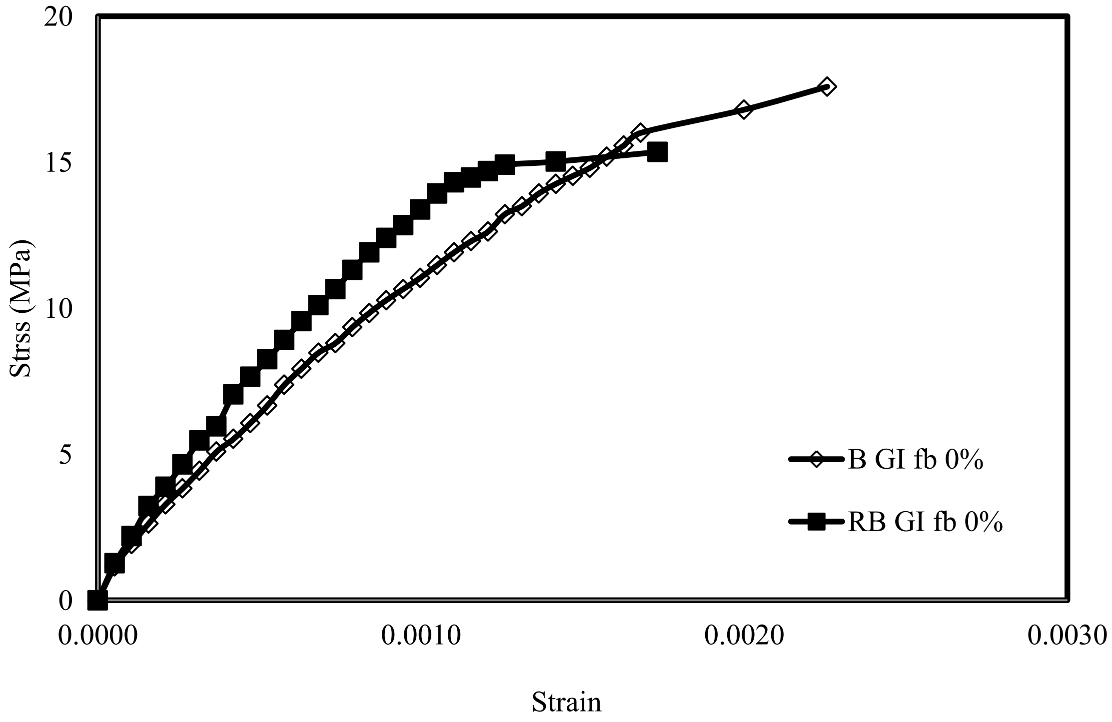


Fig 4.39: Stress-strain behavior of concrete B and RB aggregates with GI fb 0% at 14 days

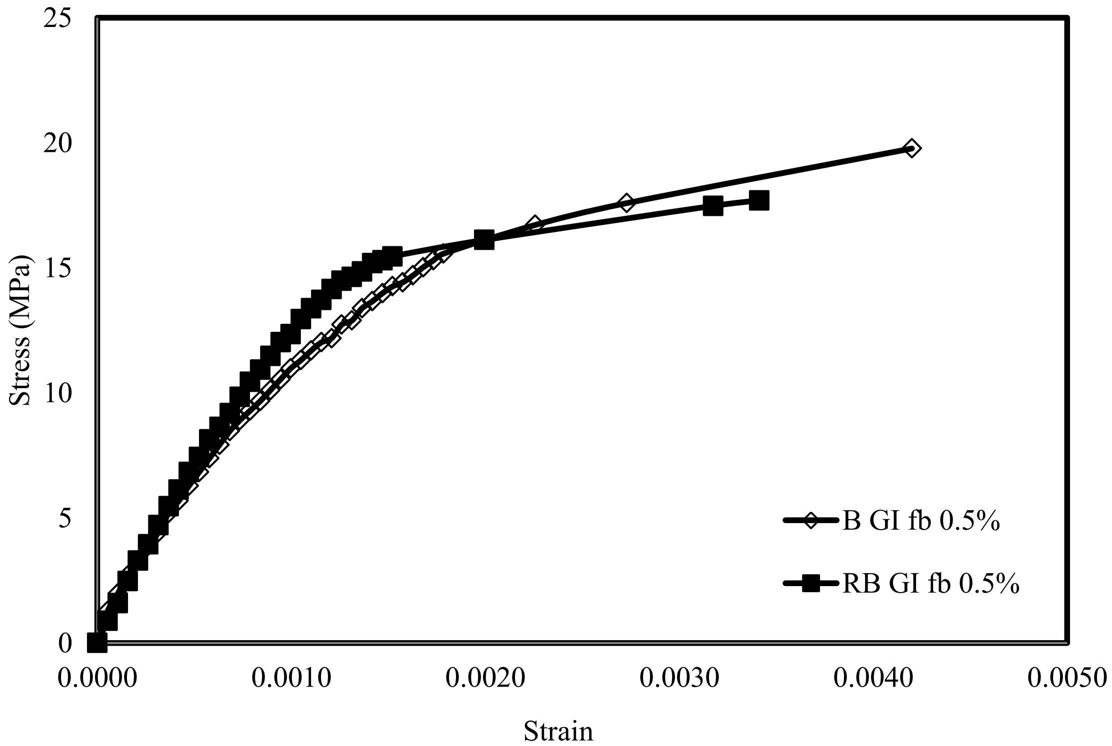


Fig 4.40: Stress-strain behavior of concrete B and RB aggregates with GI fb 0.5% at 14 days

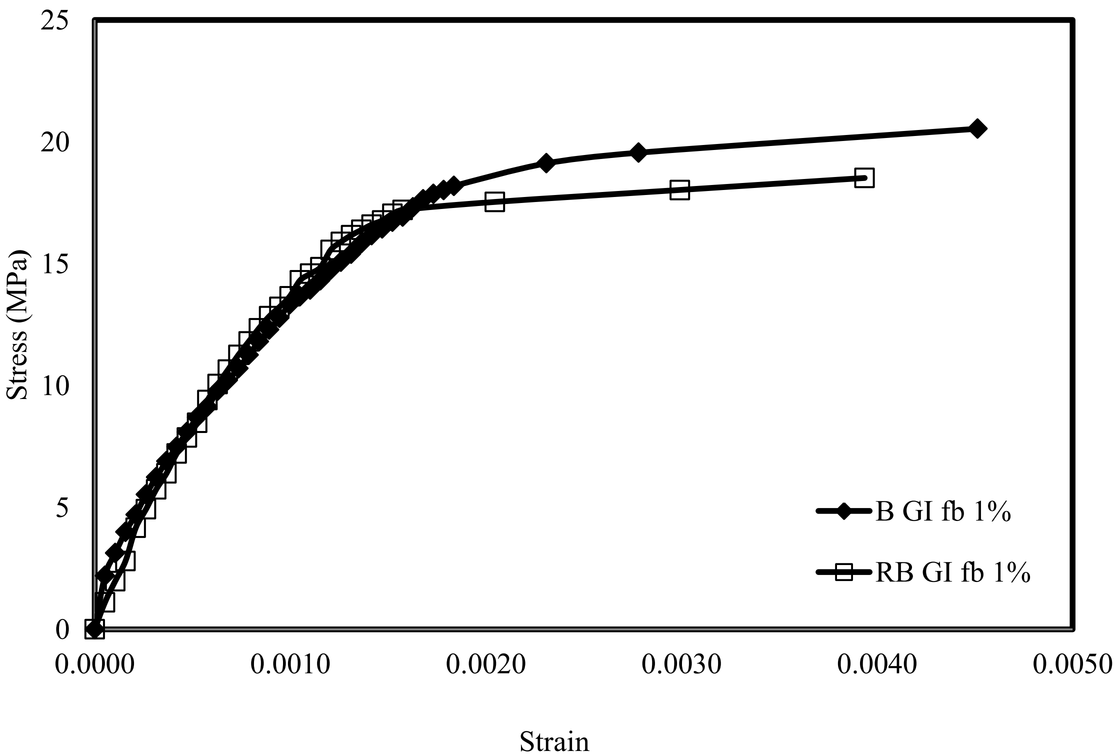


Fig 4.41: Stress-strain behavior of concrete with B and RB aggregates with GI fb 1% at 14 days

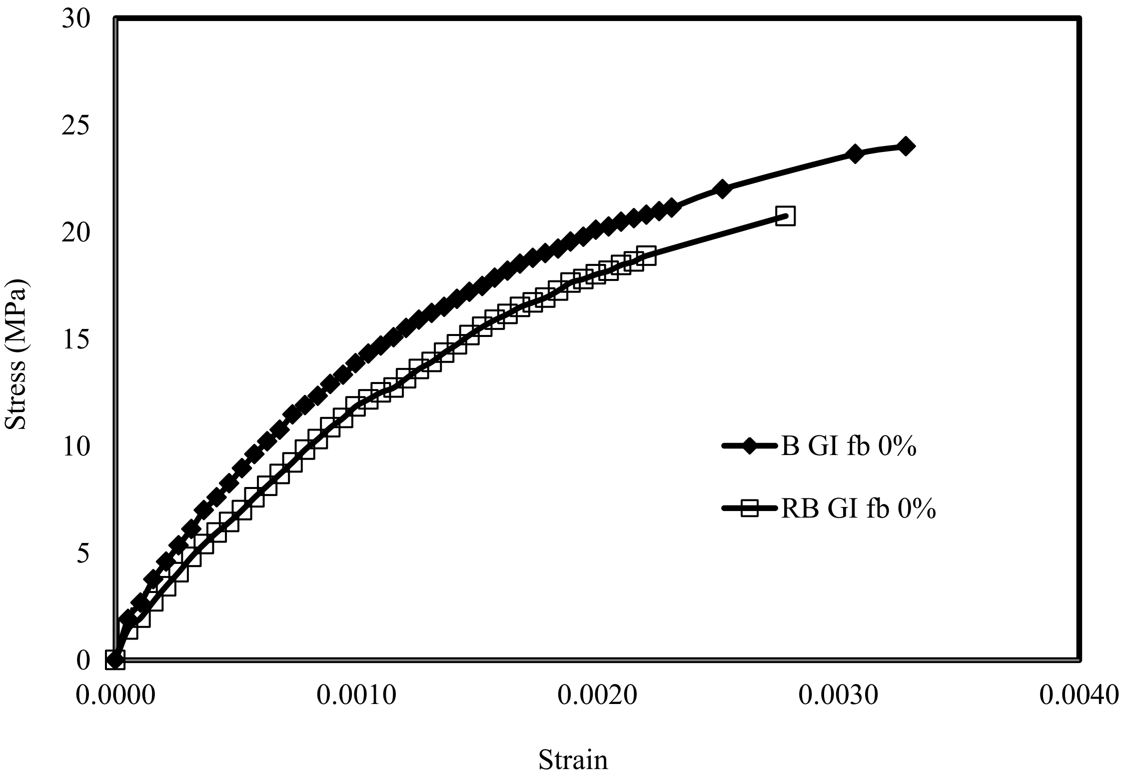


Fig 4.42: Stress-strain behavior of concrete B and RB aggregates with GI fb 0% at 28 days

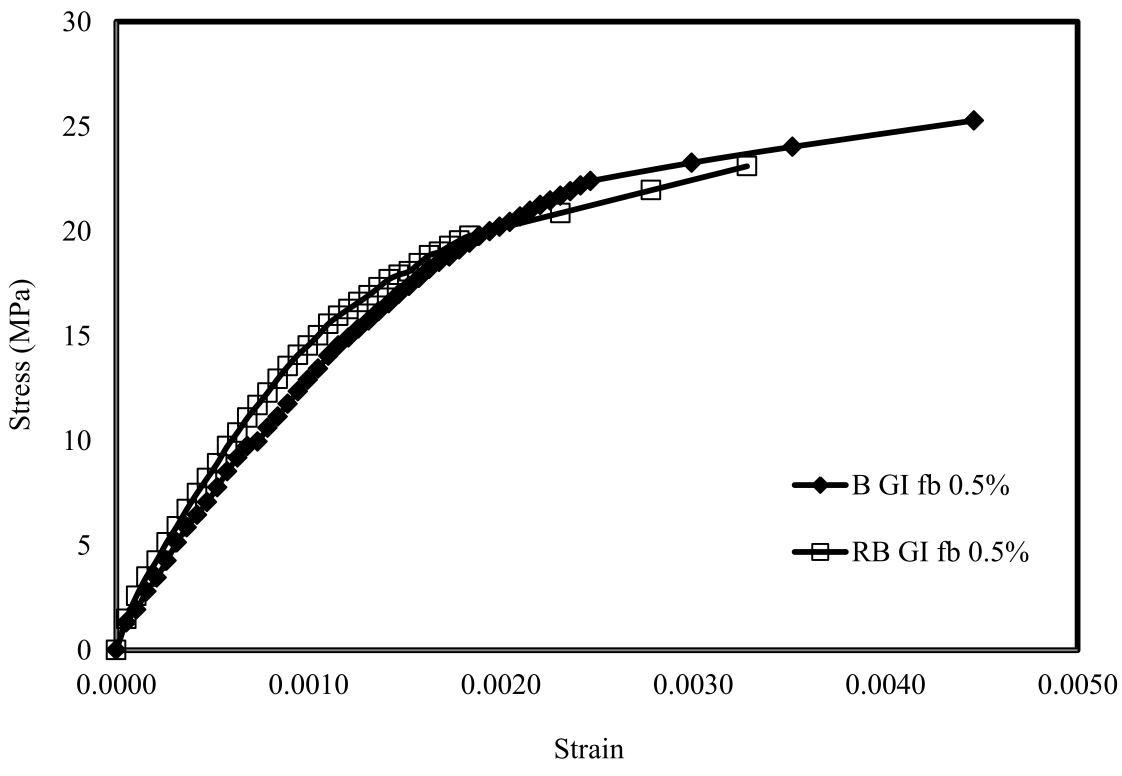


Fig 4.43: Stress-strain behavior of concrete B and RB aggregates with GI fb 0.5% at 28 days

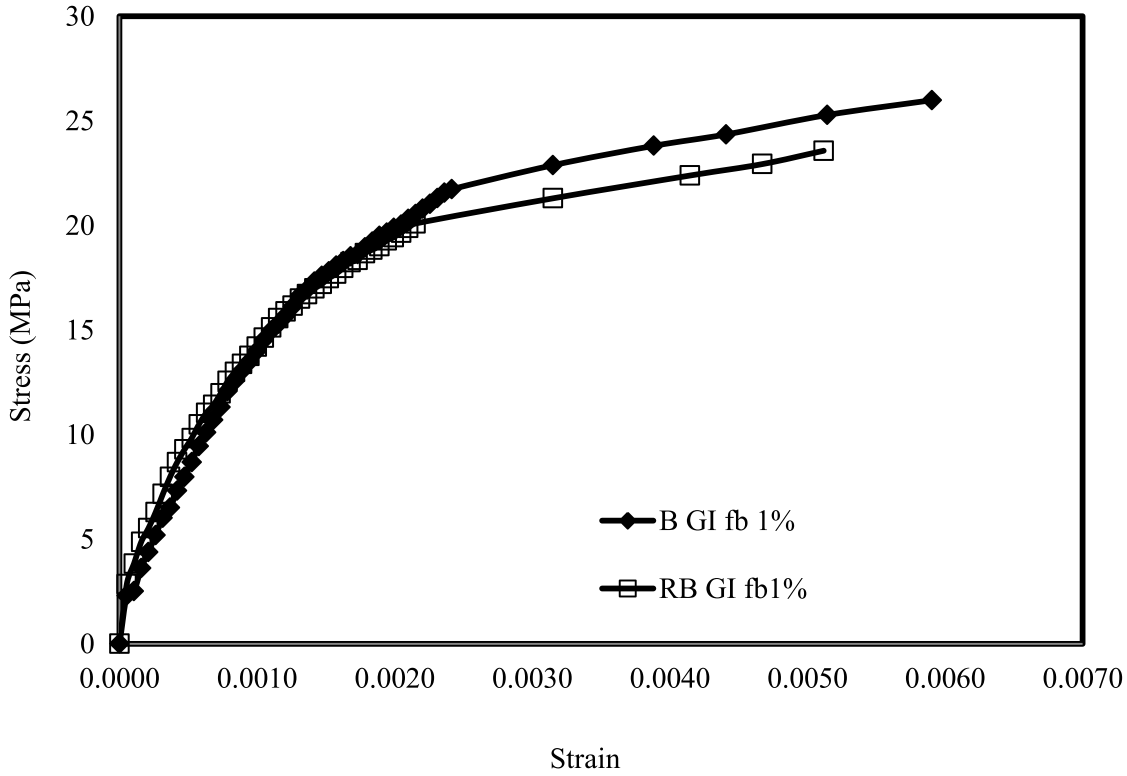


Fig 4.44: Stress-strain behavior of concrete B and RB aggregates with GI fb 1% at 28 days

4.3.4 Effect of testing age on plain and G.I. fiber reinforced concrete with B and RB aggregates

Age plays the most important role on the development of strength of concrete. Mainly C_3S and C_2S give the strength to the concrete. Hydration of cement is continuous process. Therefore, strength of concrete will increase with time. To understand the effect of G.I. fiber addition on concrete, all cylinder specimens are tested for 7 days, 14 days and 28 days.

4.3.4.1 Compressive strength

The variations of the compressive strength with age of concrete specimen are shown in Figures 4.45, 4.46 and 4.47, respectively. From these figures, it can be said that compressive strength increases with the increase of specimen age. It is seen that rate of change of compressive strength of concrete with B aggregates is more than that of RB aggregates for 0.5% fiber addition. About 10% increase in compressive strength in 28 days is observed. Similar trend is found for 1% fiber addition in 28 days.

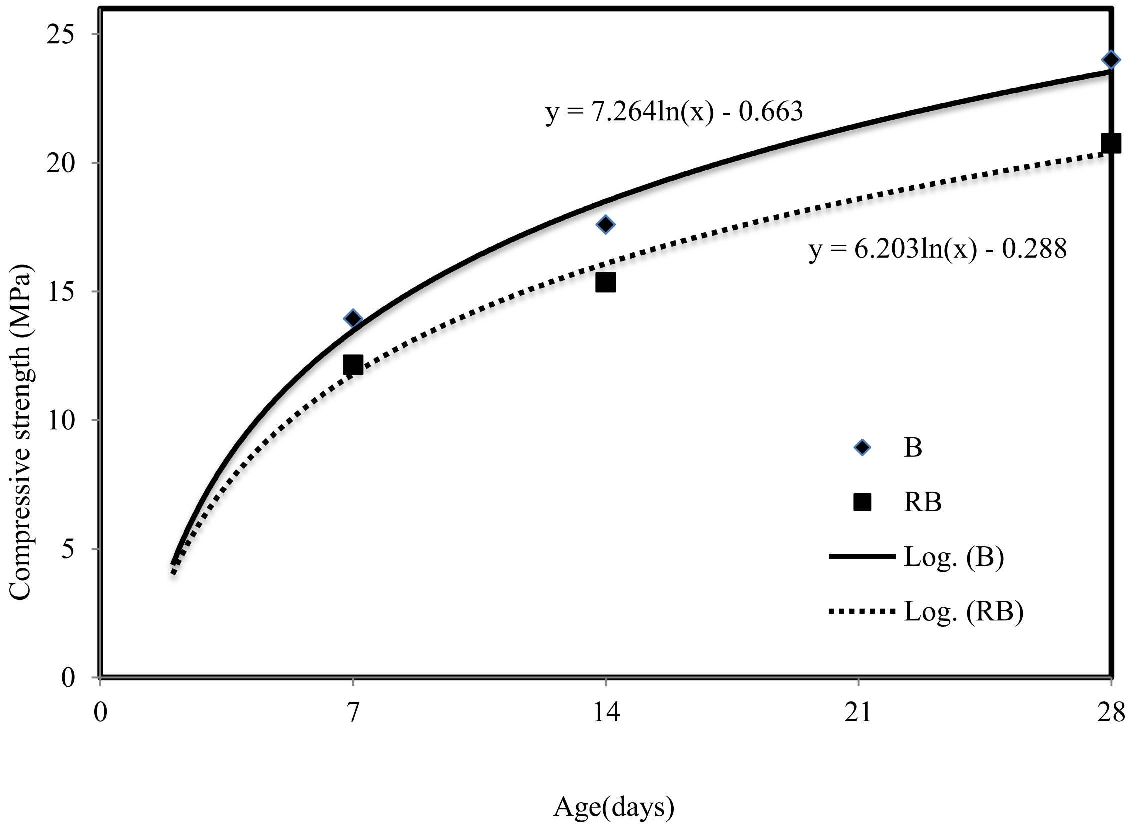


Fig 4.45: Effect of age on compressive strength of concrete with of B & RB aggregates at G.I. fiber addition of 0%

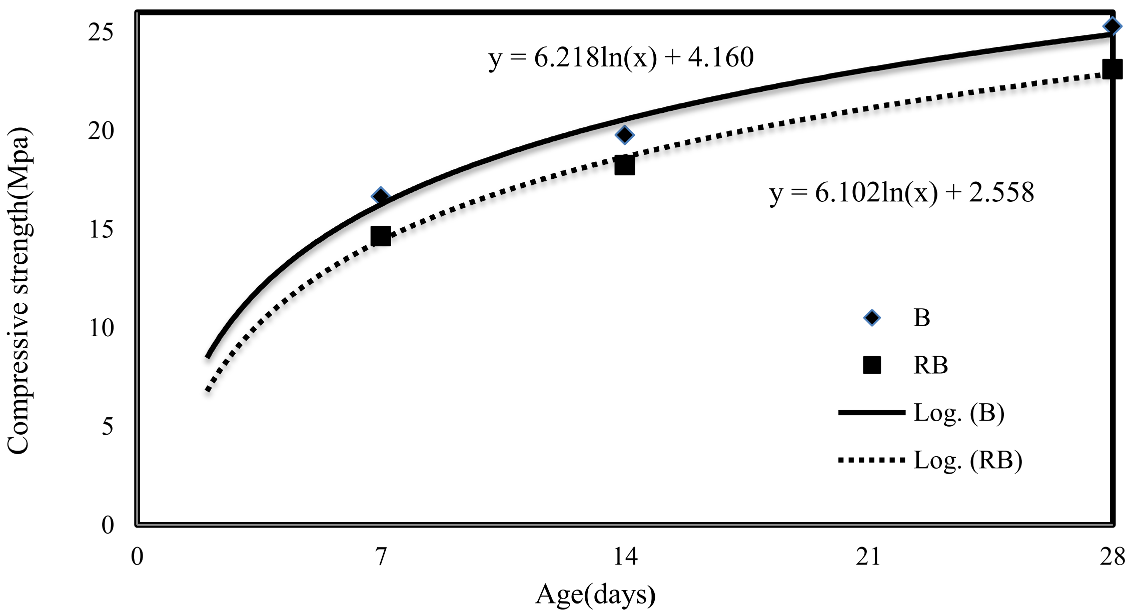


Fig 4.46: Effect of age on compressive strength of concrete with of B & RB aggregates at G.I. fiber addition of 0.5%

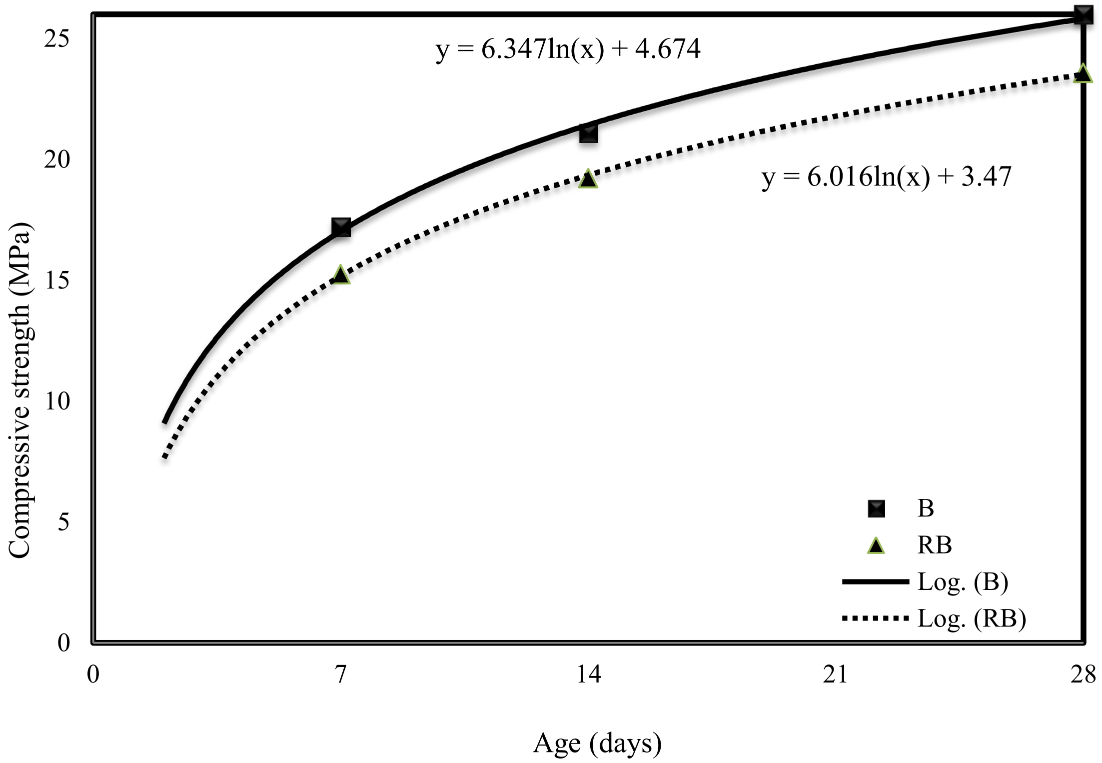


Fig 4.47: Effect of age on compressive strength of concrete with of B & RB aggregates at G.I. fiber addition of 1%

4.3.4.2 Tensile strength

The variations of the tensile strength with age of concrete specimens are shown in Figures 4.48, 4.49 and 4.50 for G.I. fiber additions of 0%, 0.5% and 1%, respectively. From these figures, it can be said that tensile strength also increases with the increase of specimen age. It is seen that rate of change of strength of concrete with B aggregates is more than that of RB aggregates for 0.5% fiber addition. About 8% increase in tensile strength is observed and the similar trend is found for 1% fiber addition in 28 days. On the other hand, 28 day's strength of concrete with RB aggregates is10% more than that of the 14 day's strength. However, this improvement is not significant for concrete with B aggregates. About 6 % increase in strength is observed for 1% fiber addition in 28 days compared to that of 14 day's strength.

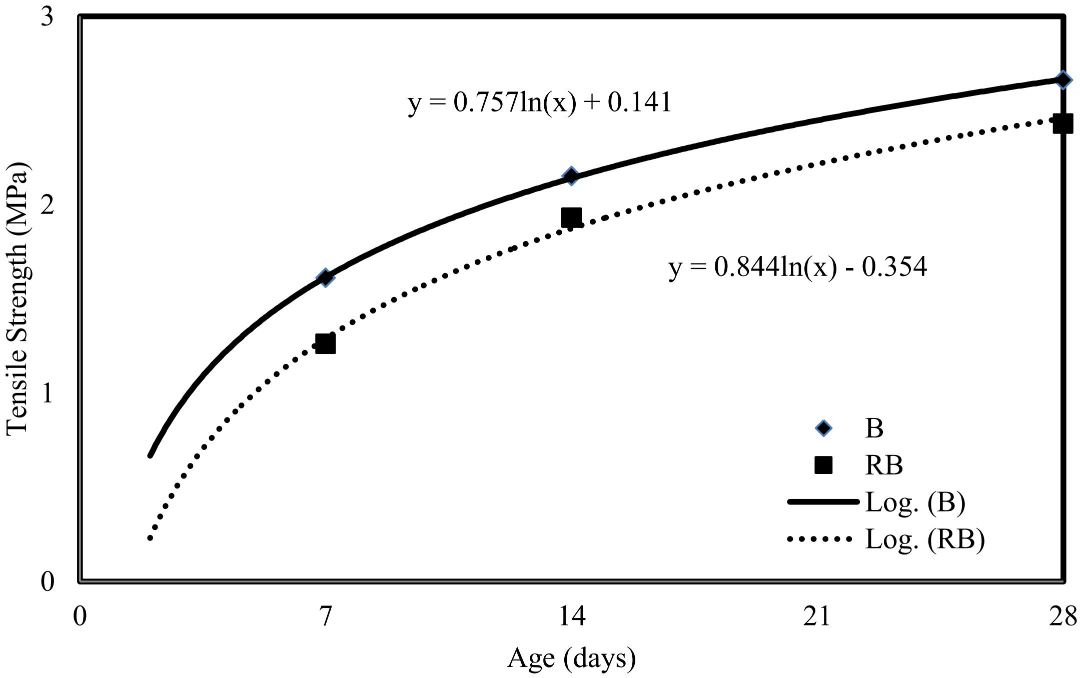


Fig 4.48: Effect of age on tensile strength of concrete with B & RB at GI fb 0%

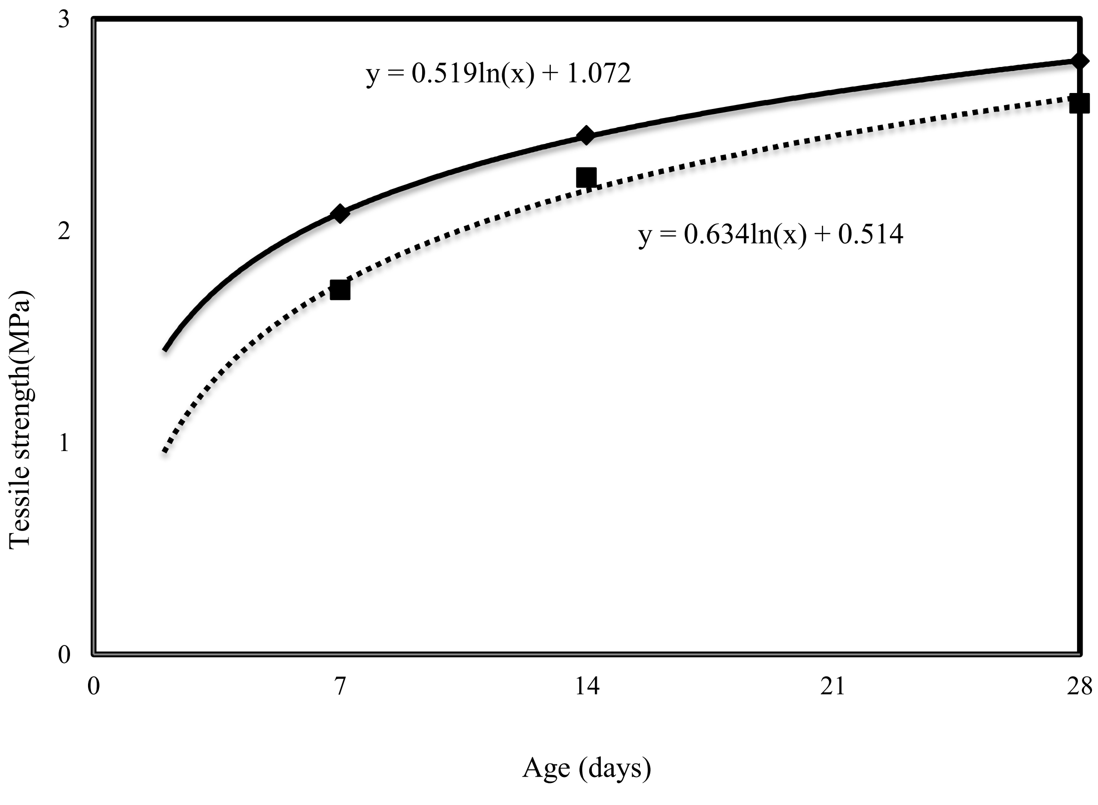


Fig 4.49: Effect of age on tensile strength of concrete with B & RB at GI fb 0.%

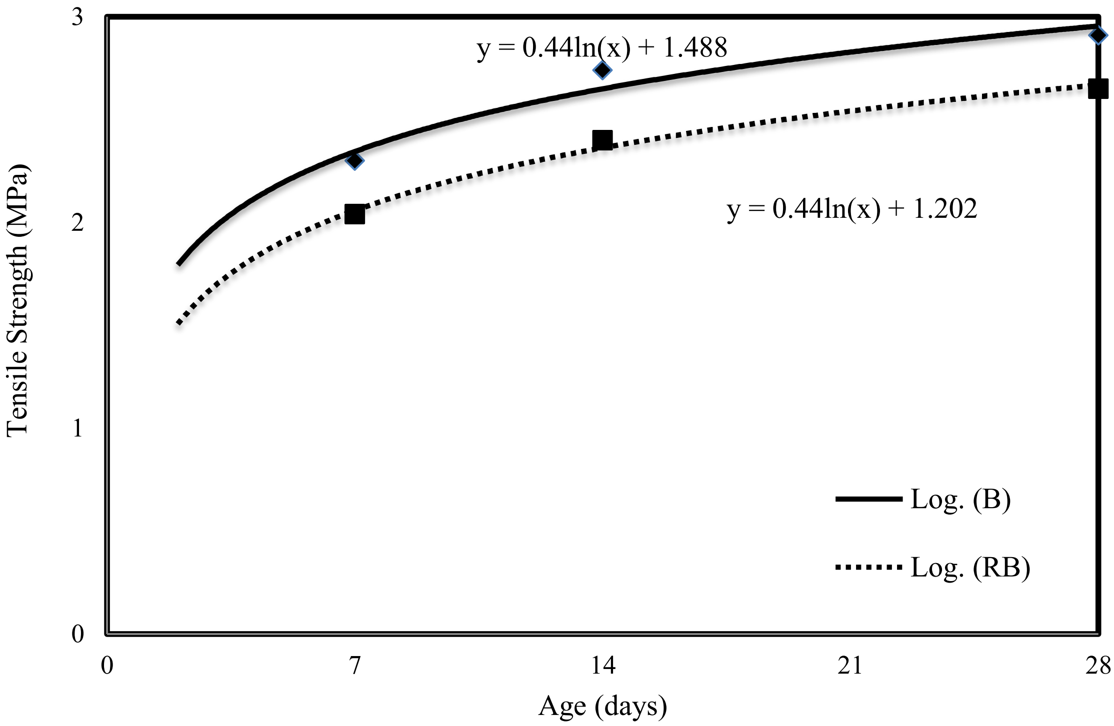


Fig 4.50: Effect of age on tensile strength of concrete with B & RB at GI fb 1%

4.3.4.3 Modulus of elasticity

The variations of the Modulus of Elasticity with age of concrete specimen are shown in Figures 4.51, 4.52 and 4.53 for G.I. fiber additions 0%, 0.5% and 1%, respectively. It is seen that rate of change of Modulus of Elasticity of concrete with RB aggregates is more than that of B aggregates for 0.5% fiber additions in 28 days. About 14% increase in Modulus of Elasticity of concrete is observed and the similar trend is found for 1% fiber addition in 28 days.

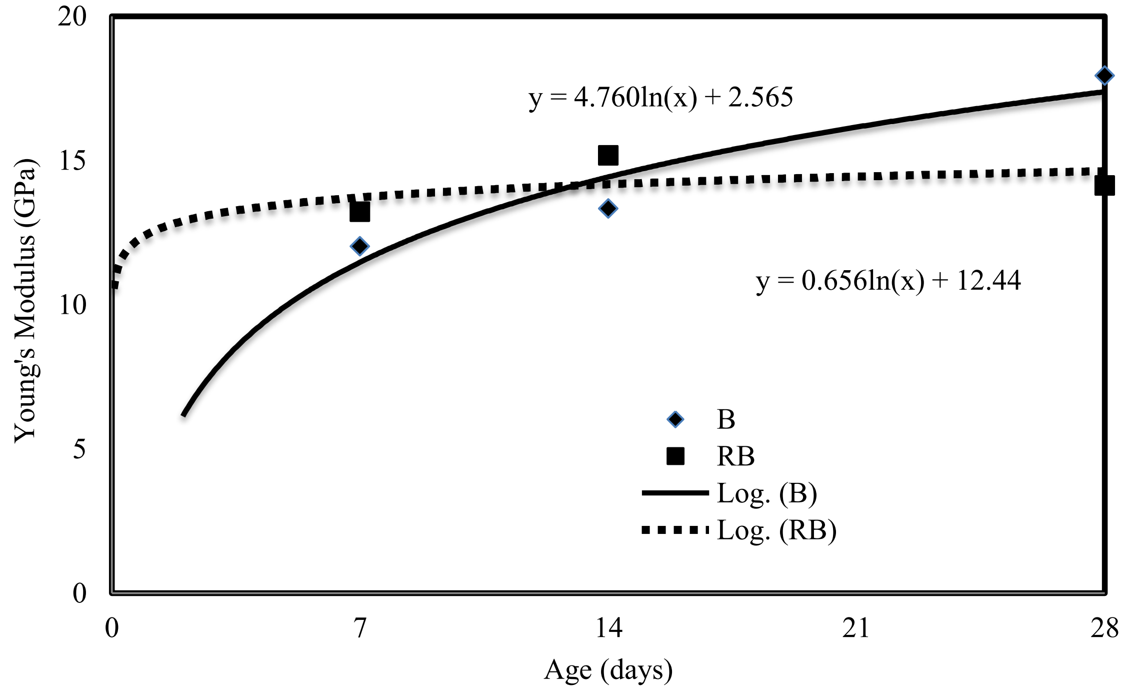


Fig 4.51: Effect of age on modulus of elasticity of concrete with B & RB aggregates having G.I. fiber 0%.

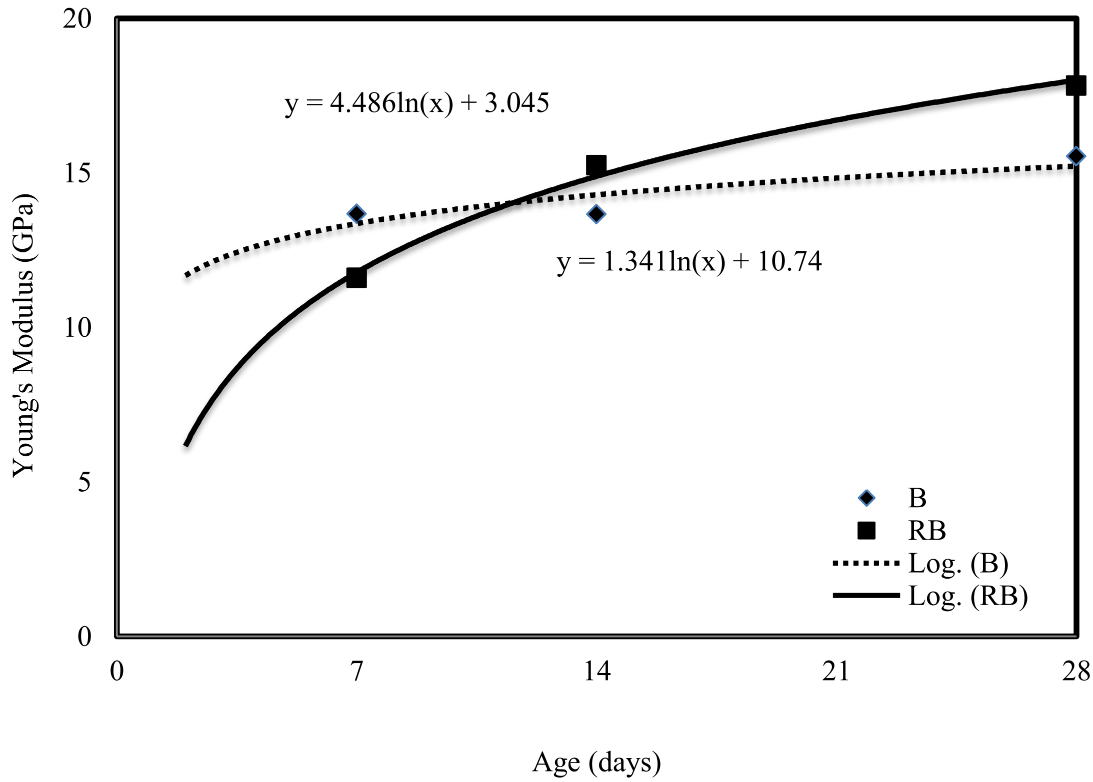


Fig 4.52: Effect of age on modulus of elasticity of concrete with B & RB aggregates having G.I. fiber 0.5%

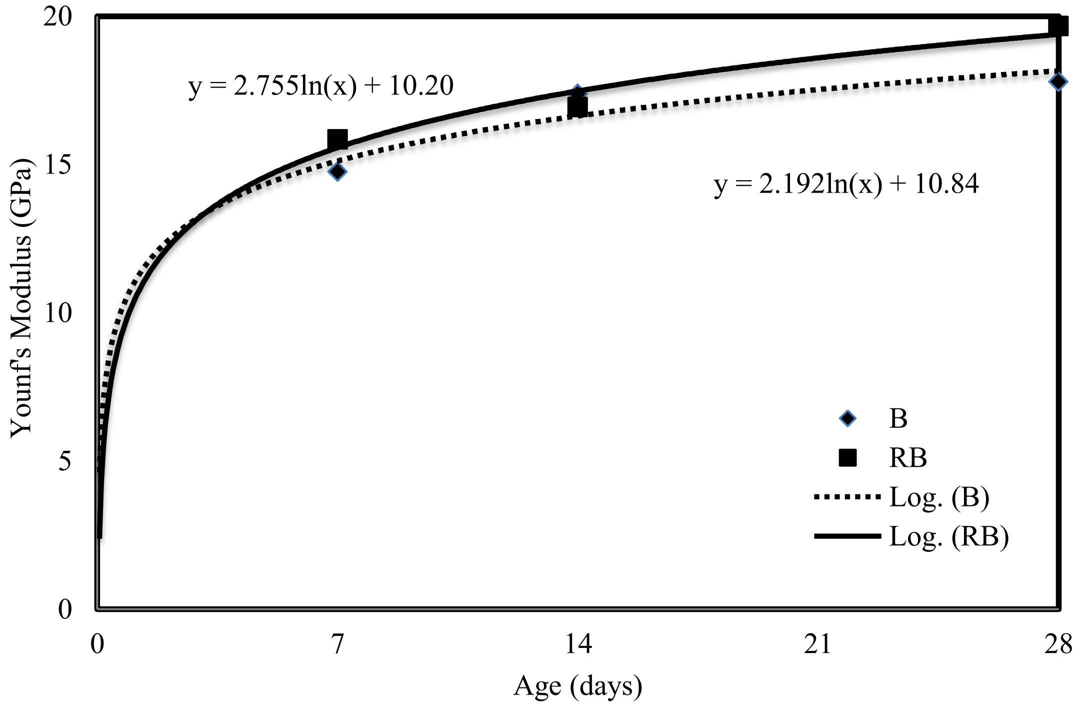


Fig 4.53: Effect of age on modulus of elasticity of concrete with B & RB aggregates having G.I. fiber 1%.

4.3.4.4 Stress-strain behavior

Effects of age on the stress-strain behavior of G.I. fiber reinforced concrete are tested for 7 days, 14 days, and 28 days. Figures 4.54, 4.55 and 4.56 show the stress strain behavior of concrete with fresh brick aggregates for 0%, 0.5% and 1%, respectively. It is observed from these figures that stress taken capacity for 0.5% fiber addition in 28 days is increased 28% compared to that of 14 days. On the other hand, no significant improvement of strain taken capacity is obtained in 28 days compared to that of 14 days. Similar trend is observed for 1% G.I. fiber additions.

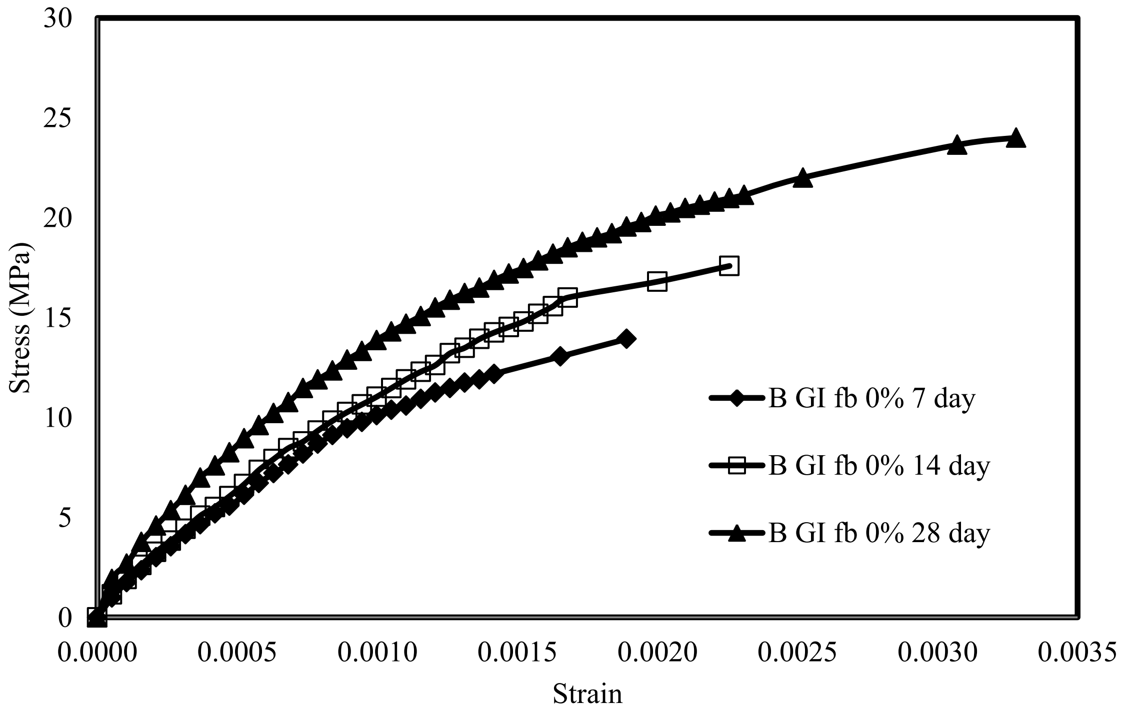


Fig 4.54: Effect of age on stress-strain behavior of concrete with B aggregates having G.I. fiber of 0%

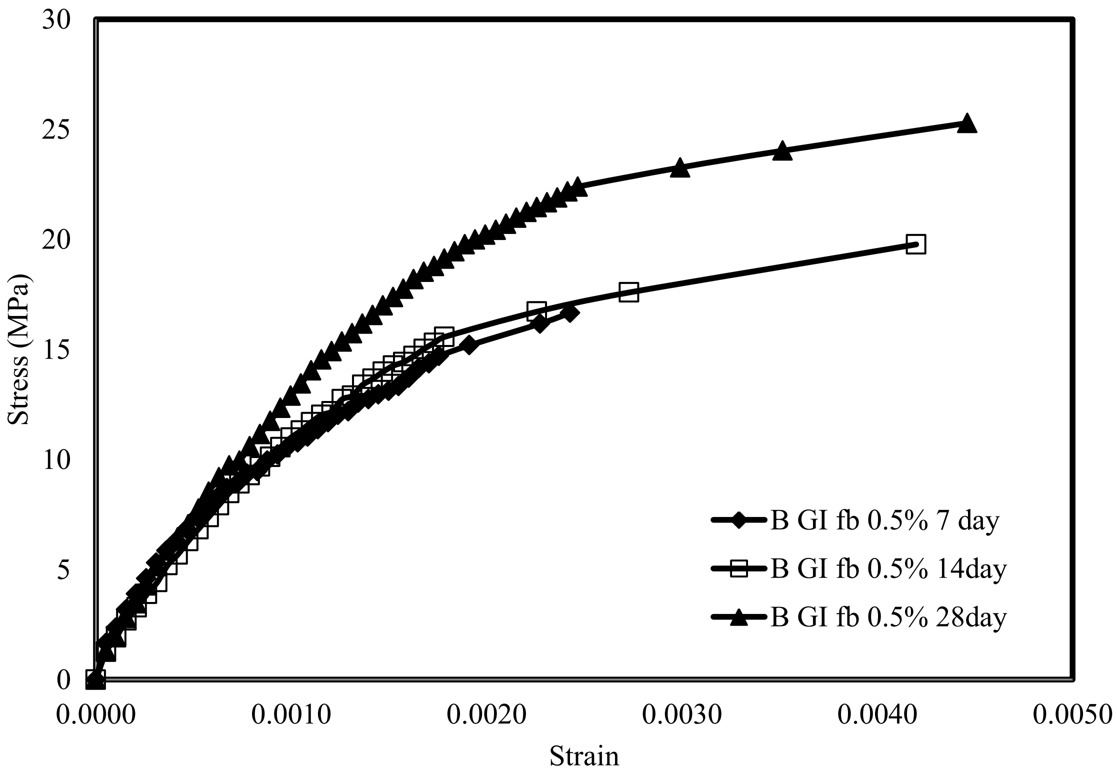


Fig 4.55: Effect of age on stress-strain behavior of concrete with B aggregates having G.I. fiber of 0.5%

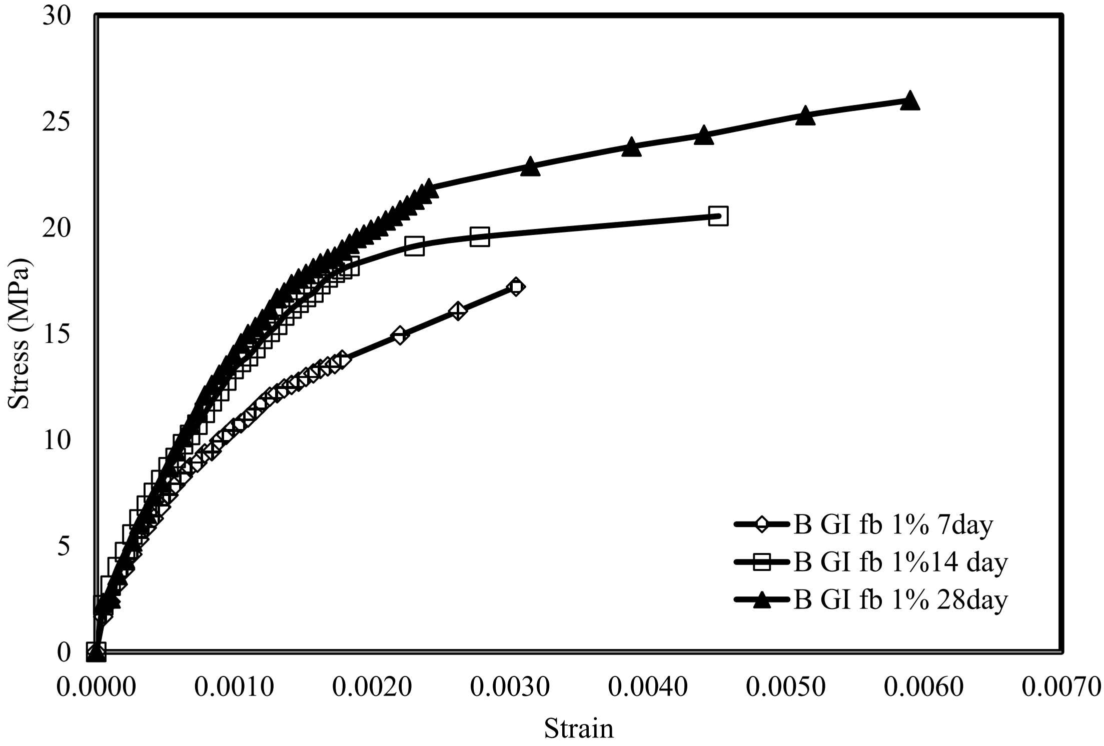


Fig 4.56: Effect of age on stress-strain behavior of concrete with B aggregates having G.I. fiber of 1%

Figures 4.57, 4.58 and 4.59 show the stress-strain behavior of RB concrete for 0%, 0.5% and 1%, respectively. It is observed that from these figures, the stress and strain taken capacity for 0.5% fiber addition in 28 days is increased 27% and 30%, respectively in comparison to that of concrete at 14 days. On the other hand, for 1% fiber addition strain taken capacity is increased 30% and a very little enhancement of stress taken capacity is observed for concrete in 28 days compared to that of 14 days.

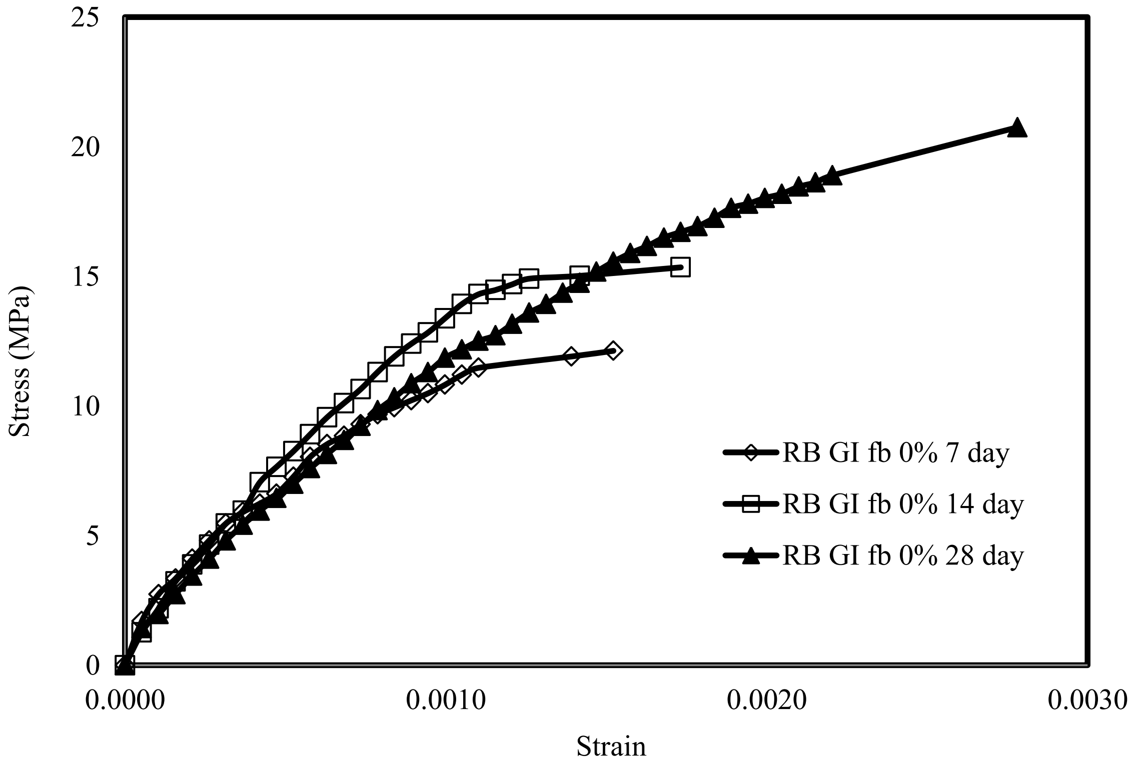


Fig 4.57: Effect of age on stress-strain properties of RB concrete at GI fb 0%

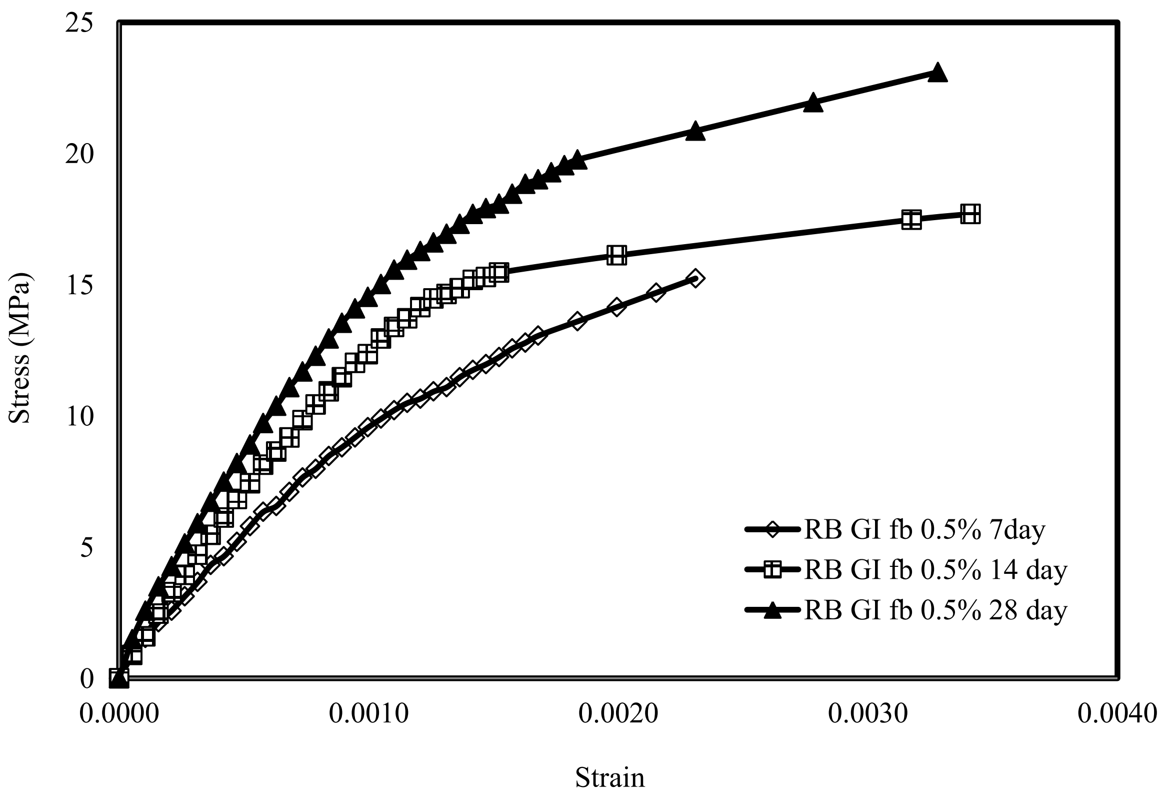


Fig 4.58: Effect of age on stress-strain properties of RB concrete at GI fb 0.5%

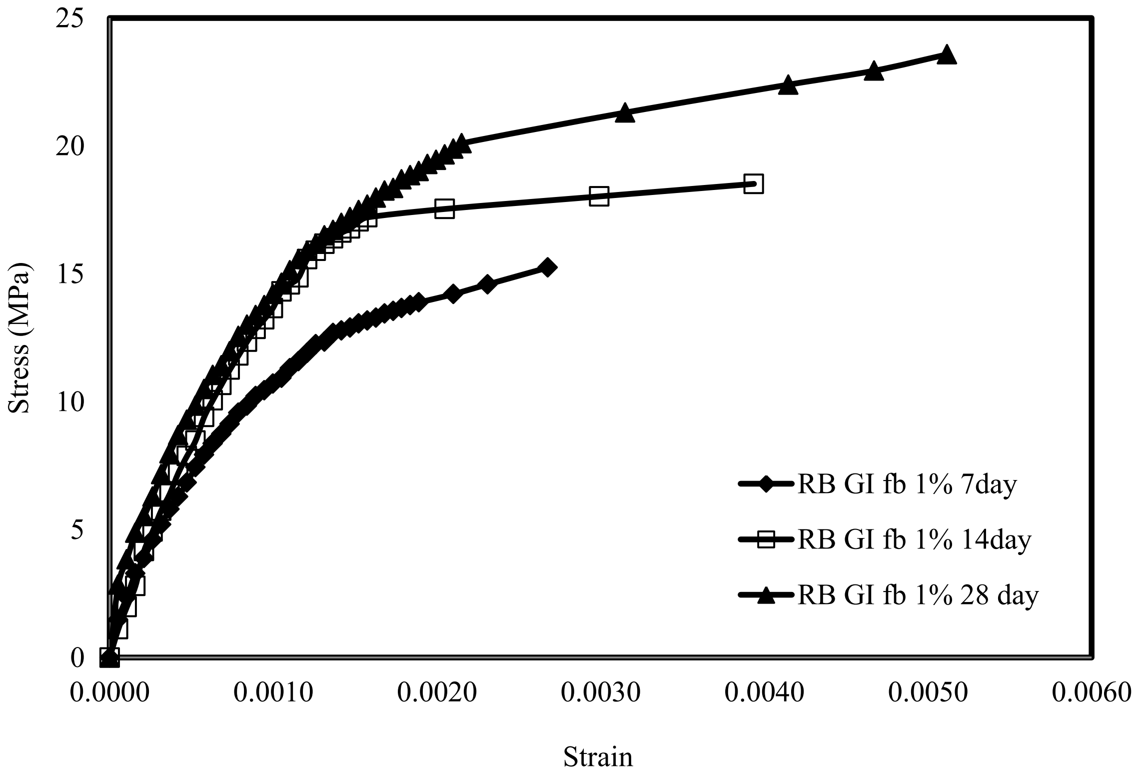


Fig 4.59: Effect of age on stress-strain properties of RB concrete at GI fb 1%

4.4 Relation between workability and strength of concrete

The relationships between workability and compressive strength as well as tensile strength are presented in Figures 4.60 and 4.61, respectively. It is observed that compressive strength increases with the decreases of workability for both the concrete with B and RB aggregates. It is also seen that tensile strength increases with the decreases of workability for both the concrete.

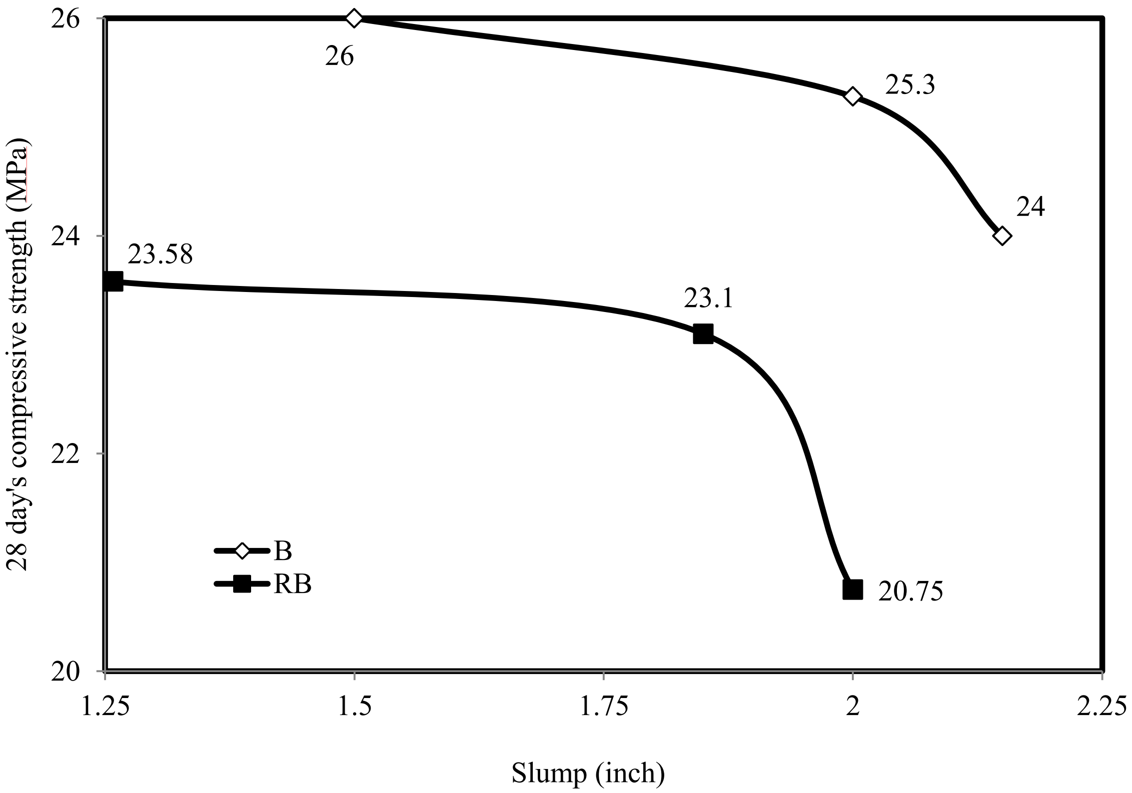


Fig 4.60: Relationship between workability and compressive strength of B and RB concrete

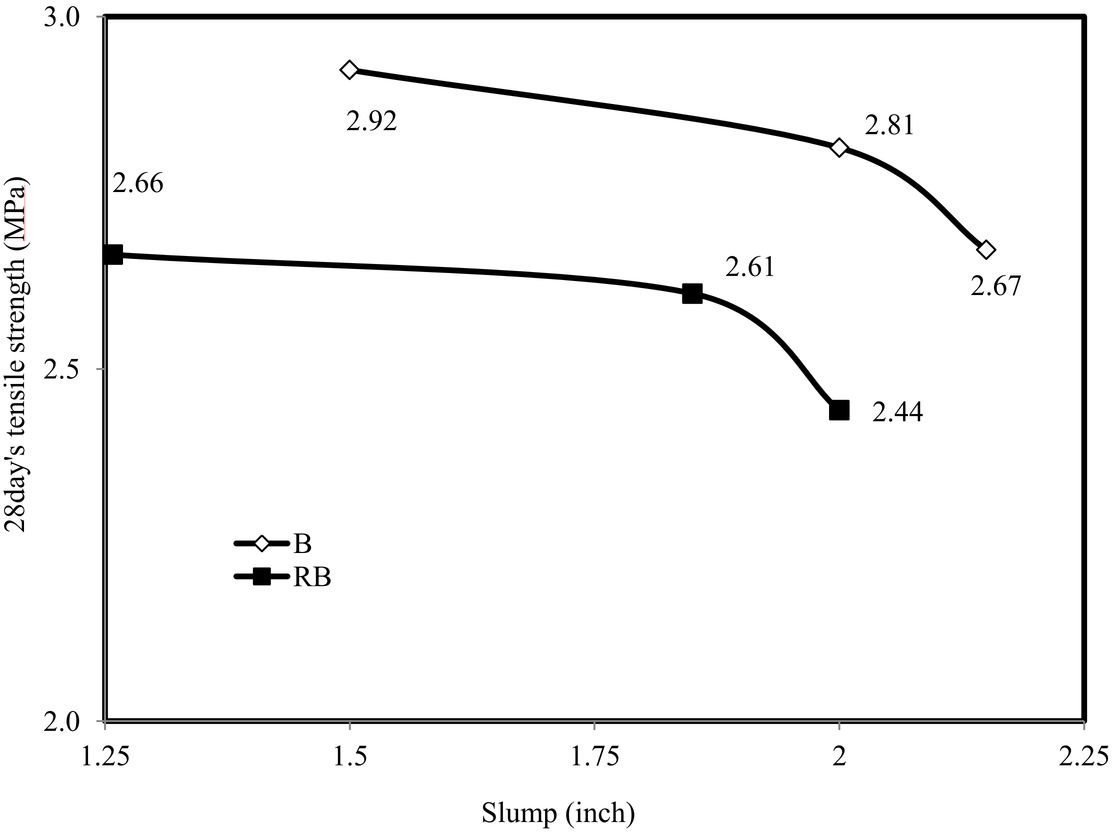


Fig 4.61: Relationship between workability and tensile strength of B and RB concrete

4.5 Relationship of compressive strength of concrete between B and RB aggregates

The relationship of compressive strength of concrete with B and RB aggregates are being proposed as shown in Figure 4.62. It can be said that compressive strength of B concrete is 1.121 times more than that of RB concrete. Therefore, the equation can be stated as follows:

$$f_{c(B)} = 1.121 f_{c(RB)} \quad \text{......} 4.1$$

Where $f_{c(B)}$ = compressive strength of brick aggregate concrete and $f_{c(RB)}$ = compressive strength of recycled brick aggregate concrete

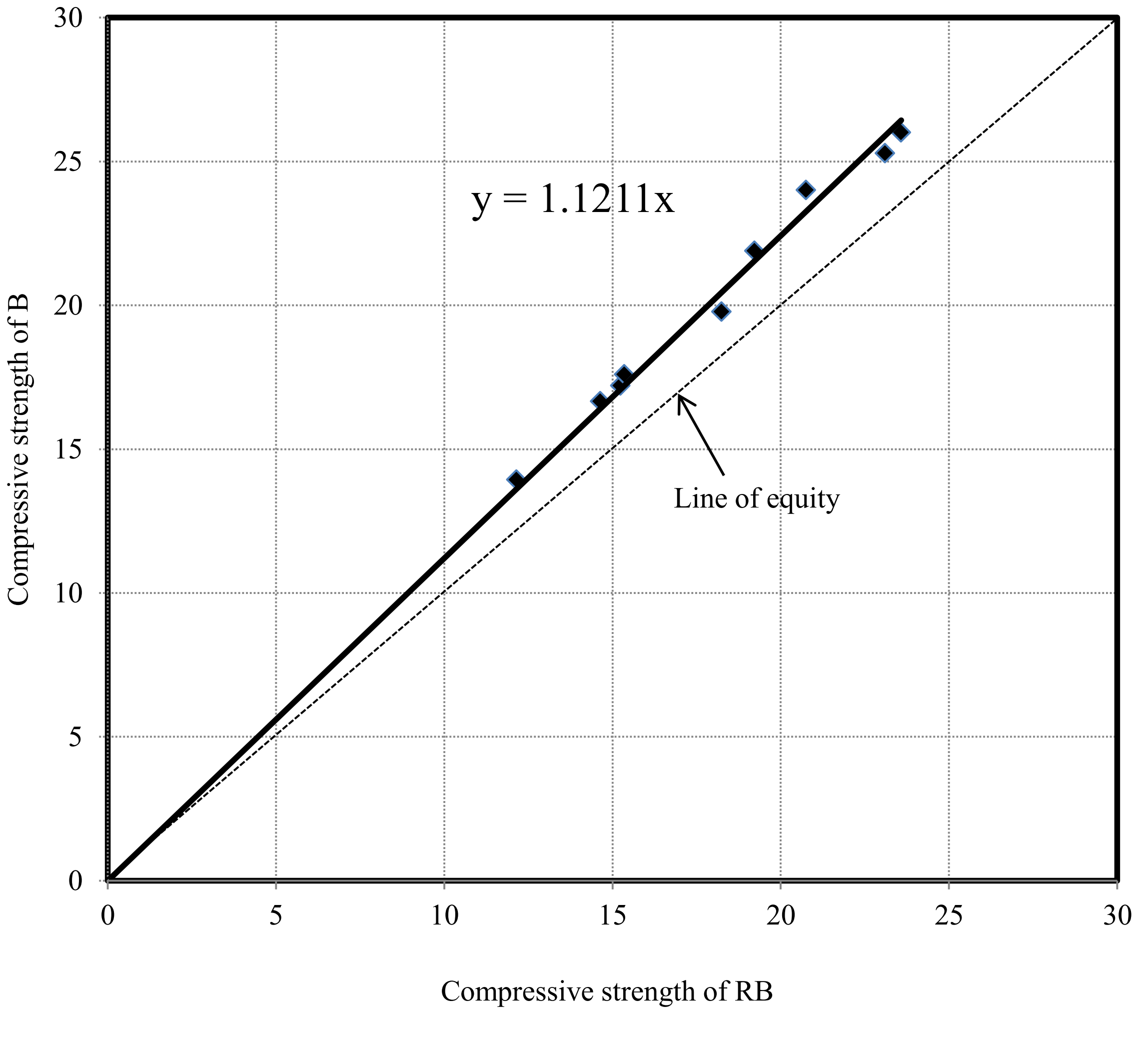


Fig 4.62: Relationship between B and RB concrete

4.6 Relationship of tensile strength between B and RB concrete

It is being proposed the relationship of tensile strength between B and RB concrete shown in Figure 4.63. It can be said that tensile strength of B concrete is 1.117 times more than that of RB concrete. So, the relationship can be written as follows:

$$f_{t(B)} = 1.117\, f_{t(RB)} \quad \text{..........} \quad 4.2$$

Where $f_{t(B)}$= tensile strength of brick aggregate concrete and $f_{t(RB)}$ = tensile strength of recycled brick aggregate concrete

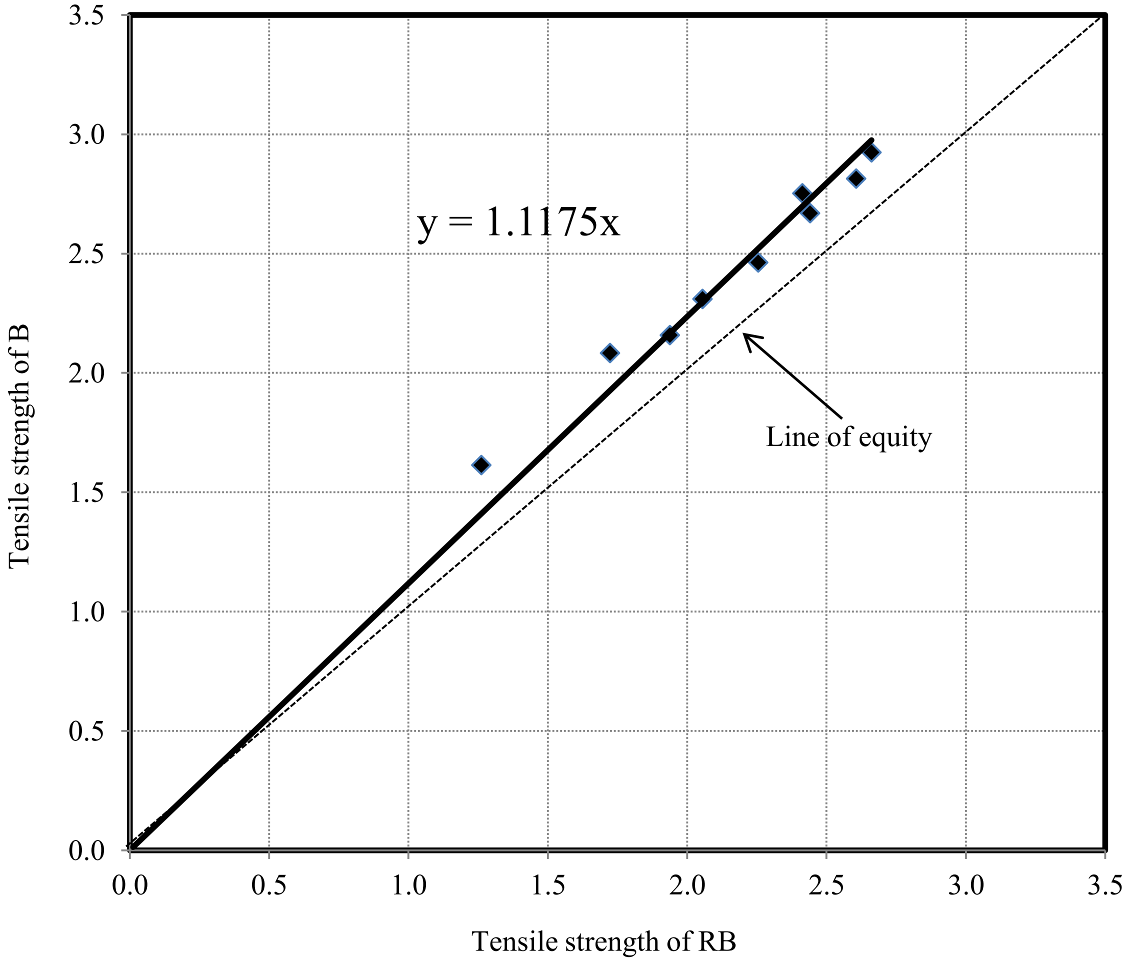


Fig 4.63: Relationship between B and RB concrete

4.7 Relationship between tensile & compressive strength of G.I. fiber reinforced concrete

The variation of tensile strength of G.I. fiber reinforced concrete with compressive strength is shown in Figure 4.64. Based on the experimental data of brick and recycled brick aggregate, the following relationship is proposed between tensile strength and compressive strength of concrete

$$f_t = 0.561\sqrt{f'c} \quad \text{.........} \quad 4.3$$

This equation is valid for G.I. fiber reinforced brick aggregate (B) concrete having the fiber percentage between 0.5 % to 1%.

$$f_t = 0.528\sqrt{f'c} \quad \text{.........} \quad 4.4$$

This equation is valid for G.I. fiber reinforced recycled brick aggregate (RB) concrete having the fiber percentage between 0.5% to 1%.

Where, f_t is tensile strength of concrete in MPa and $f'c$ is compressive strength of concrete in MPa.

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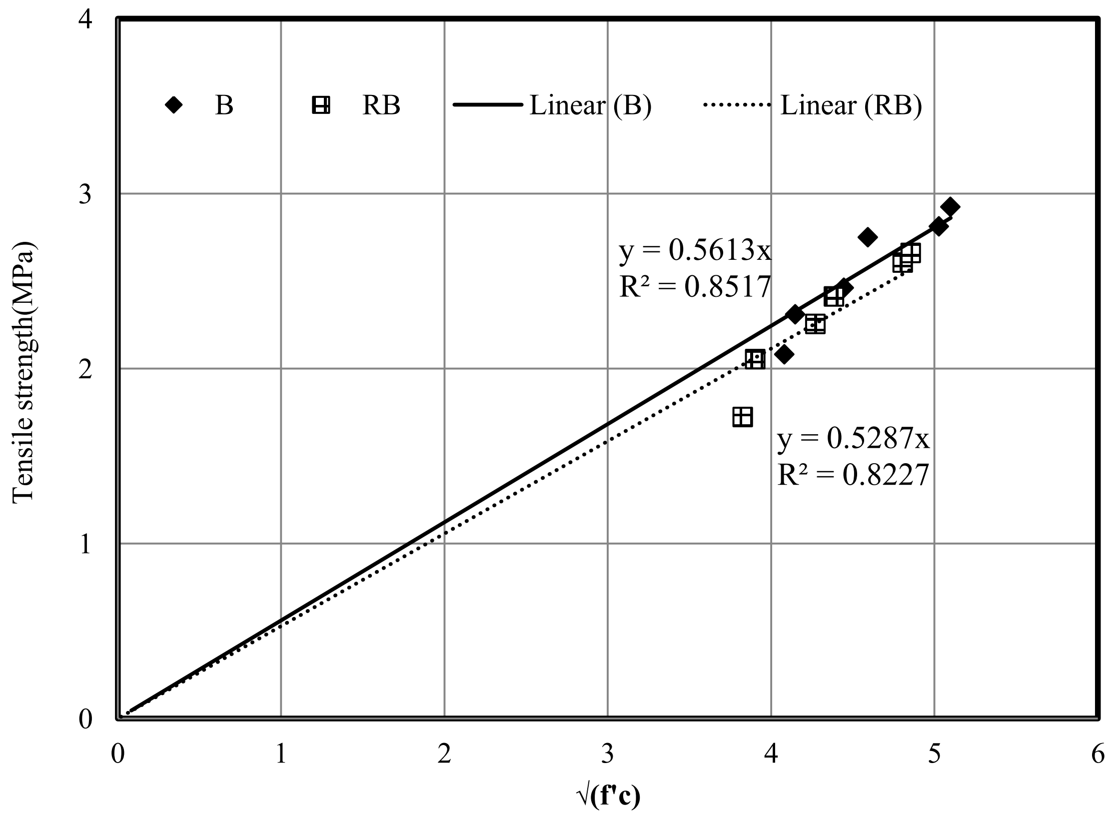

Fig 4.64: Relationship between compressive and tensile strengths of G.I. fiber reinforced concrete made with brick and recycled brick aggregate concrete

4.8 Failure surface

Failure surfaces of brick aggregate and recycled brick aggregate concrete by compressive and tensile strength test are observed and discussions are presented in following subsections.

4.8.1 Failure surface of B concrete

Figures 4.65 and 4.66 show the failure surfaces in compressive and tensile strength of concrete with fresh brick aggregates. Specimens made without G.I. fiber were broken into pieces during both the compressive and tensile strength tests but relatively less brittle failure was seen in the specimens which were made with G.I. fiber as shown in these figures.

(a)

(b)

(c) (d)

Fig 4.65: Fractured surfaces by DT of B concrete with different G.I. fiber replacement-28 days (a) 0% (b) 0.5% Top Portion (c) 0.5% Bottom Portion (d) 1%

(a) (b)

(c)

(d)

Fig 4.66: Fractured surfaces by tensile strength test of B concrete with different GI fb replacement-28 days(a) 0% (b) 0.5% (c) 1% (d) 1% (after breaking by hand)

4.8.2 Failure surface of RB concrete

Figures 4.67 and 4.68 shows the failure surfaces in compressive and tensile strength tests of concrete made with fresh brick aggregates. Specimens made with G.I. fiber were relatively less brittle compare to the control case (0% replacement of fiber).

(a)

(b)

(c)

(d)

Fig 4.67: Fractured surface by DT of RB concrete with different G.I. fiber replacement-28 days
(a) 0% (b) 0.5% (c) 0.5% (d) 1%

(a)

(b)

(c)

(d)

Fig 4.68: Fractured surface by tensile strength test of RB concrete with different G.I. fiber replacement 28- days (a) 0% (b) 0.5% (c) 0.5% (d) 1%

4.9 Summary of the test results

Summary of the mechanical properties of the G.I. fiber reinforced concrete such as compressive strength, tensile strength, modulus of elasticity and ultimate stress-strain values are summarizes in Tables 4.1, 4.2, 4.3 and 4 .4, respectively.

Table 4.1: Summary of the compressive strength test results

SL No.	Case	Compressive Strength (DT) (MPa)		
		7 day	14 day	28 day
1	B GI fb 0%	13.93	17.59	24
2	B GI fb 0.5%	16.66	19.77	25.28
3	B GI fb 1%	17.2	21.08	26
4	RB GI fb 0%	12.15	15.35	20.75
5	RB GI fb 0.5%	14.64	18.24	23..1
6	RB GI fb 1%	15.24	19.22	23.58

Table 4.2: Summary of the tensile strength test results

SL No.	Case	Tensile strength (MPa)		
		7 day	14 day	28 day
1	B GI fb 0%	1.61	2.15.	2.66
2	B GI fb 0.5%	2.08	2.45	2.8
3	B GI fb 1%	2.3	2.74	2.91
4	RB GI fb 0%	1.26	1.93	2.43
5	RB GI fb 0.5%	1.72	2.25	2.6
6	RB GI fb 1%	2.04	2.4	2.65

Table 4.3: Summary of the results of modulus of elasticity of concrete

SL No.	Case	Modulus of elasticity (GPa)		
		7 day	14 day	28 day
1	B GI fb 0%	12.02	13.33	17.93
2	B GI fb 0.5%	13.66	13.67	15.53
3	B GI fb 1%	14.75	17.37	17.79
4	RB GI fb 0%	13.88	15.17	14.13
5	RB GI fb 0.5%	11.6	15.24	17.82
6	RB GI fb 1%	15.84	16.93	19.66

Table 4.4: Summary of the results of ultimate stress-strain values

SL No.	Case	7 day		14 day		28 day	
		Stress* (MPa)	Strain*	Stress* (MPa)	Strain*	Stress* (MPa)	Strain*
1	B GI fb 0%	13.93	0.0019	17.59	0.0023	24	0.0033
2	B GI fb 0.5%	16.66	0.0024	19.77	0.0042	25.28	0.0045
3	B GI fb 1%	17.2	0.003	21.08	0.0045	26	0.0059
4	RB GI fb 0%	12.15	0.0015	15.35	0.0017	20.75	0.0028
5	RB GI fb 0.5%	14.64	0.0023	18.24	0.0034	23..1	0.0033
6	RB GI fb 1%	15.24	0.0027	19.22	0.0039	23.58	0.0051

*Ultimate

Chapter 5
COMPRESSIVE STRENGTH OF CONCRETE BY NON DESTRUCTIVE TEST (NDT)

5.1 General

For the existing structures sometimes it has become necessary to assess the strength of concrete used for the different structural members. Destructive tests such as core cutting may become vulnerable for the critical deficient structural members of structures. Non destructive tests become necessity for this case to assess the vulnerability. The results of compressive strength by destructive test, tensile strength, modulus of elasticity and behavior of stress-strain have been provided in the previous chapter. The current chapter discusses test results of compressive strength of concrete by commonly used non destructive method of Rebound Hammer test.

5.2 Principles of Rebound hammer

Rebound hammer test method is based on the principle that the rebound of an elastic mass depends on the hardness of the concrete surface against which the mass strikes. When the plunger of rebound hammer is pressed against the concrete surface, the spring controlled mass in the hammer rebounds. The amount of rebound of the mass depends on the hardness of concrete surface. Thus, the hardness of concrete and rebound hammer reading can be correlated with compressive strength of concrete. The rebound value is read off along a graduated scale value and is designated as the rebound number or rebound index. The compressive strength can be read directly from the graph provided on the body of the hammer. The only known instrument to make use of the rebound principle for concrete testing is the Schmidt hammer, which weighs about 4 lb (1.8 kg) and is suitable for both laboratory and field work. It consists of a spring-controlled hammer mass that slides on a plunger within a tubular housing. The test surface can be horizontal, vertical or at any angle but the instrument must be calibrated in this position. Calibration can be done with cylinders (6 by 12 in., 15 by 30 cm) of the same cement and aggregate as will be used on the job. The cylinders are capped and firmly held in a compression machine. Several readings are taken, well distributed and reproducible, the average representing the rebound number for the cylinder. This procedure is repeated with several cylinders, after which compressive strengths are obtained.

5.3 Advantages and disadvantages of rebound hammer tests

The rebound hammer test method is used for the following purposes

(a) To find out the likely compressive strength of concrete with the help of suitable co-relations between rebound index and compressive strength.

(b) To assess the uniformity of concrete.

(c) To assess the quality of concrete in relation to standard requirements.

(d) To assess the quality of one element of concrete in relation to another.

Rebound hammer test method can be used to differentiate the acceptable and questionable parts of the structure or to compare two different structures based on strength. The Schmidt hammer provides an inexpensive, simple and quick method of obtaining an indication of concrete strength, but accuracy of ±15 to ±20 per cent is possible only for specimens cast cured and tested under conditions for which calibration curves have been established. The results are affected by factors such as smoothness of surface, size and shape of specimen, moisture condition of the concrete, type of cement and coarse aggregate, and extent of carbonation of surface

5.4 Testing procedure of compressive strength by using Rebound Hammer

Non destructive test are carried out by Schmidt hammer and angle of the inclination is $\alpha = -90^0$ and minimum of ten times of non destructive tests are performed for both the sides of each specimens. The average value obtained from these data is determined for each cylinder specimen. This test is conducted according to ASTM C805. Figures 5.1 and 5.2 show the conversion curves from Rebound number to compressive strength of concrete and Rebound Hammer testing, respectively used in the current study.

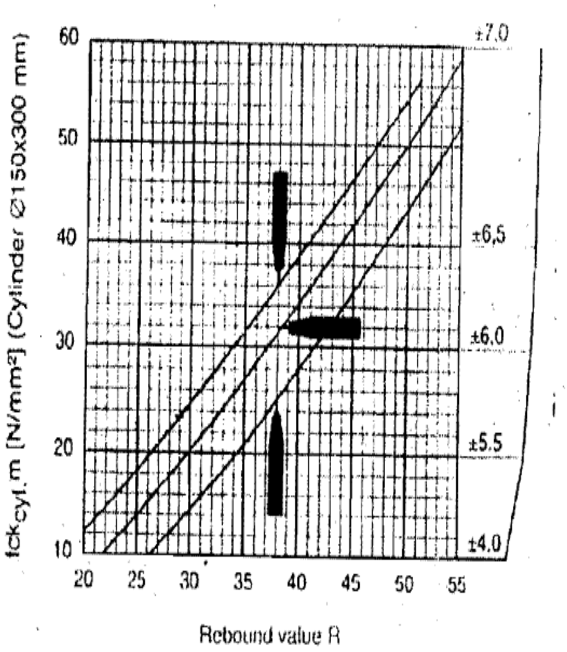

Fig 5.1: Conversion diagram of RH   Fig 5.2: RH (Schmidt hammer) testing method

5.5 Hardened concrete properties

Mechanical properties i.e. compressive strength by non destructive test (NDT) of hardened concrete has been examined in this study. Here, effects of fiber additions on compressive strength of both the aggregates as well as the effect of aggregate types and age on compressive strength have been observed. To understand the effect G.I. fiber addition on compressive strength by using rebound hammer, two types of coarse aggregates such as fresh brick and recycled brick aggregates having the same W/C = 0.44, S/A=0.44 and cement content=390 kg/m^3 are used.

5.5.1 Effect of G.I. fiber additions on concrete with fresh brick (B) aggregates

Effect of G.I. fiber additions on compressive strength by using Rebound Hammer of brick aggregate concrete is assessed at 7 days, 14 days, and 28 days. The results of investigation are presented in Figures 5.3, 5.4, and 5.5, respectively. A significant enhancement is observed for compressive strength test using rebound hammer for different fiber additions. About 21% increase in 28 days compressive strength is observed for 0.5% G.I. fiber addition compared to control case (0% G.I. fiber addition). For 1% G.I. fiber addition, 29% increase in compressive strength is obtained.

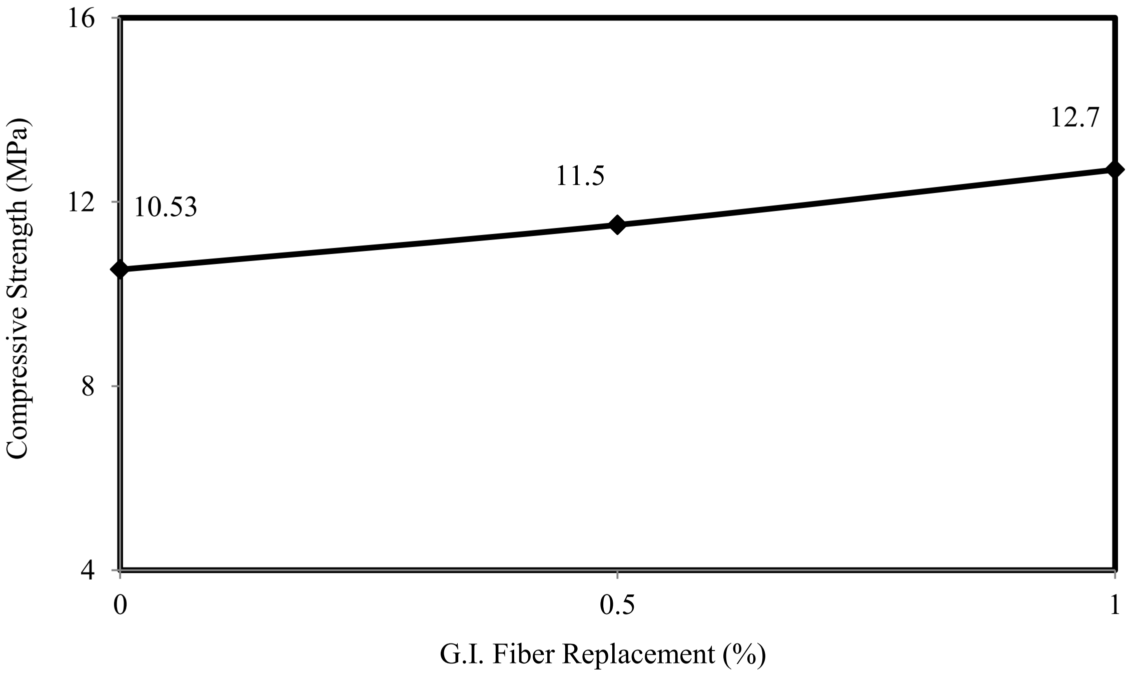

Fig 5.3: Compressive strength (NDT) of concrete with fresh brick aggregates at 7day

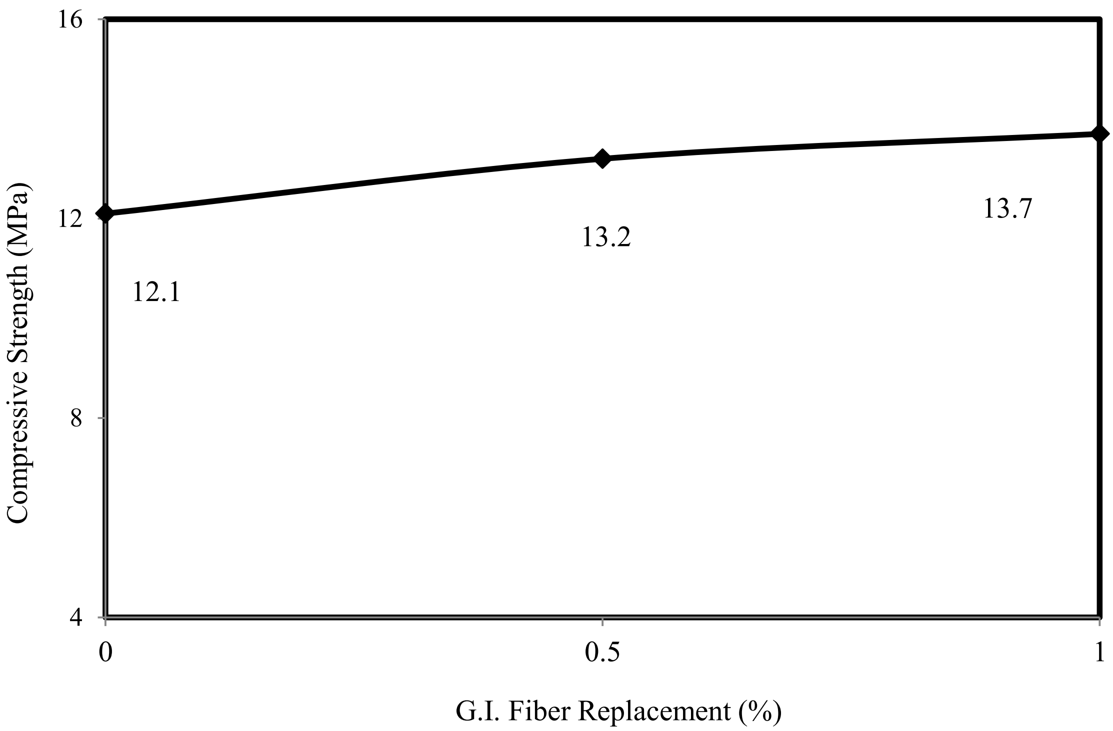

Fig 5.4: Compressive strength (NDT) of concrete with fresh brick aggregates at 14 day

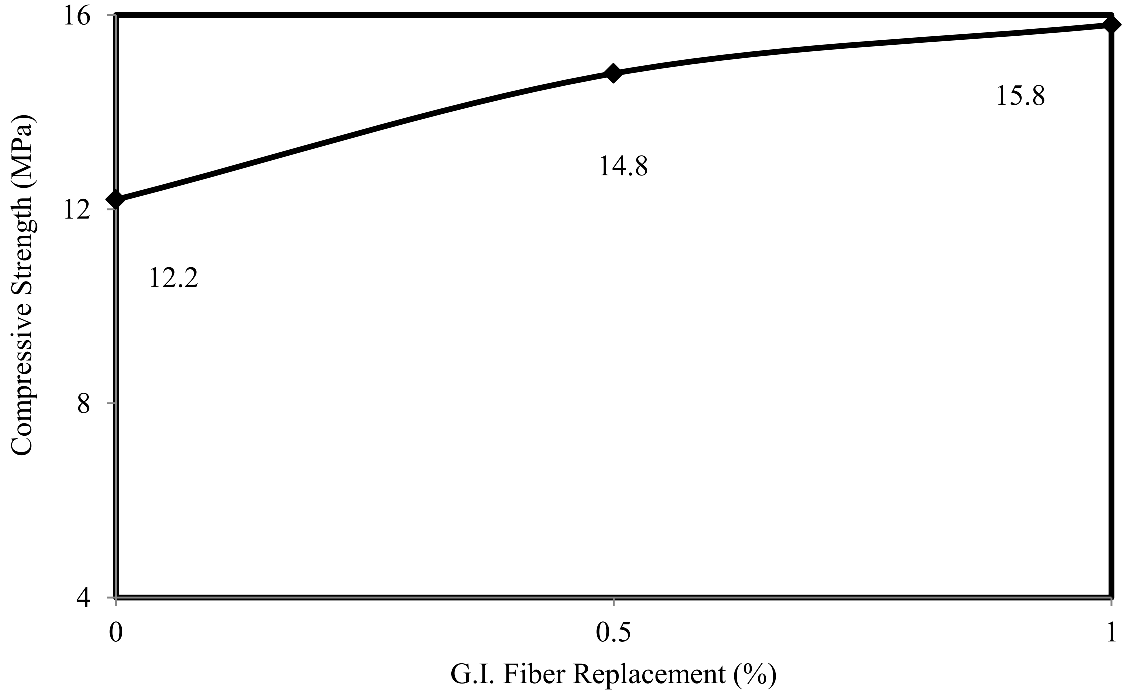

Fig 5.5: Compressive strength(NDT) of concrete with fresh brick aggregates at 28day

5.5.2 Effect of G.I. fiber additions on concrete with recycled brick (RB) aggregates

Effect of G.I. fiber additions on compressive strength of concrete with recycled brick aggregates by using Rebound Hammer is observed at 7days, 14 days, and 28 days. The results of investigation are shown in Figures 5.6, 5.7, and 5.8, respectively for 7 to 28 days. A significant enhancement is observed for compressive strength test by using rebound hammer test for different fiber additions. About 14% increase in 28 days compressive strength is observed for 0.5% G.I. fiber addition in comparison to the control case (0% G.I. fiber addition). On the other hand, for 1% G.I. fiber addition 18% increase in compressive strength is obtained.

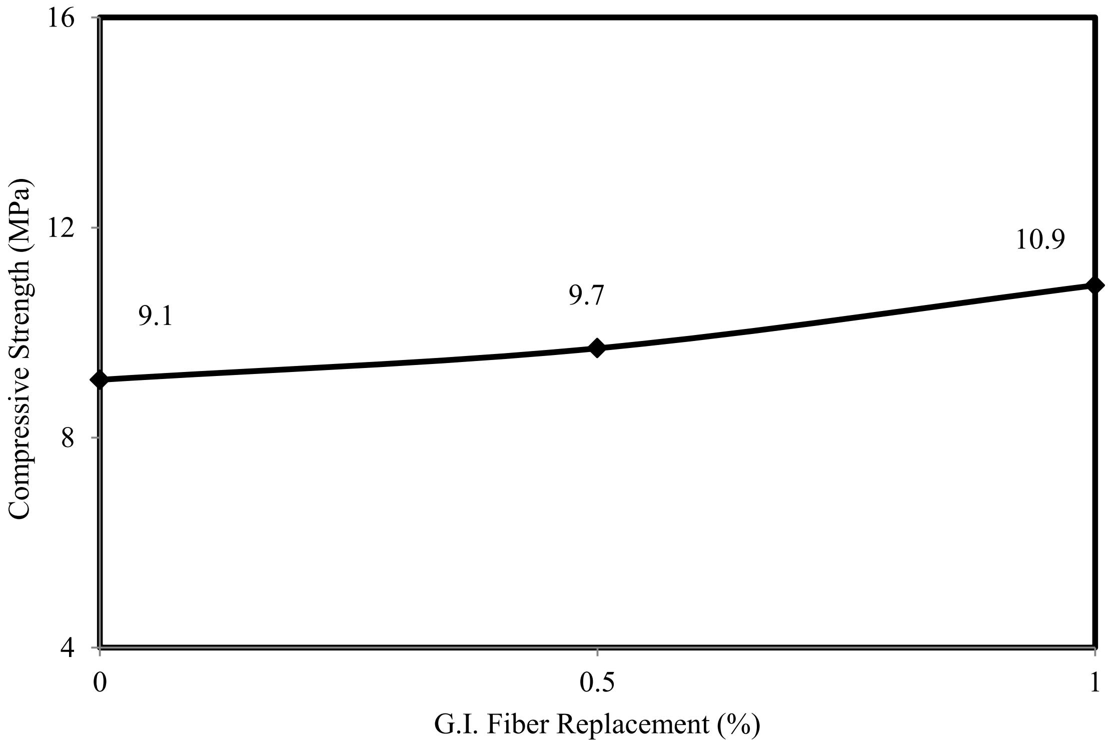

Fig 5.6: Compressive strength(NDT) of RB concrete at 7 day

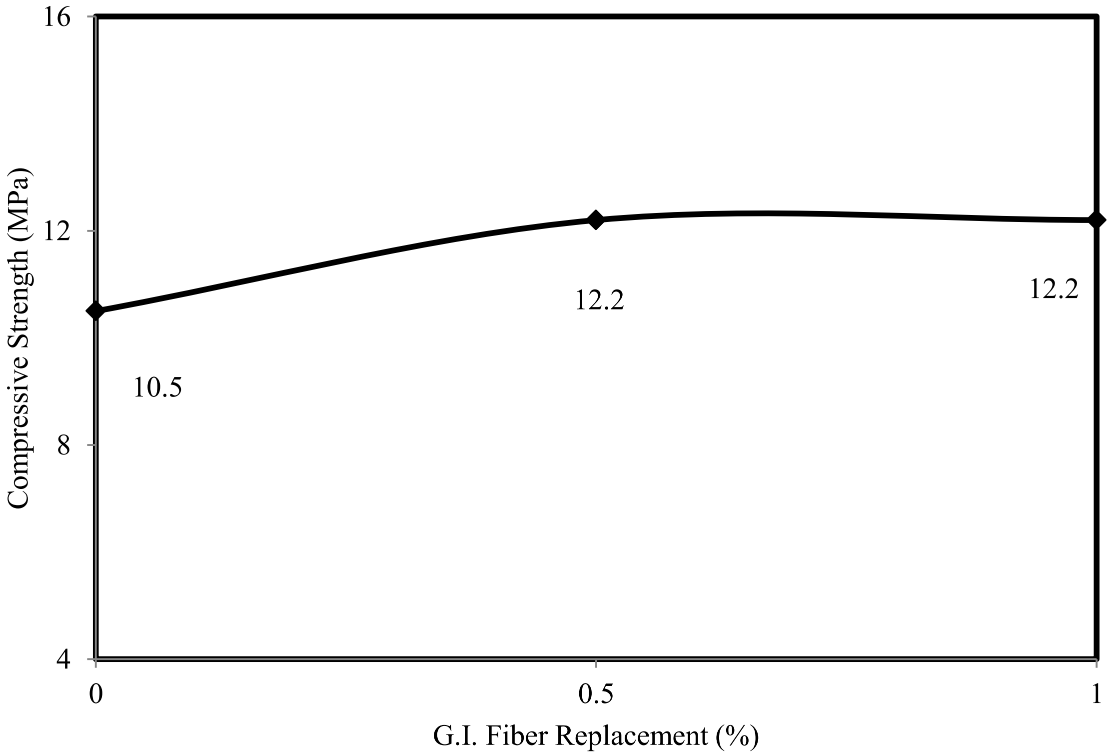

Fig 5.7: Compressive strength(NDT) of RB concrete at 14 day

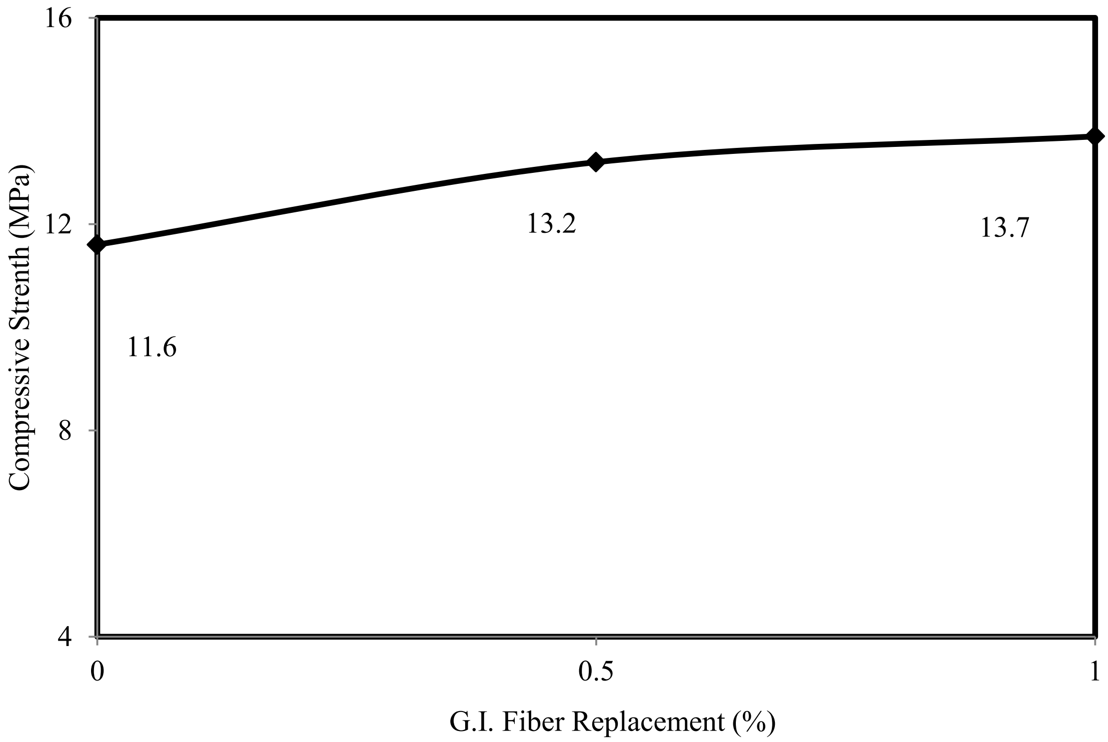

Fig 5.8: Compressive strength(NDT) of RB concrete at 28 day

5.5.3 Effect of aggregate types on compressive strength of concrete

Effect of aggregate type on compressive strength of plain and G.I. fiber reinforced concrete by using Rebound Hammer tests is assessed at 7 days, 14 days, and 28 days and the results are shown in Figures 5.9, 5.10, and 5.11, respectively. A little improvement is observed in compressive strength with the increase of G.I. fiber addition for all tested ages. About 15% increase in 28 days compressive strength of B concrete is observed for 1% G.I. fiber addition compared to RB concrete for the same fiber addition. However, no significant improvement is observed for 0.5% G.I. fiber additions.

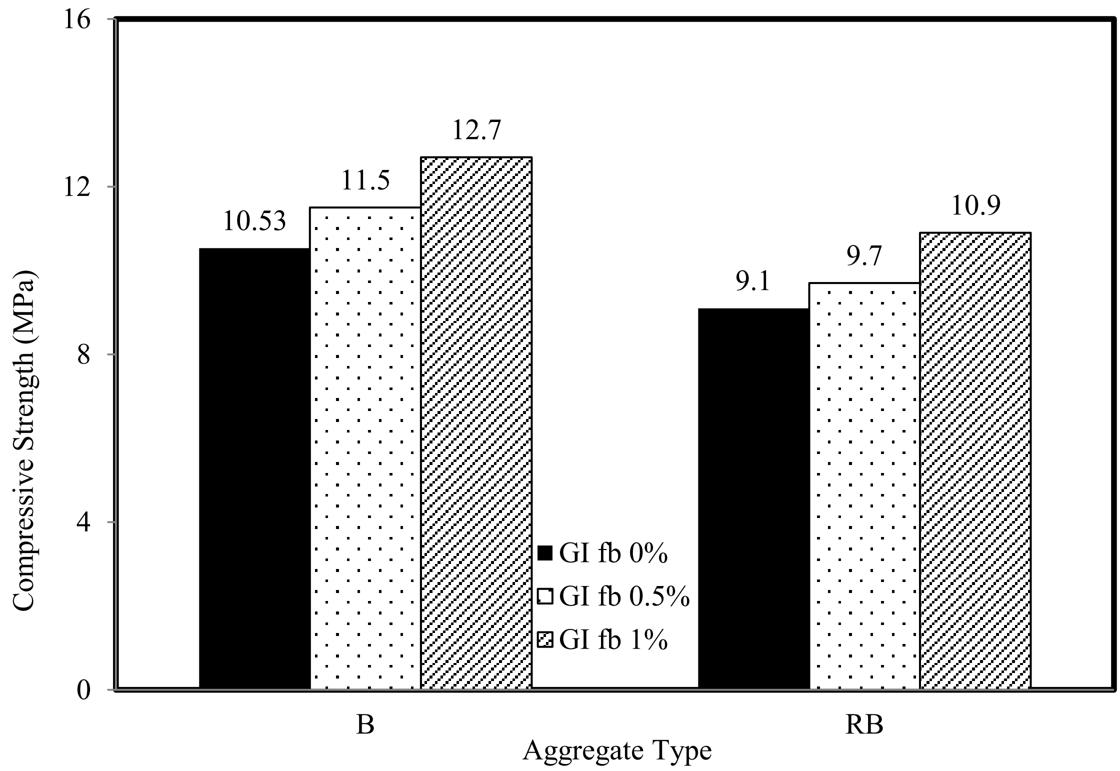

Fig 5.9: Compressive strength (NDT) of B & RB concrete at 7 day

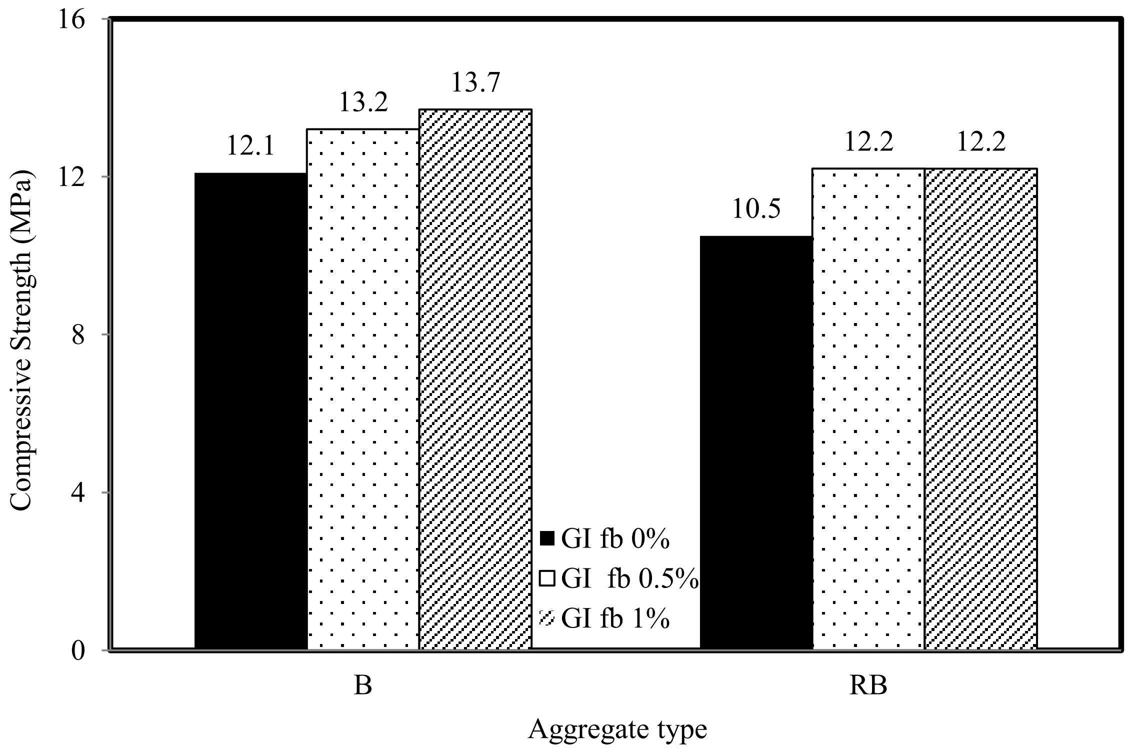

Fig 5.10: Compressive strength (NDT) of B & RB concrete at 14 day

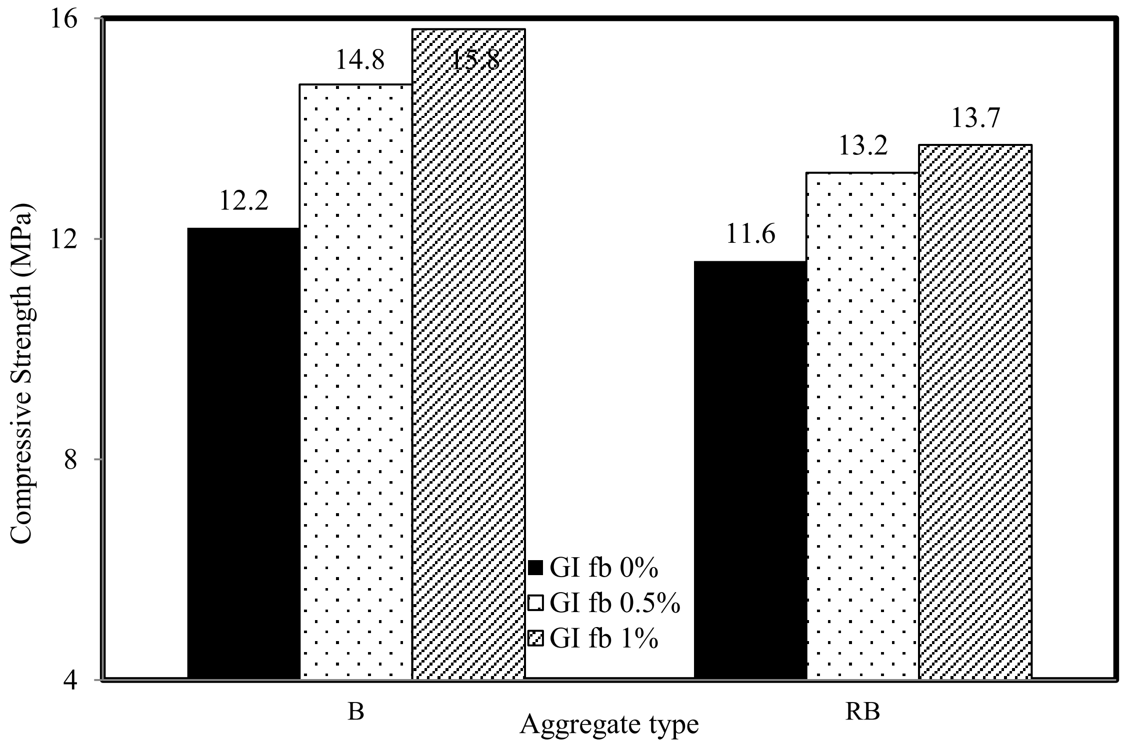

Fig 5.11: Compressive strength (NDT) of B & RB concrete at 28 day

5.5.4 Effect of age on compressive strength of concrete

The variations of the compressive strength by using Rebound Hammer with age of concrete specimens are shown in Figures 5.12, 5.13 and 5.14 for G.I. fiber 0%, 0.5% and 1%, respectively. From these figures, it can be said that compressive strength increases with the increase of specimen age. It is observed that rate of change of compressive strength of B concrete is more than that of RB concrete for 0.5% fiber additions. About 15% increase in compressive strength in 28 days is observed. Similar trend is found for 1% fiber addition in 28 days. Concrete strength increases with the age of concrete. Compressive strength can also be calculated for any desired period of time as shown in these figures.

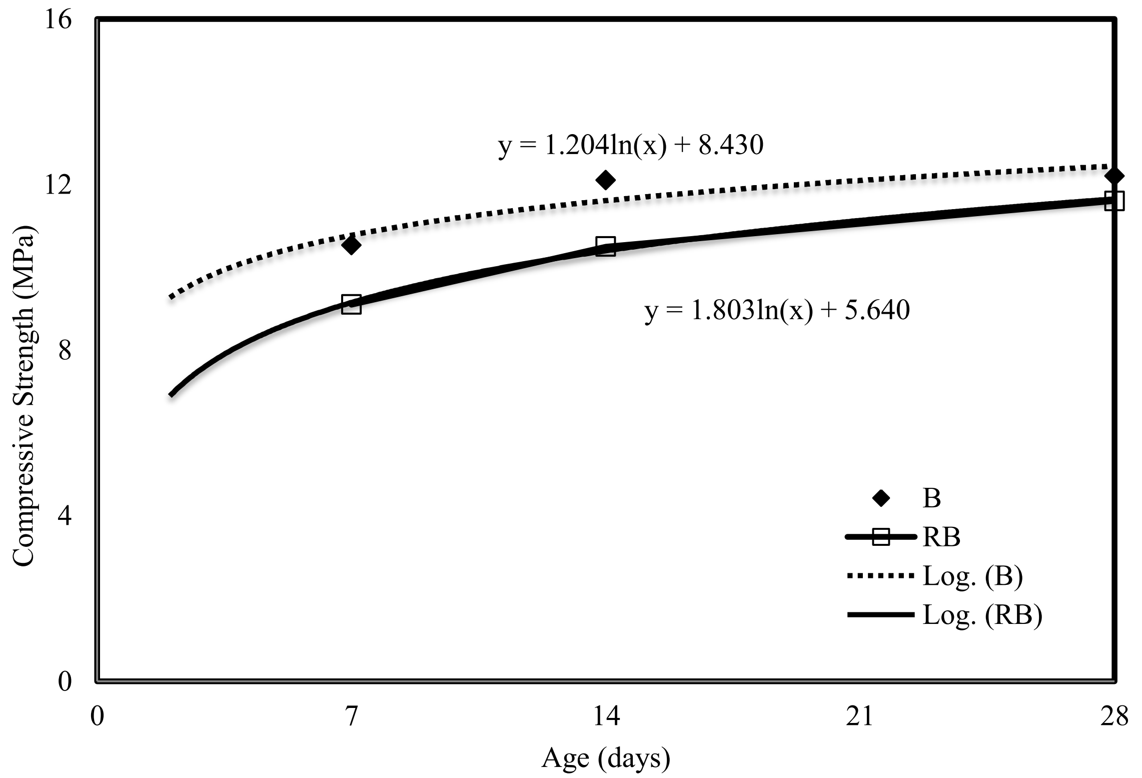

Fig 5.12: Effect of age on compressive strength (NDT) of B & RB concrete at GI fb 0%

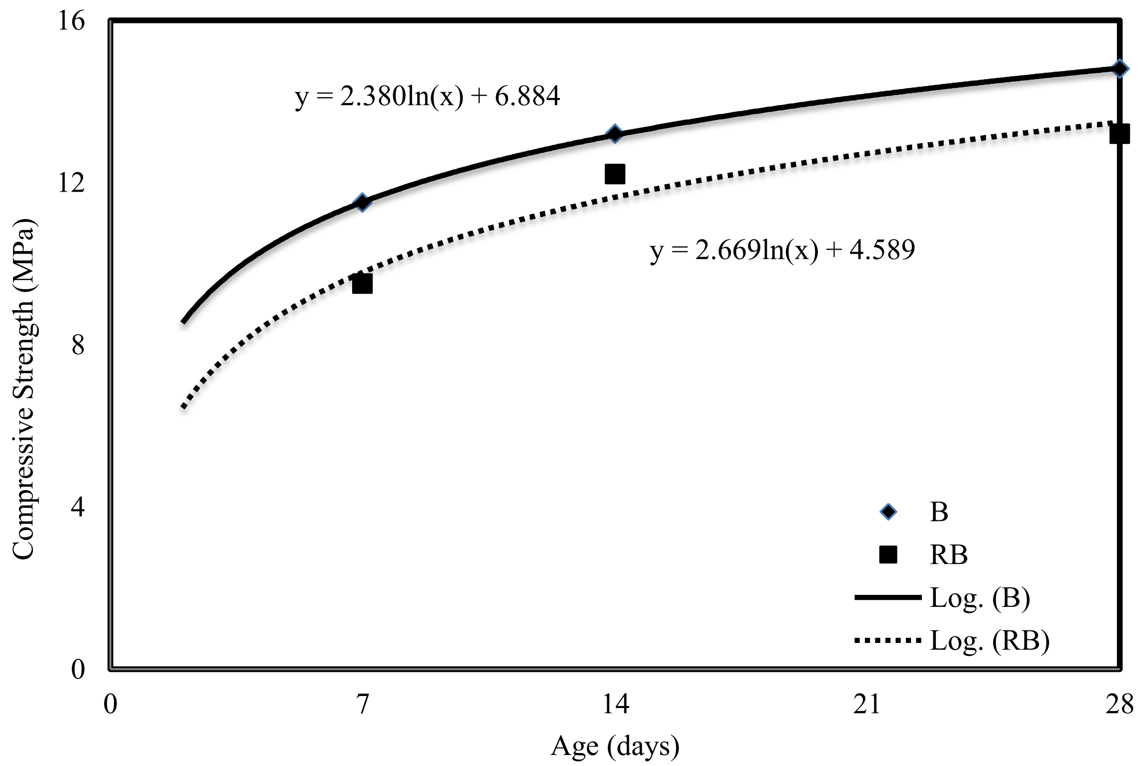

Fig 5.13: Effect of age on compressive strength (NDT) of B & RB concrete at GI fb 0.5%

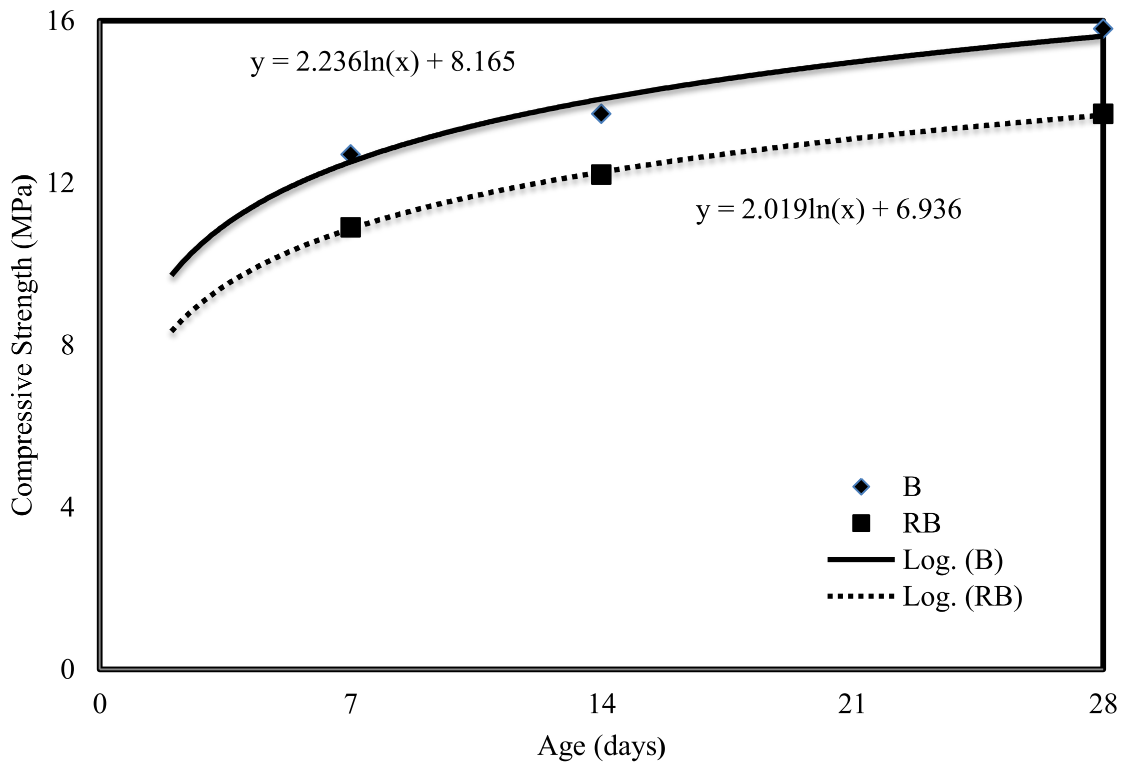

Fig 5.14: Effect of age on compressive strength (NDT) of B & RB concrete at GI fb1%

5.6 Relationship of compressive strength between NDT and DT

The relationship of compressive strength of concrete by using non destructive tests (NDT) and destructive test (DT) of G.I. fiber reinforced concrete is being proposed as shown in Figure 5.15. It can be said that compressive strength of destructive is 1.55 times more than that of non destructive tests. NDT tests provide conservative values for this case of study. Cylinder strength test provides the actual strength of the concrete specimens. To get the actual strength of concrete, NDT values shall be magnify by a factor of 1.55 for the tested concrete. Therefore, the relationship between the NDT and DT can be stated as follows:

DT* = 1.55 *NDT ……………………………………………….………..……**5.1**

Where NDT= Non destructive compressive strength and DT= destructive compressive strength.

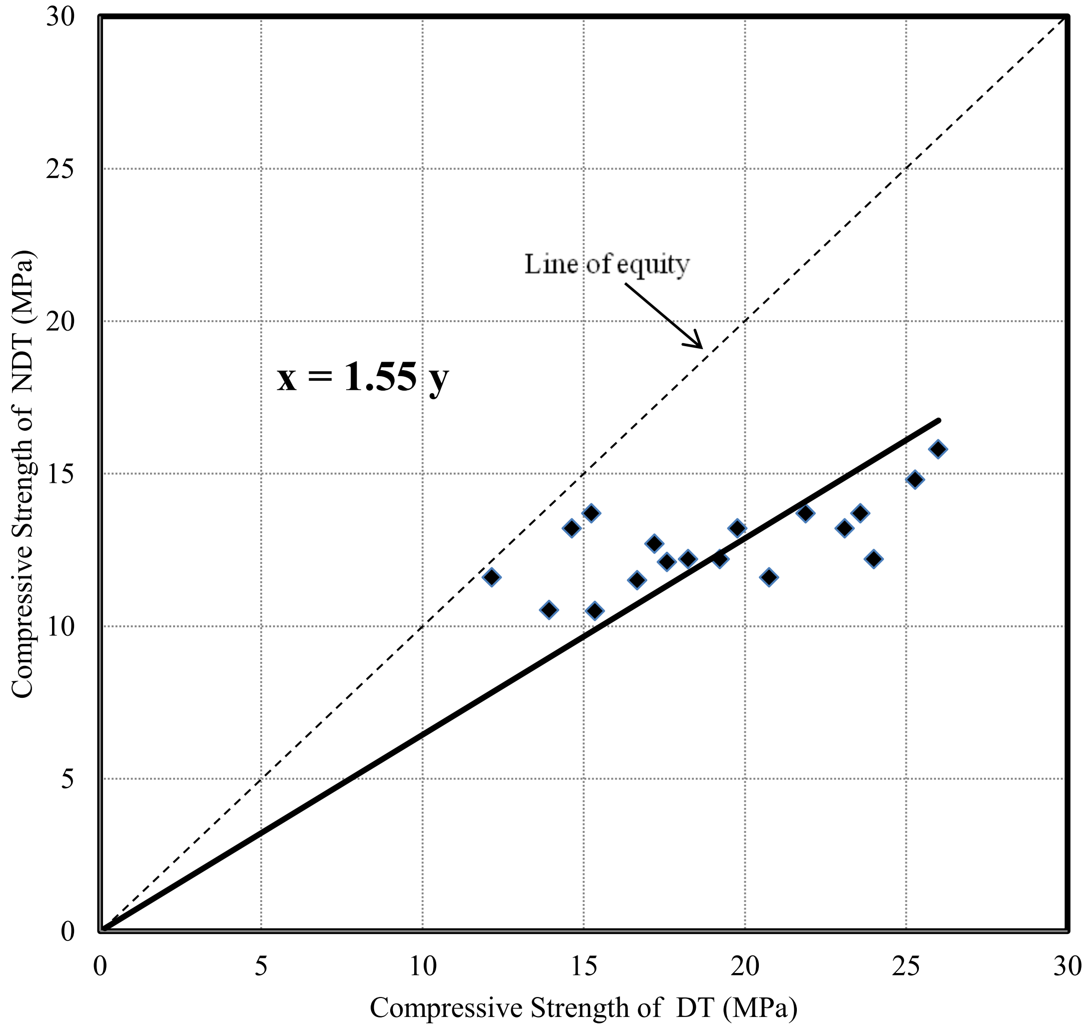

Fig 5.15: Relationship of compressive strength of concrete between NDT & DT tests

5.7 Summary of the test results

Summary of the mechanical property i.e. compressive of plain and G.I. fiber reinforced concrete has been summarized in the table 5.1

Table 5.1: Summary of the compressive strength test results by NDT

SL No.	Case	Compressive strength(NDT) (MPa)		
		7 day	14 day	28 day
1	B GI fb 0%	10.53	12.1	12.2
2	B GI fb 0.5%	11.5	13.2	14.8
3	B GI fb 1%	12.7	13.7	15.8
4	RB GI fb 0%	9.1	10.5	11.2
5	RB GI fb 0.5%	9.7	12.2	13.2
6	RB GI fb 1%	10.9	12.2	13.7

Chapter 6
CONCLUSIONS AND RECOMMENDATIONS

6.1 Introduction

An experimental program was conducted to study the behavior of Galvanized Iron (G.I.) fiber reinforced concrete made with fresh brick and recycled brick aggregates. Two different fiber additions such as 0.5% and 1% were considered in the present study. These fibers were added in concrete mix for both the fresh and recycled brick aggregates keeping the other parameters such as w/c ratio, cement concrete and fine aggregate/coarse aggregate ratio same. The experimental study was broadly categorized two cases such as concrete made with fresh brick aggregates and recycled brick aggregates. For each case, one concrete control mix without any fiber addition was tested at 7, 14, and 28 days. Concrete specimen with 0.5% and 1% G.I. fiber addition resulted in total six types of concrete mixes. A fresh concrete property such as slump of concrete was measured in each type and was compared with one another. Hardened concrete properties such as concrete compressive strength, tensile strength, modulus of elasticity and stress-strain behavior of concrete were observed in each type of concrete and was tested in 7, 14, and 28 days. The obtained results of experimental study were compared with one another to assess the applicability of using recycled brick aggregates as well as G.I. fiber additions on the concrete.

Non destructive test such as Rebound Hammer test was also performed on the concrete specimen to assess the concrete compressive strength. The relationship between destructive and non destructive test results for compressive strength of concrete was also obtained. The main conclusions of this research work and suggestions for future studies are outlined summarized in the following sections.

6.2 Conclusions

The main conclusions that can be drawn from this experimental study are stated as below:

(a) The workability of concrete decreases with the increase of amount of fibers for concrete with both the fresh brick aggregate and recycled brick aggregate. Workability is further reduced when recycled brick aggregates are used due to their high water absorption capacities.

(b) The presence of fiber alters the failure mode of cylinders, but the fiber effect was minor on the improvement of compressive strength values.

c) About 5% to 10% increase in 28 days compressive strength of G.I. fiber reinforced concrete made with brick aggregate was shown in comparison to control case (0% G.I. fiber addition). On the other hand, 10% to 15 % enhancement was observed for recycled brick aggregate compared to the control case. It may due to the rough surface and nice bonding between the fiber and recycled aggregate. The effect of addition 1% fiber on compressive strength was little compare to that of 0.5% for the both types of aggregate.

(d) About 25% to 30% increase in 28 days compressive strength by using Rebound hammer test of G.I. fiber reinforced concrete was shown having fresh brick aggregates compared to the control case (0% G.I. fiber addition). On the other hand, this value was 20% to 25 % for recycled brick aggregate concrete compared to the control case. It may be due to the hardened concrete properties of brick aggregates. The effect of 1% fiber addition on compressive strength was little compared to that of 0.5% G.I. fiber additions for both the types of aggregates.

(e) A significant improvement was found in splitting tensile strength of values of 40% and 60% for G.I. fiber reinforced concrete made with brick aggregate and recycled brick aggregates, respectively in 7 days compared to the control case (0% G.I. fiber addition). However, this improvement (about 10%) was not significant in 28 days for concrete with both the types of aggregates.

(f) About 5% improvement was found in Young's Modulus for G.I. fiber reinforced concrete made with fresh brick and recycled brick aggregates. However, no regular pattern of results were observed for both the plain and G.I. fiber reinforced concrete having both the types of aggregates.

(g) Rupture strain limit of concrete made with fresh brick aggregates was 20% more than that of the concrete with recycled brick aggregates.

(h) Rupture strain limit of G.I. fiber reinforced concrete was increased almost 2 times compared to that of the plain concrete. For the 0.5% G.I. fiber addition, strain taken capacity of concrete with fresh brick aggregate was increased about 36% in comparison to that of the concrete having recycled brick aggregates. However, for 1% fiber this improvement was not significant, about 16% increase in strain taken capacity of concrete with brick aggregates compared to that of the recycled brick aggregates.

(i) Compressive strength of concrete obtained by non destructive Rebound Hammer test shows lower values than that of destructive cylinder tests for all the tested ages. The relationship between nondestructive and destructive test are proposed and it shows that destructive strength is 1.55 times the non destructive strength.

6.3 Limitations of the present study:

Locally available low grade steel fiber made from steel wire has been considered as G.I. fiber in the present study. Locally available fresh brick aggregate and recycled brick aggregate in Bangladesh have been considered as natural and recycled aggregates, respectively in the present thesis.

6.4 Recommendations for the future studies

1. Additions of G.I. fiber used in the present study are 0.5% and 1%. A wide range of G.I. fiber addition may be used to assess the optimum value of G.I. fiber in the enhancement of different mechanical properties of concrete.
2. Different sizes and shapes of the G.I. fiber may be used to assess their applicability in enhancement on different mechanical properties of concrete.
3. Concrete made with recycled brick aggregates may be partially replaced to assess the applicability in the construction sectors.
4. Research study of G.I. fiber reinforced concrete may be extended for structural member behavior such as on reinforced concrete beams, beam-column joints of structures.
5. Effect of addition of different types of admixtures on G.I. fiber reinforced concrete made with fresh brick and recycled brick aggregates may be investigated.
6. Numerical investigation as well as analytical studies may be conducted to get a design aid for concrete made with G.I. fiber reinforced concrete.

7. New correlation curves may be established for non destructive rebound hammer test and crushing strength test of concrete made with brick and recycled brick aggregates.

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