IMPROVING COMPRESSIVE AND TENSILE STRENGTH OF SLAB SLEEPERS FOR RAILWAY BRIDGE BY MECHANISM OF STEEL FIBER REINFORCED CONCRETE

By

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DECLARATION

I, the undersigned, declare that this thesis is my original work except where indicated by full references, prepared under the guidance of Dr Asnake Adamu. All sources of materials used for the thesis have been duly acknowledged. I further confirm that the thesis has not been submitted either in part or in full to any other higher learning institution for the purpose of earning any degree or professional qualification.

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ABSTRACT

Concrete is a material that needs strengthening in tension in order to meet the structural requirements. New techniques of strengthening concrete, besides the usual ordinary reinforcement bars, are developing; fiber reinforced concrete is one of them. Fibre reinforcement is a method that has been in use over the last 30 years, yet it is unfamiliar in our country Ethiopia.

This research study deals with experimental investigation of C-30 grade concrete with the addition of 1% ,1.5% and 2% of steel fiber, 4% & 5% glass fiber and deferent percentage mix of glass steel fibre. For comparison purposes, plain control samples were also considered. This study was undertaken aiming to investigate the mechanical behavior of concrete reinforced with the addition of steel fibers, glass fibre and mix of steel glass fibre hoping to improve the compressive and tensile strength of the plain concrete in order to use on railway bridges slab track in Ethiopia railway projects to prevent cracks on bridge slab sleepers from the reputedly application of static and dynamic loads of the train.

The test program was included slump test, compressive strength test, flexural strength test and toughness tests including load-deflection curve for each mix series. And the results show that, workability of fresh concrete was largely influenced by the presence of steel fiber and glass fibre; on the other hand it was unlikely to achieve considerable improvements in compressive strength by glass fiber inclusion but it was steel fiber indicates good improvement on the concrete compressive strength up to 26.37% of relative strength grain comparing with the plain concrete and the flexural tensile strength and the post crack energy absorption were greatly increased with relative strength gain 66.2% and 273.73% respectively.

However, further, study is still necessary in order to have a more in-depth understanding of the material interactions and possible practical applications.

Key words: Concrete, steel fibers, glass fibre, fiber reinforced concrete, Compressive strength, Flexural strength, Energy absorption

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AALRT	Adis Abeba light rail transit
ACI	American Concrete Institute
ASTM	American Standard Testing Method
BS	British Standard
DOE	Department of Environment
ECWC BTCS	Ethiopian construction works corporation, Building technology and construction sector
ENRP	Ethiopian national railway program
ES	Ethiopian Standard
FRC	Fiber Reinforced Concrete
GFRC	Glass Fiber Reinforced Concrete
HBL	Hydraulic Bounding Layer
HRWR	High-range water-reducing admixtures
kN	Kilo Newton
LRT	Light rail transit
MPa	Mega Pascal
OPC	Ordinary Pozzolana Cement
PVA	Polyvinyl alcohol
SFRC	Steel Fiber Reinforced Concrete
SGFRC	Steel and glass fibre reinforced concrete
SP	Super Plasticizers
SSD	Saturated Surface Dry Condition
w/c	Water to Cement ratio

CHAPTER I - INTRODUCTION

1.1. Background

When we construct traditional houses in Ethiopia we use a mud with addition of grass in order to make it strong. Our ancestors don't know the properties of tensile strength of a mud but our ancestors know how to prevent micro cracks in order to avoid bigger cracks and failure of the wall. In the modern day of construction, we use steel fiber reinforced concrete in order to prevent micro cracks as our ancestors use grass in mud.

The well-known inherent deficiencies of concrete are its tensile strength and its brittleness. These weaknesses of concrete lead to immediate collapse of plain concrete after formation of first cracks and its propagation, at very low value of tensile stress developed in the cross section [1] due to static and dynamic loads of the train. We can increase the tensile strength of the concrete by inserting longitudinal and shear reinforcements but even by this mechanism we cannot increase compressive strength of the concrete and avoid cracks as we want. Fibres that are short materials randomly spread in the concrete mix, are however discontinuous. Fibres do not increase the (tensile) strength remarkably, but due to their random distribution in the mix, they are very effective when it comes to controlling cracks. As a result the ductility of fibre reinforced members is increased. Fibres can also be used in thin and complex members where ordinary reinforcement cannot fit, [1].

In conventional concrete, micro-cracks develop before structure is loaded because of drying shrinkage and other causes of volume change. When the structure is loaded by static and dynamic loads of the train , the micro cracks open up and propagate because of development of such micro-cracks, results in inelastic deformation in concrete, [2]. So, in this study we deal with experiments and investigation of C-30 grade ordinary mix concrete with the addition of different percentage of small metal chips of steel fiber, a number of small fibers are dispersed and distributed randomly in the concrete at the time of mixing, and thus improve concrete properties in all directions. The fibers help to transfer load to the internal micro cracks. In other words we can avoid small cracks that lead to bigger cracks in our bridge sleepers because the addition of small closely and uniformly dispersed metal fiber chips to concrete would act as crack arresters and would substantially improve the response of the bridge sleeper to static and dynamic loads of the train.

As we all know Ethiopia was the first East Africa country to have railway transportation system and infrastructure for about 100 years ago but by different problems the old railway transportation system and infrastructure collapsed in two generations.

Currently the country is building new railway transportation and infrastructure again. These infrastructures build today are for the current generation and for generation to come next . In order to fulfill safety requirements, the railway infrastructure constructed must be strong and durable. But as have been noticed in the Adis Ababa LRT railway projects there are defects located on the bridges slab sleepers (there are some small cracks on them). Small cracks (small problems) today will propagates and become bigger cracks (bigger problems) and this will lead in to total failure of the bridge slab sleepers and the transportation system. If the total failure of the bridges slab sleepers and transportation system happens it will put negative impact in our Economy

Exhibited photos that the bridges slab sleepers having cracks in the AA LRT from Mexico, Legehar and Stadium stations are shown below.

Fig.1.1 Bridge slab sleeper around Legehar

Fig.1.2 Cracked bridge slab sleeper around Mexico

Fig.1.3 Cracked sleeper at stadium station

Fig.1.4 Crashed sleeper at Mexico station

In this study, it is aimed at improving the compressive strength of bridge slab sleepers by a method where, metal chips added in to the ordinary C-30 concrete. By adding metal chips in to concrete we expect the following improvements;

- Decreasing or avoiding of the cracks on the bridge slab sleepers is the main expecting output from this project,
- Increase the tensile strength of the bridge slab sleepers,
- Increase the fatigue life and impact strength of the bridge slab sleepers,
- Increase the post cracking capacity of the bridge slab sleepers and
- Increase the ductility strength of the bridge slab sleepers.

1.2. Objective

1.2.1. General Objective

The main objective of this thesis is by minimizing or avoiding cracks on bridge slab sleepers (track slab sleepers) increase the life time of the slab sleepers and totally the structure in other words by adding different percentage of steel and glass fibre in to the ordinary concrete mix increasing the properties of compressive strength, tensile strength, flexural toughness and over all the mechanical properties of the concrete that we use on bridge slab sleepers to increasing the life time of the slab sleepers (track slab sleepers) and the total structure.

1.2.2. Specific objective

- Minimize or avoid cracks on bridge slab sleepers,
- Introduce steel fiber reinforced concrete to the bridge railway structures,
- Increase the life time of the bridge slab sleepers and totally the bridge structure,
- Minimizing the maintenance cost for bridge slab sleepers by increasing the life time of the structure and
- Increase the Mechanical properties of the bridge slab sleepers,

1.3. Scope and limitation of the study

This Study limits on experimental study to improve the three mechanical properties of concrete compressive, flexural strength and flexural toughness by adding small amount of steel fiber to ordinary concrete. Based on type of bridges and track slabs the scope of the study is also limited to concrete structures specifically on railway track slab sleepers. Since most of railway infrastructures in Ethiopian are concrete structures this work will be very helpful in order to build them strong and durable. In this regard the experimental study is made to improve compressive, flexural strength and toughness of track slab sleepers by mechanism of steel fibre reinforced concrete in order to use in Ethiopian railway projects.

Thus, the thesis will be concerned to railway track slab sleepers made up of cast in place reinforced concrete and the study;

- Do not cover all the mechanical properties of concrete except compressive, flexural strength and toughness,

- Do not include design of Steel fiber reinforced concrete it only deals with laboratory experimental study of SFRC,
- It also more focused on steel fiber reinforced concrete and
- It only shows better alternative of concrete to use on track slab.

1.4. Methodology

The research started off with problem identification of cracked slab tracks (Slab sleepers) on AALRT and through a brief literature reading. Upon obtaining the identified problem thorough literature review was conducted to provide a depth understanding on fibre reinforced Concrete, focusing on Mechanical properties of SFRC, fresh properties of SFRC, durability of SFRC, mix design considerations for SFRC, mixing, placing and finishing of SFRC and practical application of SFRC. This study was undertaken aiming to investigate the mechanical behavior of concrete reinforced with the addition of steel fibers, glass fibre and mix of steel & glass fibre hoping to improve the compressive and tensile strength of the plain concrete..

Since the research specifically emphasizes on steel fiber reinforced concrete, the literature review will provide further understanding on the measurement of properties of SFRC. Therefore, an overview of currently available and modified test methods used to evaluate the compressive strength, flexural strength and the toughness of SFRC will also be provided as a supplement to the literature review. The advantages and shortcomings of these test methods will also be discussed.

Initially, important tests have been conducted on the constituent material to determine the gradation and physical properties of fine and coarse aggregate, chemical composition and other characteristic of cement and properties of steel fibers. After carrying out tests on the fresh concrete the specimens for the testing of mechanical properties in the hardened state have been prepared by pouring the concrete into lubricated moulds. For mix of 0%, 1%, 1.5% & 2% of steel fibre, 0%, 4% & 5% glass fiber and mix of steel & glass fiber have been casted in three 150mm cubes and three 100x100mm cross section with 600mm span beams for each percentage of fibre. Cubes have been used for the determination of compressive strength. And Beam specimens have been used for the determination of flexural tensile strength.

After carrying out the tests the results obtained will be discussed and by using inputs form the laboratory results design of Slab track (slab sleeper) by software called SAP will be made. Finally, conclusions will be made and recommendations for future studies will be forwarded.

1.5. Application of the study

Application of this study is for all concrete structures. The world we living today prefers concrete to build structures because of its strength and ability to cast in any mould that's why we use concrete to build our railway infrastructures too but the concrete we use today in our railway infrastructures are one step behind because the new technology of concrete is Steel fiber reinforced concrete. we already practicing to use steel fibre for shotcrete on railway tunnel lining ,in Awash-Weldiya-Haragebeya project, that is good sign in introducing steel fiber to our construction industry but we can use steel fiber in all our concrete structures and this thesis shows by experiment how mechanical properties of ordinary concrete improves by adding small percentage of steel fiber so that we can use on track slab sleepers.

When we see other county's application of steel fiber reinforced concrete, Precast concrete track slabs for high speed passenger trains in Europe have used steel-fber reinforced concrete in combination with traditional reinforcement to significantly reduce crack width and/or the required amount of reinforcement leading to durability improvement. A reduction of reinforcing bar up to 50% is possible while keeping crack width constant. The quality of the structure is increased due to better material properties and workability. Significant time savings can be achieved in addition, [7].

We can mention a lot of steel fiber applications in construction industry but in order to relate to this paper the above example will be enough.

1.6. Thesis out line

1.6.1. What is on this thesis

The thesis is organized to six chapters. Chapter one of the study include the background, objectives and Scope of the study in addition to briefing the contents of the study. The Back ground describes general ideas about conventional concrete micro-cracks and steel fiber reinforced concrete. The objective describes the general goals of the study and what to expect at the end of the study. The scope and limitation of the study describe the range of the study according to different parameters and also what the study does not include.

The second chapter is devoted to literatures survey on steel fiber reinforced concrete in general and its properties in particular. It addresses on types and classification of steel fiber, Lists and explains properties of steel fiber reinforced concrete and at the end lists and explains reinforcement mechanism in fiber reinforced.

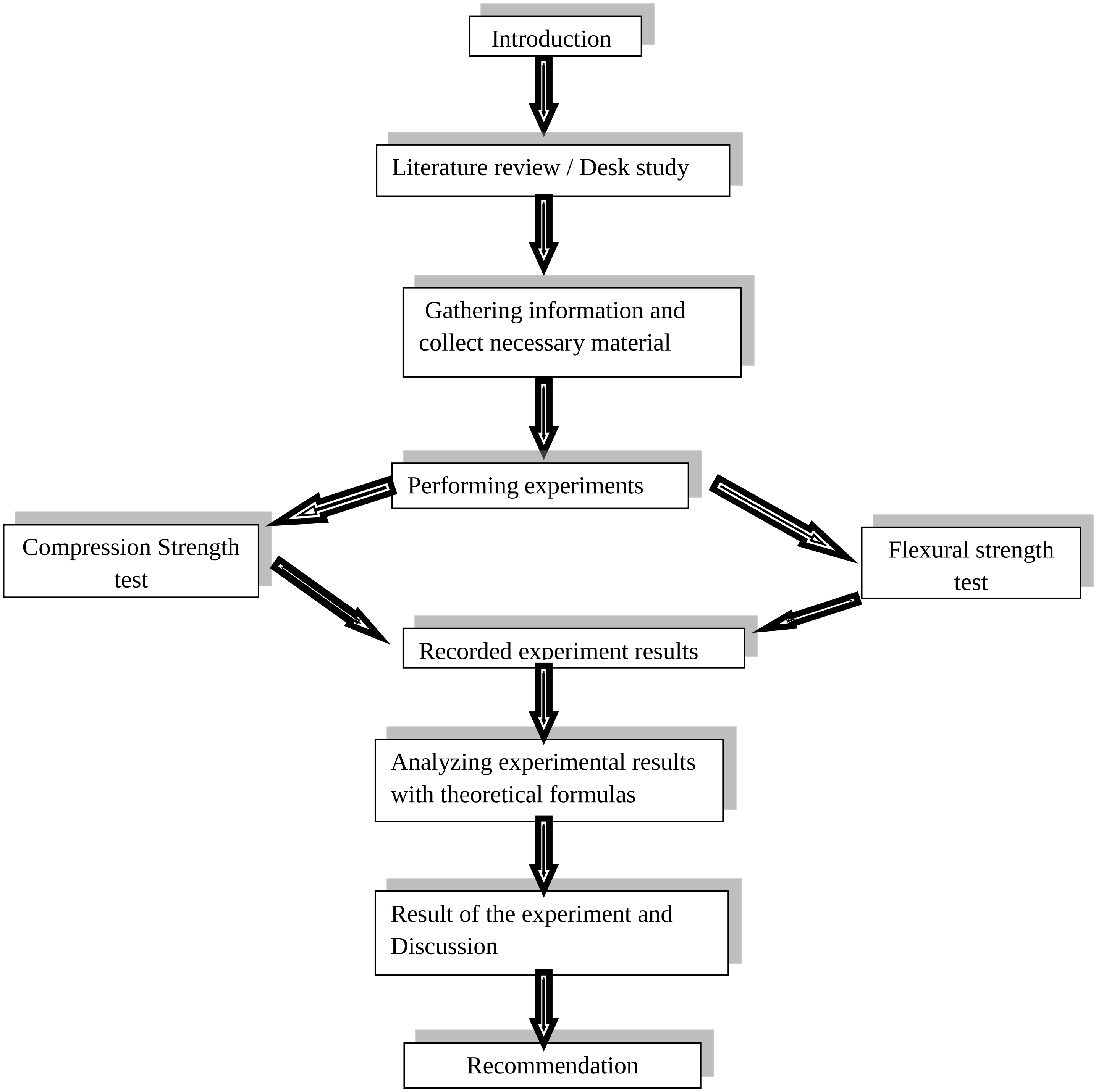
The assessment of slab sleepers on AALRT is addressed on the third chapter which includes the background and history of sleepers, Comparison between ballasted and balastless track, concrete crack on ballast less track, crack in track slab and base slab in AALRT which shows some defects on AALRT track slabs by image, damage of the concrete crack in ballast less truck structure and at the last of this chapter analysis of track sleepers.

The fourth chapter discuses on Experimental testing and results which includes, back ground, explains every material on the experiment, types of tests on material and on sleeper elementary, procedures and method of test, further Experimental results and comparison discussed in detail.

The Fifth chapter deals with Analysis and design of Steel fibre reinforced concrete Slab sleeper.

The final and Sixth chapter is devoted to the conclusion and recommendation of the study.

1.6.2. Conceptual framework of the thesis



CHAPTER II - LITERATURE REVIEW

CHAPTER II - LITERATURE REVIEW

2.1. General

This is one of the portions of the study that reviews the previous related works which are basic guide for the introduction of the current work. Some of them may have a direct relation to rail system where as the others may have indirect relations to the rail system. Generally, there are many journals, articles, conference papers, proceedings and books related to the improving compressive and tensile strength of plain concrete by mechanism of steel fiber. But to manage the thesis work, the review of literatures mainly considers more related studies to this subject. This strengthens the deep analysis of the previous related works and selection of appropriate conditions, approaches and methodologies for the successful accomplishment of the research.

Concrete is a material that needs strengthening in tension in order to meet the structural requirements. New techniques of strengthening concrete, besides the usual ordinary reinforcement bars, are developing, creating a need for new design methods. Fibre reinforcement is a method that has been in use over the last 30 years, yet it is unfamiliar, [1].

Concrete has proved to be a versatile material in the construction of structures due to the possibility of moulding it into virtually any shape and geometry. Utilizing this formable nature of the material, concrete architecture has made rapid progress in the recent years Concrete is a material with varying material behavior with high strength in compression but poor in tension. This has led to a need for reinforcement in the tensile parts of the structures. Traditionally this has been done using ordinary reinforcing bars. However, the need for designing structures with more complex geometries has led to the development of relatively new reinforcement materials such as steel fibres, which have further raised the potential of designing such geometries. Steel fibres can partly or entirely replace conventional reinforcement owing to the fact that steel fibres also increase the load carrying capacity of structures and improve crack control, [1].

Concrete made from Portland cement, 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 steel bars reinforcement as indicated above and to some extent by the mixing of a sufficient volume of certain fibers. The use of fibers also recalibrates the behavior of the fiber-matrix composite after it has cracked through improving its toughness.

In conventional concrete, micro-cracks develop before structure is loaded because of drying shrinkage and other causes of volume change. When the structure is loaded, the micro cracks open up and propagate because of development of such micro-cracks, results in inelastic deformation in concrete. Fibre reinforced concrete (FRC) is cementing concrete reinforced mixture with more or less randomly distributed small fibres. In the FRC, a numbers of small fibres are dispersed and distributed randomly in the concrete at the time of mixing, and thus improve concrete properties in all directions. The fibers help to transfer load to the internal micro cracks. FRC is cement based composite material that has been developed in recent years. It has been successfully used in construction with its excellent flexural-tensile strength, resistance to spitting, impact resistance and excellent permeability and frost resistance. It is an effective way to increase toughness, shock resistance and resistance to plastic shrinkage cracking of the mortar. These fibers have many benefits. Steel fibers can improve the structural strength to reduce in the heavy steel reinforcement requirement, [2].

According to Bentur & Mindess (2006)[3] , fibres have been used as reinforcement for quite some time now. Asbestos was the first material widely used in the beginning of the 20th century. Man-made fibres produced from steel, glass, synthetics, asbestos and natural fibres such as cellulose, sisal and jute, are examples of materials that are used in FRC today. Unreinforced concrete is as known, a brittle material with high compressive strength but low tensile strength. Therefore, concrete requires reinforcement. The most known method has been, using ordinary continuous reinforcing bars in order to increase the load carrying capacity in the tensile and shear zones. Fibres that are short materials randomly spread in the concrete mix, are however discontinuous. Fibres do not increase the (tensile) strength remarkably, but due to their random distribution in the mix, they are very effective when it comes to controlling cracks. As a result the ductility of fibre reinforced members is increased. Fibres can also be used in thin and complex members where ordinary reinforcement cannot fit, [3].

The strength and durability of concrete can be changed by making appropriate changes in its ingredients like cementitious material, aggregate and water and by adding some special ingredients. Hence concrete is very well suitable for a wide range of applications. However concrete has some deficiencies as listed below;

- Low tensile strength,
- Low post cracking capacity,
- Brittleness and low ductility,
- Limited fatigue life,
- Incapable of accommodating large deformations and
- Low impact strength.

The presence of micro cracks in the mortar-aggregate interface is responsible for the inherent weakness of plain concrete. The weakness can be removed by inclusion of fibres in the mixture. Different types of fibers, such as those used in traditional composite materials can be introduced into the concrete mixture to increase its toughness, or ability to resist crack growth. The fibres help to transfer loads at the internal micro cracks. Such a concrete is called fibre-reinforced concrete (FRC), [4].

2.2. Fibres

2.2.1. Fiber classification

According to Naaman (2003)[5] , fibres used in cementitious composites can be classified with regard to:-

1. **Origin of fibres:** According to origin, the fibres can be classified as: Natural organic (cellulose, sisal, bamboo, jute etc.), natural inorganic (asbestos, wollastonite, rock wool etc.) and man-made (steel, glass, synthetic etc.)
2. **Physical/Chemical properties:** Fibres are classified based on their physical/chemical properties such as density, surface roughness, flammability, reactivity or non-reactivity with cementitious matrix etc.
3. **Mechanical properties:** Fibres are also characterized on the basis of their mechanical properties e.g. specific gravity, tensile strength, elastic modulus, ductility, elongation to failure, stiffness, surface adhesion etc.
4. **Shape and size:** Classification of fibres is also based on geometric properties, such as cross sectional shape, length, diameter, surface deformation etc. Fibres can be of any cross sectional shape such as circular, rectangular, diamond, square, triangular, flat, polygonal, or any substantially polygonal shape. Figure 2.1 and Figure 2.2 show the different cross sectional geometries of fibres.

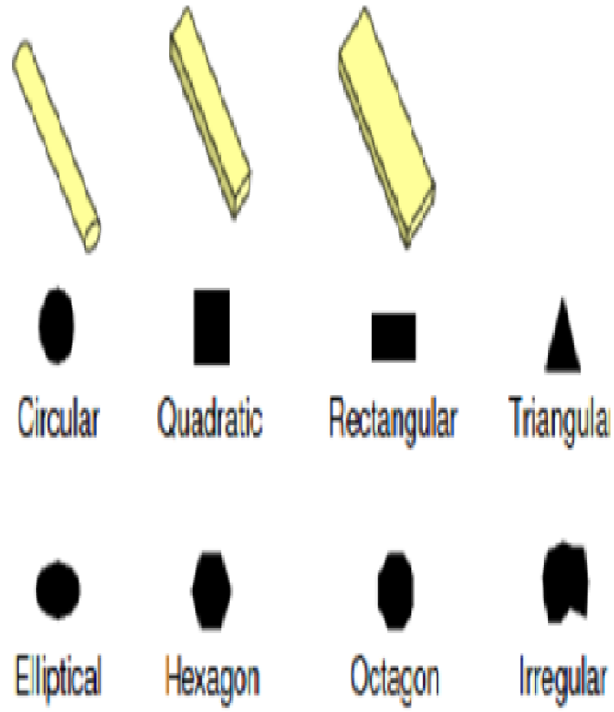


Fig. 2.1 Cross Sectional Geometries of Fibers[6]

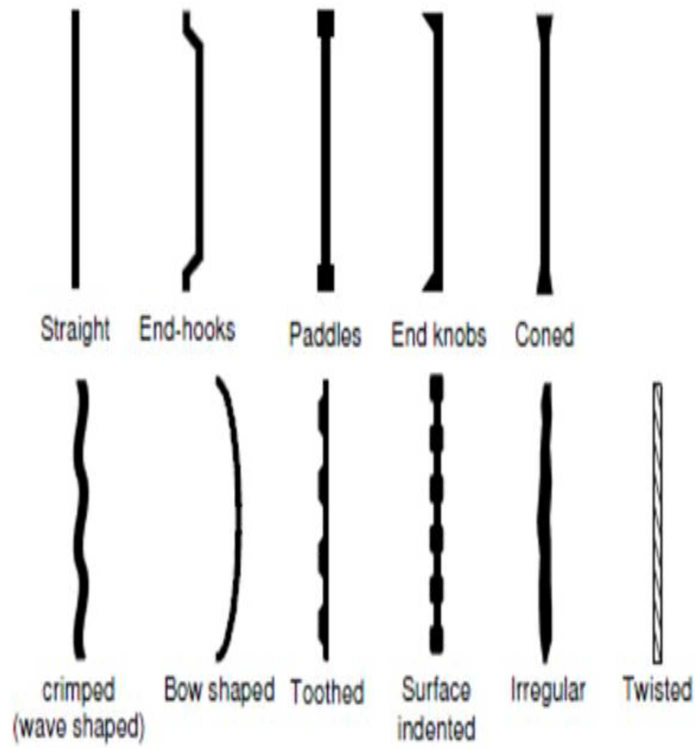


Fig. 2.2 Typical Geometries of Fibers [6]

2.2.2. Fibre types

Fiber is a small piece of reinforcing material possessing certain characteristic properties. They can be circular or flat. The fiber is often described by a convenient parameter called "aspect ratio". The aspect ratio of the fiber is the ratio of its length to its diameter. Typical aspect ratio ranges from 30 to 150. Although every type of fiber has been tried out in cement and concrete, not all of them can be effectively and economically used. Each type of fiber has its characteristic properties and There are numerous fiber types available for commercial and experimental use. The basic fiber categories are steel, glass, synthetic and natural fiber materials. Specific descriptions of these fiber types along with their physical property and applications are discussed below.

- **Steel fiber** - Steel fibers have relatively high strength and modulus of elasticity and are protected from corrosion by the highly alkaline matrix. The fiber-matrix bond can be enhanced by mechanical anchorage through surface roughness or deformation, [7].

Steel fibres are the most commonly used man-made metallic fibres generally made of carbon or stainless steel. The different mechanical properties for steel fibres are given in Table 2.1, according to which the tensile strength is in the range of 200-2600 MPa and ultimate elongation varies between 0.5 and 5%. It can be said, according to Jansson (2008)[8] , that pull-out tests, where the fibres have been of much higher strength than the concrete, yielding in the fibres has not been the issue but spalling of the concrete. With a minimum strength of 200 MPa, it can be concluded that the yielding strength is sufficient enough to prevent fibre rupture.

According to Bentur and Mindess (2006)[3] , fibres are added and treated as any other component in a concrete mix, but due to difficulties in handling, only about 2 volume percent can be applied.

Today, straight fibres are very rarely used due to their weak bonding with the cement matrix. It is however, quite common to use brass-coated straight fibres with high strength concrete mix since the bond obtained is relatively strong.

- **Synthetic fibers** - Developed primarily by the petrochemical and textile industries, synthetic fibers are nonmetallic fibers including polymers that are available in a variety of formulations. Following is an account of some of the commonly used synthetic fibers in precast concrete products.
- **Carbon** - The advantages of carbon-fiber reinforcement over steel, polypropylene, or glass fibers are in its inert nature, high modulus, thermal resistance, and long-term chemical stability in alkaline and other chemically aggressive environments. In addition, carbon-fiber reinforcement improves the mechanical properties. Historically, the first uses of carbon fibers in cement-based matrices were in the form of high-modulus polyacrylo nitrile fibers whereby significant improvements in the mechanical properties were noted. These carbon fibers are manufactured by carbonizing polyacrylonitrile yarn at high temperatures and then aligning the resultant graphite crystallites by a process called hot stretching. However, polyacrylonitrile-based fibers were not commonly used in FRC because of their high cost. In the early 1980s, interest in the use of carbon fibers in cementitious matrices was revived with the development of relatively inexpensive pitch-based carbo fibers, [9].

- **Nylon** - Characterized by the presence of the amide functional group, nylon represents a family of polymers. These fibers exhibit good tensile strength, high toughness, excellent elastic recovery, a hydrophilic character, and relative stability in cementitious matrices, [10].
- **Polypropylene** - Produced from the homopolymer polypropylene resin, this fiber has a low modulus of elasticity and also a low melting point, which may hinder its use in autoclaved precast concrete products. However, the low melting point may be beneficial in producing refractory products or products with a high fire resistance because the fiber is expected to melt and provide a system of relief channels to dissipate internal pressure.

  There are two types of polypropylene fibers available for concrete reinforcement, monofilament and fibrillated. These fibers are hydrophobic and exhibit a high contact angle with water. Hence they develop a poor bond with the matrix relative to hydrophilic fibers. In addition, there is no evidence of a chemical bond with the matrix. However, geometrical deformations obtained during the process of fibrillation can provide a mechanical bond with the matrix, [11].
- **Polyvinyl alcohol (PVA) -** Fiber is manufactured from PVA resin where a multistep high stretch production process provides a high stiffness and water insolubility. A special surface treatment allows for improved fiber dispersion in cementitious systems, [12]. Unfortunately, PVA fiber has a negative coefficient of thermal expansion, shrinking 4% in length at 200°C (392°F). PVA is generally resistant to alkaline and organic solvents but demonstrates a minor strength loss after long-term exposure to ultraviolet radiation

- **Glass fibers** - Glass fiber is a predominantly used mineral fiber. Glass fibers are silica based glass compounds that contain several metal oxides, which can be tailored to manufacture different types of glasses. Glass fibers are produced in the process in which molten glass is drawn, in the form of filaments, through the bottom of a heated platinum tank or bushing. Most commonly, 204 filaments are drawn simultaneously; after solidification, they are collected into a strand consisting of the 204 filaments. Glass fibers are available both as “chopped strand” and as a continuous roving. Glass fibers have relatively high tensile strength and modulus of elasticity compared to polymeric fibers. Furthermore they are quite economical and hence are the most commonly used fibers for structural applications. In the initial stages borosilicate glass fibers (E-glass) and soda lime-silica glass fibers (A-glass) were employed to reinforce cement based composites. Since both E-glass and A-glass fibers were found to lose their strength property in the alkaline environment of cement based composites (pH ≥ 12.5), the need for alkali resistant fibers resulted in the development of Alkali-resistant glass (AR-glass) fibers. Table 2.1 gives the strength and elastic properties of some selected glass fibers, [44]. Using the conventional mixing technique for normal concrete, it is not possible to mix more than about two percent by volume of fibers of length up to 25 mm. One of the most important improvements in the property achieved by glass fiber is the spectacular improvement in impact strength of up to 1500 percent can be registered as compared to other materials, such as plain concrete. With a two percent fiber content (up to 25 mm in length), the flexural strength is almost doubled. The second important improvement is in the resistance in the thermal shock. The ductility also improves along with the increase in strength and modulus of rupture, [44]. By far, the single largest application of glass fiber reinforced concrete (GFRC) has been the manufacturing of exterior building facade panels. A growing application for GFRC is building restoration, replacing existing walls and ornate tile facades capitalizing on the light weight and shape versatility of the composite. However, the use of glass fibers in Ethiopia is very much limited to the manufacturing of water tankers.

Table 2.1 Physical Properties of some selected glass fibers, [44].

Property	**A-Glass**	**E-Glass**	**AR-Glass**
Specific gravity	2.46	2.54	2.7
Tensile strength, MPa	3030	3450	2480
Modulus of Elasticity, MPa	64,800	71,700	80,000
Strain at break, %	4.7	4.8	3.6

2.2.3. Physical properties of fibre

The basic fibre categories are steel, glass, synthetic and natural fibre materials. In Table 2.2, typical physical properties of a few fibres are listed.

Table 2.2 Physical properties of typical Fibers, [6].

Type of fiber	Diameter (µm)	Specific gravity (g/cm)	Tensile strength(Mpa)	Elastic modulus (Gpa)	Ultimate elongation (%)
Metallic					
Steel	5-1000	7.89	200-2600	195-210	0.5-5
Glass					
E glass	8-15	2.24	2000-4000	72	3-4.8
AR glass	8-20	2.7	1500-3700	80	2.5-3.6
Synthetic					
Acrylie(PAN)	5.17	1.18	200-1000	14.6-19.6	7.5-50
Aremid	10-12	1.4-1.5	2000-3500	62-130	2-4.6
Carbon(low modules)	7-18	1.6-1.7	800-1000	38-43	2.1-2.5
Carbon(high modules)	7-18	1.7-1.9	1500-4000	200-800	1.3-1.8
Nylon	20-25	1.16	965	5.17	20
Polyester(PEC)	10-8	1.34-1.39	280-1200	10-18	10-50
Polyethylene(PE)	25-1000	0.96	80-600	5	12-100
Polyethylene(HPPE)	---	0.97	4100-3000	80-150	2.9-4.1
Polyethylene(PP)	10-200	0.9-0.91	310-760	3.5-4.9	6-15
Polyvinylacetote(PVA)	3-8	1.2-25	800-3600	20-80	4-12
Natural organic					
Cellulose(Wood)	15-125	1.5	300-2000	10-50	20
Coconut	100-400	1.12-1.15	120-200	19-25	10-25
Bamboo	50-400	1.5	350-500	33-40	---
Jute	100-200	1.02-1.04	250-350	25-32	1.5-1.9
Natural inorganic					
asbestos	0.02-25	2.55	200-1200	164	2.3
wallastonate	25-40	2.87-3.09	2700-4100	303-530	---

2.3. Fibre reinforced concrete

Fibre-reinforced concrete (FRC) is a cement-based composite material reinforced with discrete, usually randomly distributed, fibres. Fibres of various shapes and sizes produced from steel, synthetics, glass, and natural materials can be used. However, for most structural purposes, steel fibres are the most used of all fibre materials, whereas synthetic fibres (e.g. polypropylene and nylon) are mainly used to control the early cracking (plastic-shrinkage cracks) in slabs, [6]. Fibre reinforcement mainly enhances the post-cracking properties of concrete and leads to a more ductile material behavior. The increased ductility is due to the ability of the fibres to transfer tensile stresses across a cracked section, potentially leading to a reduction in crack widths. The extent of the crack-width reduction depends on the amount of fibres added as well as their physical properties (e.g. surface roughness and chemical stability) and mechanical properties (e.g. tensile strength).

Fibers may be used in concrete at volume fractions varying from 0.1% to 5%. The volume fraction is determined by both the ease of mixing and the application. For example, a low fiber dosage in the range of 0.1% to 0.3% is often provided for control of secondary stresses arising from shrinkage and temperature change. At dosage rates above 0.3%, the mechanical response of FRC is substantially different from that of the plain matrix in that it has post cracking load-carrying ability. The ability of FRC to absorb energy beyond matrix cracking is often termed toughness, [7].

2.3.1. Steel fibre reinforced concrete

Steel fibre reinforced concrete is a composite material made up of a cement mix and steel fibres. The steel fibres, which are randomly distributed in the cementitious mix, can have various volume fractions, geometries, orientations and material properties, see Löfgren (2005) [6].

Generally SFRC is very ductile and particularly well suited for structures which are required to exhibit; [2]

- High fatigue strength resistance to impact, blast and shock loads,
- Shrinkage control of concrete,
- Tensile strength, very high flexural, shear,

- Erosion and abrasion resistance to splitting,
- Temperature resistance, high thermal and
- Earth quake resistance.

2.3.1.1. Properties of steel fiber reinforced concrete

A. Mechanical properties

The mechanical properties of steel fiber reinforced concrete are influenced by the type of fiber; length-to diameter ratio (aspect ratio); the amount of fiber; the strength of the matrix; the size, shape, and method of preparation of the specimen; and the size of the aggregate. For this reason, mixtures proposed for use in design should be tested, preferably in specimens representing the end use, to verify the property values assumed for design.

SFRC mixtures that can be mixed and placed with conventional equipment and procedures use from 0.5 to 1.5 volume percent fibers. However, higher percentages of fibers (from 2 to 10 volume percent) have been used with special fiber addition techniques and placement procedures, [14]. Most properties given below are for the lower fiber percentage range. Some properties, however, are given for the higher fiber percentage mixtures for information in applications where the additional strength or toughness may justify the special techniques required.

Fibers influence the mechanical properties of concrete and mortar in all failure modes , especially those that induce fatigue and tensile stress, e.g., direct tension, bending, impact, and shear. The strengthening mechanism of the fibers involves transfer of stress from the matrix to the fiber by interfacial shear, or by interlock between the fiber and matrix if the fiber surface is deformed. Stress is thus shared by the fiber and matrix in tension until the matrix cracks, and then the total stress is progressively transferred to the fibers.

Aside from the matrix itself, the most important variables governing the properties of steel fiber reinforced concrete are the fiber efficiency and the fiber content (percentage of fiber by volume or weight and total number of fibers). Fiber efficiency is controlled by the resistance of the fibers to pullout, which in turn depends on the bond strength at the fiber-matrix interface. For fibers with uniform section, pullout resistance increases with an increase in fiber length; the longer the fiber the greater its effect in improving the properties of the composite.

Also, since pullout resistance is proportional to interfacial surface area, non-round fiber cross sections and smaller diameter round fibers offer more pullout resistance per unit volume than larger diameter round fibers because they have more surface area per unit volume. Thus, the greater the interfacial surface area (or the smaller the diameter), the more effectively the fibers bond. Therefore, for a given fiber length, a high ratio of length to diameter (aspect ratio) is associated with high fiber efficiency. On this basis, it would appear that the fibers should have an aspect ratio high enough to insure that their tensile strength is approached as the composite fails.

Unfortunately, this is not practical. Many investigations have shown that use of fibers with an aspect ratio greater than 100 usually causes inadequate workability of the concrete mixture, non-uniform fiber distribution, or both if the conventional mixing techniques are used, [15]. Most mixtures used in practice employ fibers with an aspect ratio less than 100, and failure of the composite, therefore, is due primarily to fiber pullout. However, increased resistance to pullout without increasing the aspect ratio is achieved in fibers with deformed surfaces or end anchorage; failure may involve fracture of some of the fibers, but it is still usually governed by pullout.

An advantage of the pullout type of failure is that it is gradual and ductile compared with the more rapid and possibly catastrophic failure that may occur if the fibers break in tension. Generally, the more ductile the steel fibers, the more ductile and gradual the failure of the concrete. Shah and Rangan(1970)[16] have shown that the ductility provided by steel fibers in flexure was enhanced when the high-strength fibers were annealed (a heating process that softens the metal, making it less brittle).

An understanding of the mechanical properties of SFRC and their variation with fiber type and amount is an important aspect of successful design. These properties are discussed below

- **Compression**

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 percent for concrete containing 2 percent by volume of fiber with l/d = 100 , 19-mm maximum-size aggregate, and tested with 150 x 300 mm cylinders, [17].. For mortar mixtures, the reported increase in compressive strength ranges from negligible to slight, [17].

Typical stress-strain curves for steel fiber reinforced concrete in compression are shown in Fig. 2.3, [30]. Curves for steel fiber reinforced mortar are shown in Fig. 2.4 and 2.5, [17]. 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. The improved toughness in compression imparted by fibers is useful in preventing sudden and explosive failure under static loading, and in absorbing energy under dynamic loading.

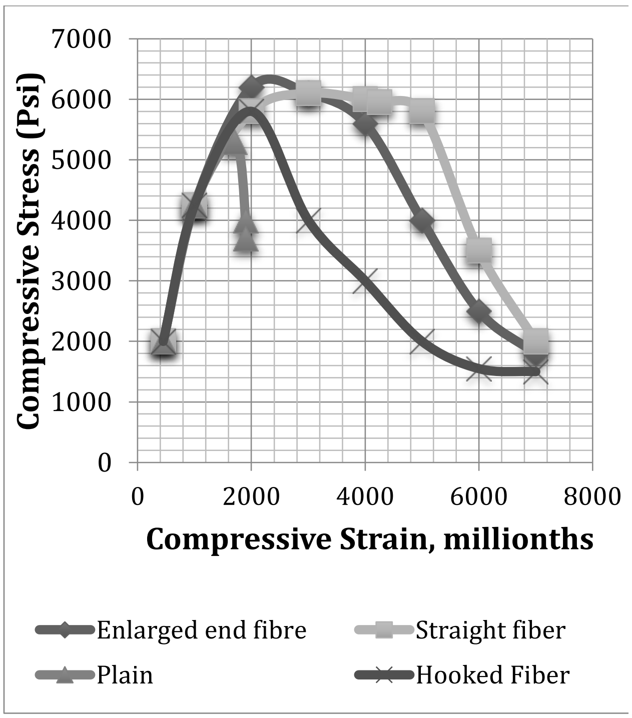


Fig.2.3 Stress- strain curves for steel fiber reinforced concrete in comprassion,9.5mm aggregate mixtures, [29].

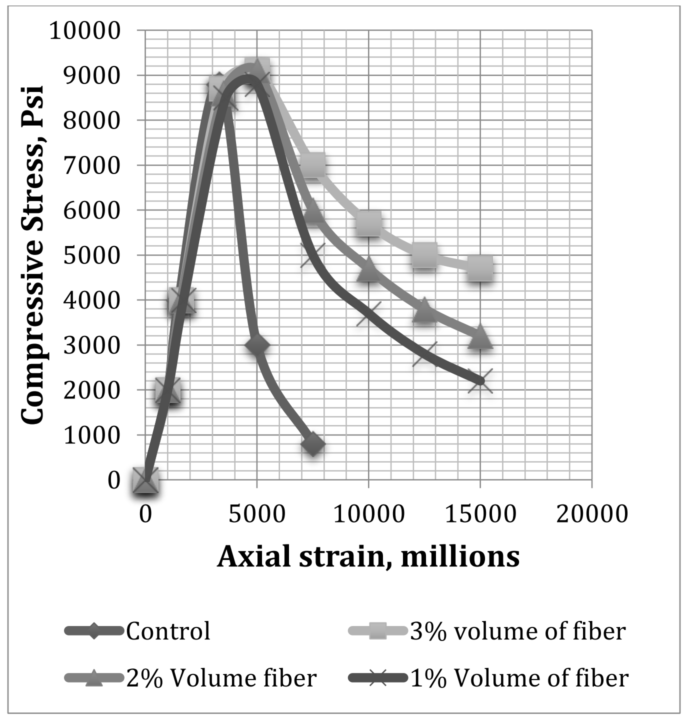


Fig.2.4 influence of the volume fraction of fibers on the compressive stress-strain curve [29]

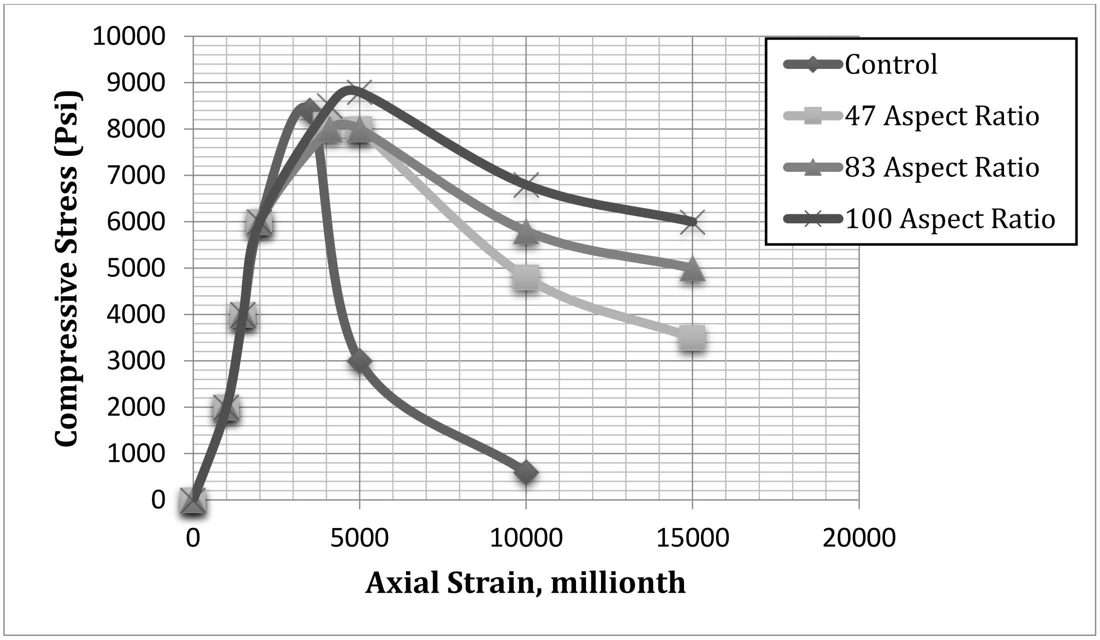


Fig.2.5 Influence of the aspect ratio of fibers on the stress-strain curve

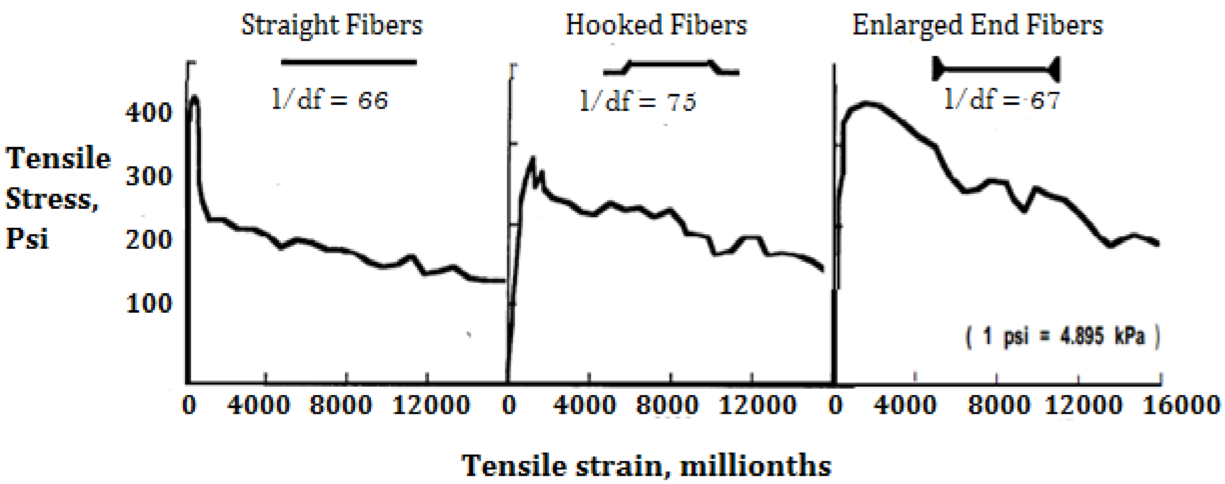


Fig. 2.6 Stress – Strain curves for steel fiber reinforced mortar in tension (1.73% febers by volume)[29]

- **Flexural strength**

The influence of steel fibers on flexural strength of concrete and mortar is much greater than for direct tension and compression. Two flexural strength values are commonly reported. One, termed the first-crack flexural strength, corresponds to the load at which the load-deformation curve departs from linearity (Point A on Fig. 2.7). The other corresponds to the maximum load achieved, commonly called the ultimate flexural strength or modulus of rupture (Point C on Fig.

2.7). Strengths are calculated from the corresponding load using the formula for modulus of rupture given in ASTM C 78, although the linear stress and strain distributions on which the formula is based no longer apply after the matrix has cracked.

Fig. 2.8 shows the range of flexural load-deflection curves that can result when different amounts and types of fibers are used in a similar matrix and emphasizes the confusion that can occur in reporting of first-crack and ultimate flexural strength. For larger amounts of fibers the two loads are quite distinct (upper curve), but for smaller fiber volumes the first-crack load may be the maximum load as well (lower curves).

Ultimate flexural strength generally increases in relation to the product of fiber volume concentration v and aspect ratio l/d. Concentrations less than 0.5 volume percent of low aspect ratio fibers (say less than 50) have negligible effect on static strength properties. Prismatic fibers, or hooked or enlarged end (better anchorage) fibers, have produced flexural strength increases over unreinforced matrices of as much as 100 percent, [19].

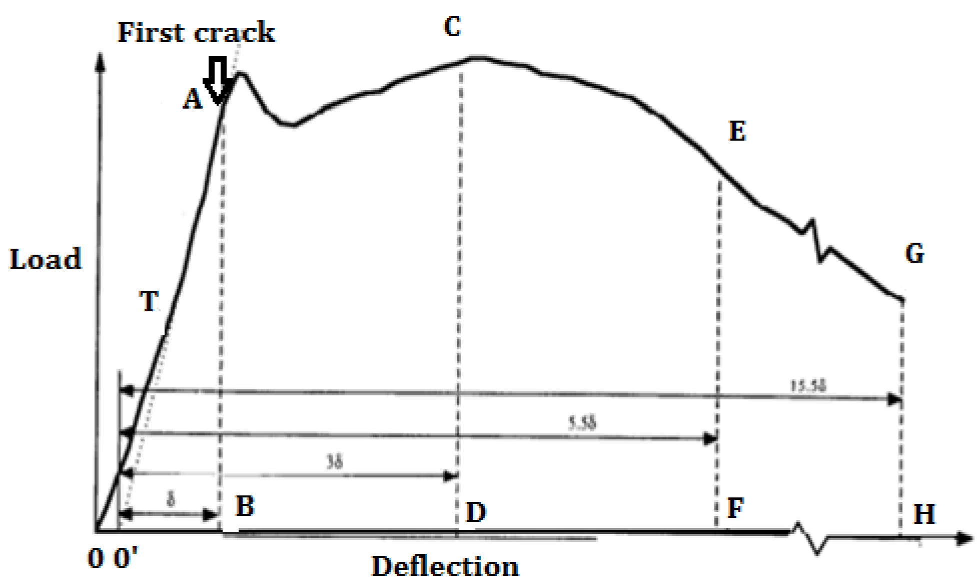


Fig. 2.7 Important characteristics of the load deflection curve(ASTMC 1018)

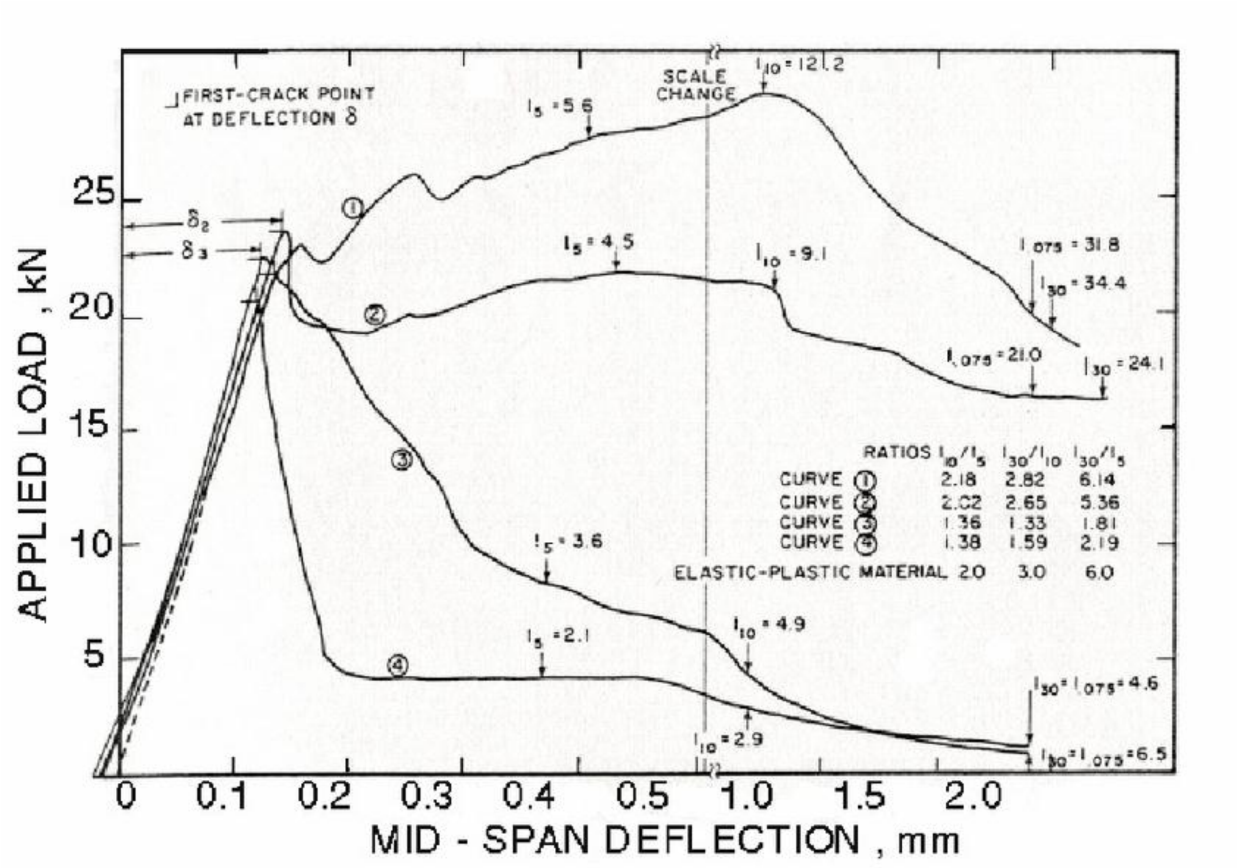


Fig. 2.8 Load deflection curves illustrating the range of material behavior possible for four mixtures containing various amount and types of fibers, [21].

- **Flexural toughness**

Toughness is an important characteristic for which steel fiber reinforced concrete is noted. Under static loading, flexural toughness may be defined as the area under the load-deflection curve in flexure, which is the total energy absorbed prior to complete separation of the specimen. Typical load-deflection curves for concrete with different types and amounts of fiber are shown in Fig. 2.8, above, [21]. Flexural toughness indexes may be calculated as the ratio of the area under the load-deflection curve for the steel fiber concrete to a specified endpoint, to the area up to first crack.

Strengthening effects of this nature depend primarily on matrix characteristics such as water-cement ratio. In general, crimped fibers, surface-deformed fibers, and fibers with end anchorage produce toughness indexes greater than those for smooth straight fibers at the same volume concentration, or allow similar index values to be achieved with lower fiber concentrations

- **Shrinkage and creep**

Tests have shown that steel fibers have little effect on free shrinkage of SFRC. However, when shrinkage is restrained, tests using ring-type concrete specimens cast around a restraining steel ring have shown that steel fibers can substantially reduce the amount of cracking and the mean crack width, [22]. However, compression-creep tests carried out over a loading period of 12 months showed that the addition of steel fibers does not significantly reduce the creep strains of the composite. This behavior for shrinkage and creep is consistent with the low volume concentration of fiber when compared with an aggregate volume of approximately 70 percent.

- **Freeze-thaw resistance**

Steel fibers do not significantly affect the freeze-thaw resistance of concrete, although they may reduce the severity of visible cracking and spalling as a result of freezing in concretes with an inadequate air-void system,[23]. A proper air-void system remains the most important criterion needed to insure satisfactory freeze-thaw resistance, just as with plain concrete.

- **Abrasion/cavitation/erosion resistance**

Both laboratory tests and full-scale field trials have shown that SFRC has high resistance to cavitation forces resulting from high-velocity water flow and the damage caused by the impact of large waterborne debris at high velocity. Even greater cavitation resistance is reported for steel fiber concrete impregnated with a polymer. It is important to note the difference between erosion caused by impact forces (such as from cavitation or from rocks and debris impacting at high velocity) and the type of erosion that occurs from the wearing action of low velocity particles. Tests at the Waterways Experiment Station indicate that steel fiber additions do not improve the abrasion/erosion resistance of concrete caused by small particles at low water velocities. This is because adjustments in the mixture proportions to accommodate the fiber requirements reduce coarse aggregate content and increase paste content, [24].

- **Performance under dynamic loading**

The dynamic strength of concrete reinforced with various types of fibers and subjected to explosive charges; dropped weights; and dynamic flexural, tensile, and compressive loads is 3 to 10 times greater than that for plain concrete. The higher energy required to pull the fibers out of the matrix provides the impact strength and the resistance to spalling and fragmentation under rapid loading, [25].

Steel fiber reinforced beams have been subjected to impact loading in instrumented drop-weight and Charpy-type systems, [25]. It was observed that the total energy absorbed (measured from the load-deflection curves) by SFRC beams can be as much as 40 to 100 times that for unreinforced beams.

B. **Quasi-static and impact response**

The role of fibers in improving the mechanical properties of concrete is well known. Experiments using the drop weight method that evaluates resistance to blows have shown that concrete specimens with polypropylene fibers at 0.1% to 0.2% by volume have higher impact strength for both first crack and final fracture compared with plain concrete. Similar results were obtained for concrete of normal strength having deformed steel fibers. There is no standard test method to evaluate the dynamic compressive response for fiber-reinforced concrete. Bischoff and Perry [26] found that the axial compressive strength of plain concrete increased 85% to 100%, but further research has shown that there is no post peak ductility in the compressive response under impact loading largely because the concrete fragments do not bond to the fibers. Also, whereas deformed steel fibers were seen to result in a dynamic impact factor of 3 at a strain rate of 50 S^{-1} , polymeric fibers did not perform any differently from plain concrete and had a dynamic impact factor of 1.5.

Also, their study showed steel fibers with three-dimensional deformation to impart considerably higher dynamic impact factor in compression over those with two dimensional deformations. However, there is a significant improvement to the tensile strength and post crack residual flexural strength in cementitious systems under dynamic loading. Fiber reinforcement improves the energy absorption capacity of concrete by enhancing its post peak stress-transfer capability and, hence, is an effective way of improving concrete's resistance to impact. However, the choice of fiber type, its length, and its shape greatly influence these properties. As stated, there are various types of fibers, such as steel, synthetic, glass, and natural fibers. Short, discrete polymeric fibers increase the energy dissipated by concrete under impact loading [27] , sometimes even exceeding the dynamic impact factor of steel fibers. A case may be made for hybrid fiber-reinforced systems that have both steel and a low-modulus fiber. The existing reports show synergy under impact for concrete with steel and cellulose fibers and similarly for steel and polypropylene fibers. The failure performance of polypropylene fibers is said to change from fracture to pullout in the presence of the steel fibers.

The performance of fibers in concrete under impact loading depends largely on how the fiber-matrix bond behaves at high rates of crack opening displacement. Bindiganavile and Banthia [28] used contoured double cantilevered beam specimens to find that at increasing loading rates, the steel-fiber reinforced concrete shows greater crack growth resistance than a companion set of concrete specimens reinforced with polypropylene fibers. However, the latter appeared to catch up with the steel-fiber-reinforced specimens, presumably because polypropylene itself is more strain-rate sensitive than steel. This stiffening in the response of a low-modulus fiber under higher stress rates was manifest in the progressive drop of the crack opening displacement associated with peak bond stress in a fiber subjected to impact loading. For instance, glass fibers were seen to pull out from an MgO based ceramic matrix under quasi-static loading but without exception fractured under impact loading, leading to poor post crack dynamic toughness, [28]. However, at significantly higher dosage (about 2% by volume) these fibers imparted a substantial increase in the flexural strength under impact loading, which indicates fiber bridging and crack arrest during subcritical crack growth

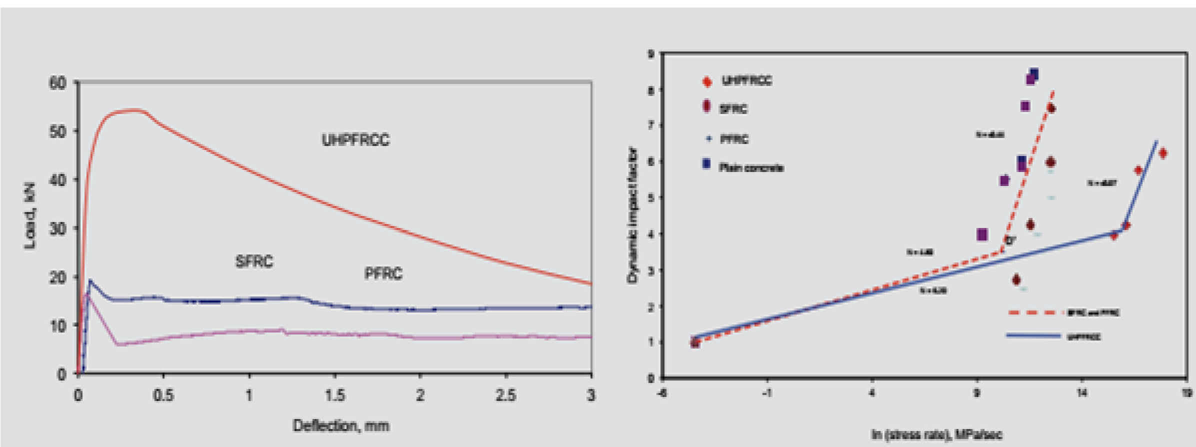


Fig. 2.9 Quasi static response of an ultra-high strength fibre reinforced Cementous composite.[29]

The nature of the cementitious system also plays a significant role in how the system will respond to higher rates of loading when reinforced with fibers. A stronger matrix will be stiffer but less resilient. Bischoff and Perry [26] reported a higher dynamic impact factor for high-strength fiber-reinforced concrete in compression compared with normal strength FRC.

However, a lower dynamic impact factor for high-strength FRC, which was further verified for an ultra-high-strength cement based composite by Bindiganavile et al.[29] (Fig. 2.9) and found that if fiber pullout can be ensured as the dominant mode of failure, then a high-strength matrix favors their impact response (Fig. 2.10).

C. **Shrinkage crack control**

Fibers are known to significantly affect the free shrinkage and other early-age properties of cement-based composites. A study by Wang et al.[30] reported that fiber addition increased the number of large pores in cement paste, thereby changing the bleeding behavior and reducing the free shrinkage and found that the use of polypropylene fibers (1% by volume) reduced free plastic shrinkage by about 30%.

In addition to free shrinkage, the effect of fibers on restrained shrinkage has also been studied using various techniques. The presence of fiber is expected to influence both the lengths and the widths of shrinkage-induced cracks under restrained conditions. A major study by Gupta [31] provided insight into the effectiveness of various fibers in controlling shrinkage cracking (Fig. 2.11). Other conclusions from the study were the following;

- Fiber material and type have a pronounced effect cracking. At the same fiber volume, glass fibers are the most effective in inhibiting crack growth, followed by synthetic fibers.
- For a given fiber volume fraction and type, longer fibers and fibers of smaller diameter are much more effective than shorter fibers and coarser fibers. Fibers with extensive geometric deformations such as fibrillations impart greater efficiency than their un deformed counterparts.
- In the case of cellulose fibers, both coated and uncoated fibers are effective only at dosages above 0.3% by volume

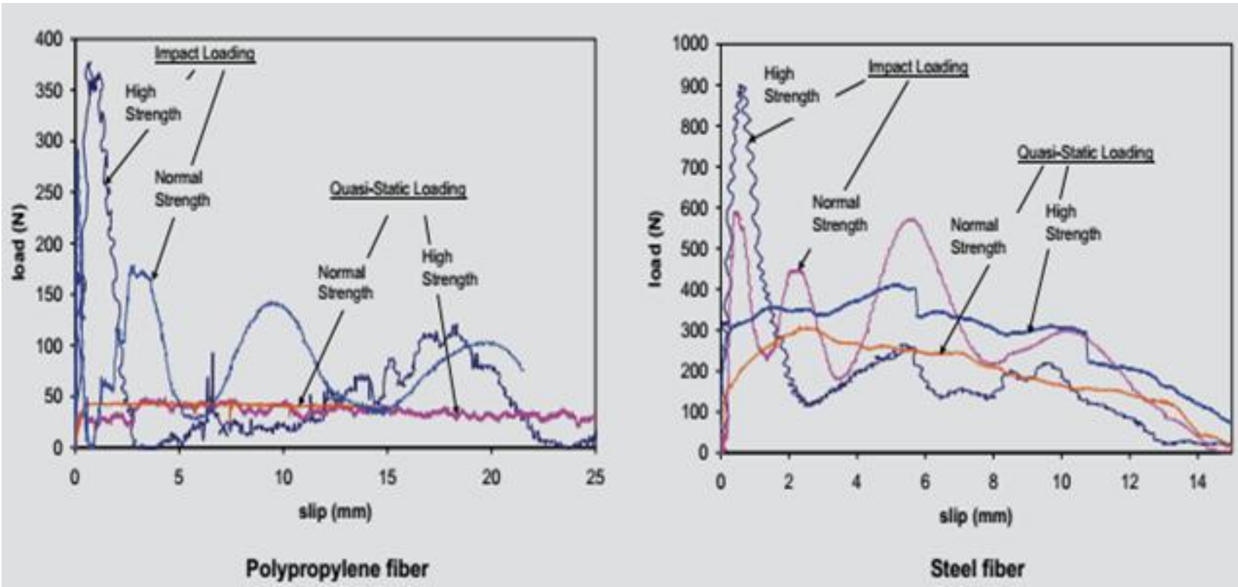


Fig. 2.10 Effect of matrix strength on the static and impact response of fibers,[29]

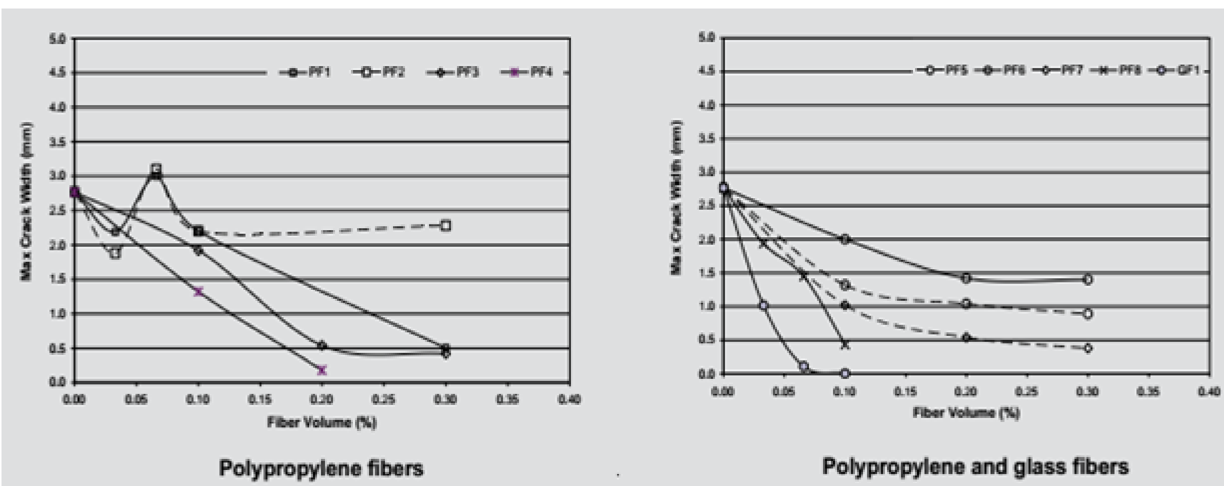


Fig.2.11 Shrinkage control of various fibers,[31]

D. Water tightness and durability

Precast concrete products are susceptible to degradation as a result of sulfate attack, freeze-thaw cycling, alkali-silica reaction, and corrosion of embedded reinforcing bars, if present. In all of these cases, permeability to water plays an important part. Durability of precast concrete products is therefore influenced by the rate at which water may enter. Results have indicated that permeability, in turn, depends largely on cracking in concrete, and an increase in the crack width will produce a highly permeable concrete. Fiber reinforcement improves crack resistance, increases the surface roughness of cracks, and promotes multiple-crack development, thereby significantly reducing the permeability of concrete in service. In case of stresses and stress-induced cracks, results have shown that cracks dramatically increase the permeability of plain concrete, while the permeability of fiber-reinforced concrete remains far below that of plain concrete under service conditions. Other research has shown a similar trend, but the effectiveness of a fiber in controlling permeability is a function of the crack opening. A detailed review of the effectiveness of fibers in controlling water permeability under stress. Fibre reinforcement has also been shown to reduce gas permeability under stress, [32].

Corrosion of steel reinforcing bars in precast concrete remains a major concern. Chloride contamination of concrete is usually to blame, and the mechanisms by which chloride ions promote reinforcing bar corrosion in concrete are well understood. Unfortunately, cracks in concrete permit ready ingress of chlorides and other deleterious chemicals and further promote corrosion. Because chloride ions diffuse only through water in the capillaries, chloride diffusion depends principally on water permeability. As indicated before, fibers decrease water permeability in both stressed and unstressed concrete and, hence, slow the rate of chloride diffusion. The inclusion of fiber in concrete could be a feasible solution for prolonging the life of concrete structures. A recent study has indicated that both cellulose and polypropylene fibers might increase the coefficient of apparent (total) chloride diffusion but decrease the coefficient of effective (free) chloride diffusion. In other words, while greater amounts of chlorides diffuse through fiber-reinforced concrete, fibers chemically combine with the passing chlorides such that only limited amounts of free chlorides are available for steel corrosion. This ability of fibers to bind chlorides was further verified in loaded reinforced concrete beams where corrosion was delayed significantly as a result of fiber reinforcement, [32].

2.4. Reinforcement mechanisms in fiber reinforced (FRC)

In the hardened state, when fibers are properly bonded, they interact with the matrix at the level of micro-cracks and effectively bridge these cracks there by providing stress transfer media that delays their coalescence and unstable growth. If the fiber volume fraction is sufficiently high, this may result in an increase in the tensile strength of the matrix . Indeed, for some high volume fraction fiber composite, a notable increase in the tensile/flexural strength over and above the plain matrix has been reported. Once the tensile capacity of the composite is reached, and coalescence and conversion of micro-cracks to macro cracks has occurred, fibers, depending on their length and bonding characteristics continue to restrain crack opening and crack growth by effectively bridging across macro cracks. This post peak macro-crack bridging is the primary reinforcement mechanisms in majority of commercial fiber reinforced concrete composites, [32].

2.4.1. Effect on workability of steel fiber

Slump tests were carried out to determine the workability and consistency of fresh concrete. The efficiency of all fiber reinforcement is dependent upon achievement of a uniform distribution of the fibers in the concrete, their interaction with the cement matrix, and the ability of the concrete to be successfully cast or sprayed. Essentially, each individual fiber needs to be coated with cement paste to provide any benefit in the concrete. Regular users of fiber reinforcement concrete will fully appreciate that adding more fibers into the concrete, particularly of a very small diameter, results in a greater negative effect on workability and the necessity for mix design changes. The slump changed due to the different type of fiber content and form. The reason of lower slump is that adding steel fibers can form a network structure in concrete, which restrain mixture from segregation and flow. Due to the high content and large surface area of fibers, fibers are sure to absorb more cement paste to wrap around and the increase of the viscosity of mixture makes the slump loss,[33].

2.4.2. Effect of steel fiber on compressive, splitting tensile and modulus of rupture of concrete

Presently, a number of laboratory experiments on _mechanical properties of SFRC have been done. Shah Suendra and Rangan [34], in their investigations conducted uniaxial compression test on fiber reinforced concrete specimens. The results shown the increase in strength of 6% to 28% compressive strength, 18% to 47% split tensile _strength, 22% to 63% flexural strength and 8% to 25% modulus of elasticity, respectively. Byung Hwan Oh [35], in their investigations, the mechanical properties of concrete _have been studied, these results shown the increase in strength of 6% to 23% compressive strength, 14% to 49% split tensile strength, 25% to 55% flexural strength and 13% to 27% modulus of elasticity respectively. Barrows and Figueiras [36], in their investigations the mechanical properties of concrete have been studied, these results shown the increase in strength of 7% to 25% compressive strength, 19% to 48% split tensile strength, 25% to 65% flexural strength and 7% to 25% modulus of elasticity respectively and stated that the minimum fiber volume dosage rate for steel, glass and polypropylene fibers in the concrete matrix is calculated approximately 0.31%, 0.40% and 0.75%.

2.4.3. Effect of steel fiber on impact capacity and toughness of concrete

Toughness is a measure of the ability of the material to _absorb energy during deformation estimated using the area under the stress-strain curves. Luo et. al [37], studied and conducted test on the mechanical properties and resistance against impact on steel fiber reinforced high-performance concrete. Five different geometry of fibers included steel sheet-cut fibers and steel ingot milled fibers with four fiber volume fractions (4%, 6%, 8% and 10%) were applied in to the mix studied and conducted test for fibre content dosage Vf ranged from 0.0 to 2.0 percent. Steel and Polyolefin fibers were combined in different proportions and their impact on strength and toughness _studied. Addition of 2.0 percent by volume of hooked-end _steel fibers increases the toughness by about 19.27%, when compared to the plain concrete. When the fibers were used in a hybrid form, the increase in above study parameters was about 31.42%, when compared to the plain concrete.

2.5. Factors affecting properties of fiber reinforced concrete

Fiber reinforced concrete is the composite material containing fibers in the cement matrix in an orderly manner or randomly distributed manner. Its properties would obviously, depend upon the efficient transfer of stress between matrix and the fibers, which is largely dependent on the type of fiber, fiber geometry, fiber content, orientation and distribution of the fibers, mixing and compaction techniques of concrete, and size and shape of the aggregate. These factors are briefly discussed in the following sections.

2.5.1 Relative Fiber Matrix Stiffness

The modulus of elasticity of matrix in most cases is lower than that of fiber for efficient stress transfer. Low modulus of fibers such as nylons and polypropylene are, therefore, unlikely to give strength improvement, but they help in the absorption of large energy and, therefore, impart greater degree of toughness and resistance to impact. High modulus fibers such as steel, glass and carbon impart strength and stiffness to the composite, [46].

Interfacial bond between the matrix and the fibers also determine the effectiveness of stress transfer, from the matrix to the fiber. A good bond is essential for improving tensile strength of the composite. The interfacial bond could be improved by larger area of contact, improving the frictional properties and degree of gripping and by treating the steel fibers with sodium hydroxide or acetone, [46].

2.5.2 Volume of Fibers

The strength of the composite largely depends on the quantity of fibers used in it. Fig. 2.2 and 2.3 show the effects of volume on the toughness and strength. It can be seen from Fig. 2.3 that the increase in the volume of fibers, increase approximately linearly, the tensile strength and toughness of the composite. It has been reported that the use of higher percentage of fibers is likely to cause segregation and harshness of concrete and mortar, [46].

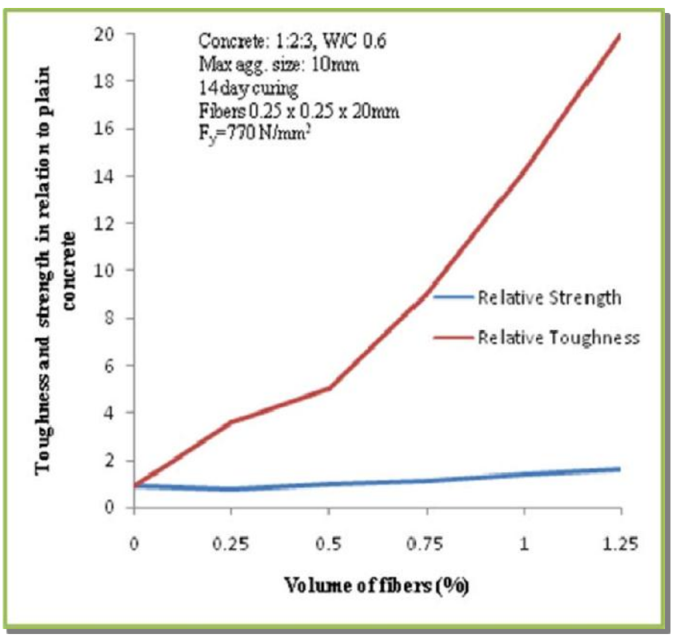


Fig 2.12 Effects of volume of fibers in Flexure, [46].

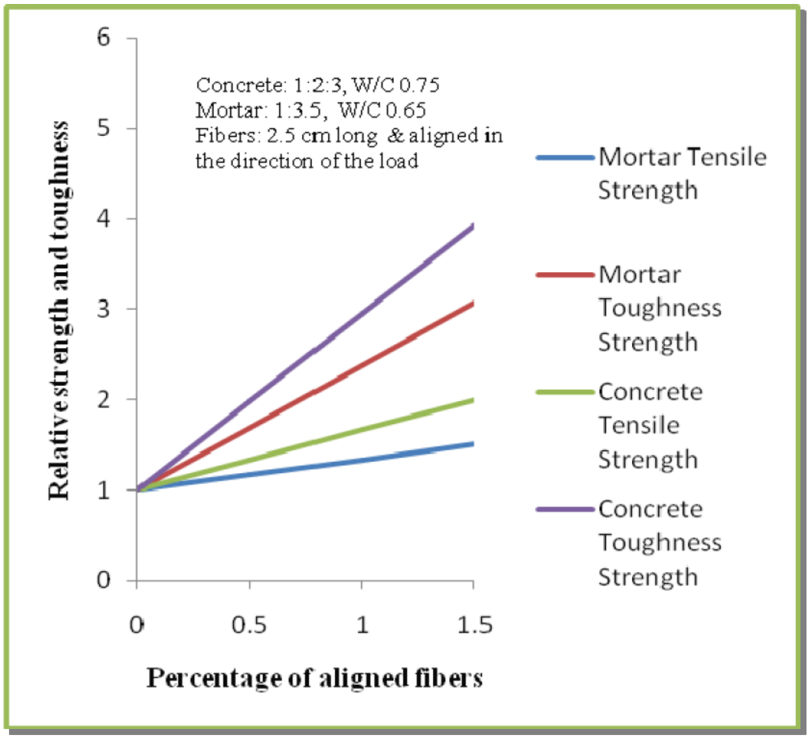


Fig 2.13 Effects of volume of fibers in Tension, [46].

2.5.3 Aspect Ratio of the Fiber

Another important factor which influences the properties and behavior of the composite is the aspect ratio of the fiber. It has been reported that up to an aspect ratio of 75, increase in the aspect ratio increases the ultimate strength of the concrete linearly. Beyond 75, relative strength and toughness is reduced. Table 2.5 shows the effects of aspect ratio on strength and toughness, [46].

Table 2.3 Effects of Aspect Ratio on Strength and Toughness, [46].

Type of concrete	Aspect ratio [l/d]	Relative strength [FRC/Plain]	Relative toughness [FRC/Plain]
Plain concrete with Randomly dispersed fibers	0	1.00	1.0
	25	1.50	2.0
	50	1.60	8.0
	75	1.70	10.5
	100	1.50	8.5

2.5.4 Orientation of Fibers

One of the differences between conventional reinforcement and fiber reinforcement is that in conventional, bars are oriented in the direction desired while fibers are randomly oriented. To see the effects of randomness, mortar specimens reinforced with 0.5 percent volume of fibers were tested. In one set specimens, fibers were aligned in the direction of the load, in another along the direction perpendicular to that of the load, and in the third randomly distributed. It was observed that the fibers aligned in the direction of the applied load offered more tensile strength and toughness than randomly distributed or perpendicular fibers, [46].

2.5.5 Workability and Compaction of Concrete

Researches indicate that incorporation of steel fibers decrease the workability considerably. This situation adversely affects the consolidation of fresh mix. Even prolonged external vibration fails to compact the concrete. The fiber volume at which this situation is reached depends on the length and diameter of the fiber.

Another consequence of poor workability is non uniform distribution of the fibers. Generally, the workability and compaction standard of the mix is improved through increased water/cement ratio or by the use of some kind of water reducing admixtures, [46].

2.5.6 Size of Coarse Aggregates

Several investigators recommended that the maximum size of the coarse aggregate should be restricted to 10mm, to avoid appreciable reduction in strength of the composite. Fibers also in effect, act as aggregate. Although they have a simple geometry, their influence on the properties of fresh concrete is complex. The inter-particle friction between fibers, and between fibers and aggregates controls the orientation and distribution of the fibers and consequently the properties of the composite. Friction reducing admixtures and admixtures that improve the cohesiveness of the mix can significantly improve the mix workability, [46].

2.5.7 Mixing

Mixing of fiber reinforced concrete needs careful conditions to avoid balling of fibers, segregation, and in general the difficulty of mixing the materials uniformly. Increase in the aspect ratio, volume percentage and size and quantity of coarse aggregate intensify the difficulties and balling tendencies. A steel fiber content in excess of 2 percent by volume and an aspect ratio of more than 100 are difficult to mix.

It is important that the fibers are dispersed uniformly throughout the mix. This can be done by the addition of fibers before the water is added. When mixing in a laboratory mixer, introducing the fibers through a wire mesh basket will help even distribution of fibers. For field use, other suitable methods shall be adopted, [46].

2.6. Economic evaluation of fiber reinforced concrete

Traditionally the decision between various alternative solutions to the problems concrete encounter has been made on the basis of initial costs. This approach has some disadvantages in the way that the useful life span for different options and the maintenance cost are not considered. The concept of life cycle costs is found to be better in determining the most cost effective options because the maintenance cost and useful life span are included. Any new technology should, at the same level of performance, be cheaper than the one it substitutes; otherwise it will stay in the laboratory stage. FRC is not cheaper than the conventional concrete in many applications. Therefore it is very important to select and develop these applications where sufficient economies are guaranteed. Generally the higher initial cost incurred by adding fibers has limited the use of FRC to special applications.

Since the mixing, placing and finishing of FRC can be carried out with conventional equipment with minor refinements in technique and workmanship, the cost of FRC principally depends on the type and amount of fiber volume used together with the admixtures added for enhancement of the workability. An increase in the fiber volume always contributes to the higher initial price.

The low energy required for their extraction and the abundantly occurring parent material makes natural fiber the cheapest among the different fiber types. Carbon fibers are the most expensive of all the fibers. This is due to the increased cost of their manufacturing process as well as the increased cost of raw materials required for their manufacture. As a result new technologies are under development to produce low cost carbon fibers.

The extra cost of adding fibers to the concrete mix and other additional cost is usually offset by the savings in maintenance and rehabilitation and the special advantages that could be achieved. It was established by many researchers that initial saving could be made by using FRC in applications such as industrial floor and pavements by reducing the number of joints and thickness of the slab. According to some researches the FRC for pavements is economically viable when compared to the plain concrete. A minimum of 10% to a maximum of 40% saving could be achieved in warehouse and overlay pavements respectively. It was further described that more saving could be perceived if the life cycle performance is considered for the evaluation of different pavement alternatives.

In summary, the concept of reinforcing a brittle matrix with discrete fibers is an age old practice. The modern day use of fibers in concrete started in early 1960s. Plain concrete possesses a very low tensile strength, limited ductility and little resistance to cracking. It has been recognized that the addition of small, closely spaced and uniformly dispersed fibers to concrete would act as a crack arrester and would substantially improve its static and dynamic properties. Fibers suitable for reinforcing concrete have been produced from steel, glass, organic polymers and natural fibers. For a composite system such as FRC, the mechanical behavior depends not only on the properties of the fibers and the cementitious systems, but also on the bonding between them. The addition of fibers significantly improves many of the engineering properties of the concrete, notably impact strength and toughness. Flexural strength, fatigue strength and the ability to resist cracking and spalling are also improved. However, fibers have no significant effect on the compressive, shear and torsional strength, elastic modulus and creep characteristics. The extent of improvement in concrete properties will vary based on the concrete matrix, the type, quantity and orientation of fibers, mixing, compaction and maximum aggregate size. Measurement of properties of FRC is very essential. As some of the properties are matrix dependent, they can be measured using test methods originally developed for conventional concrete. However, tests like toughness and impact strength are different from those of the conventional concrete and should be measured using tests specifically developed for FRC. Regarding the cost the higher initial cost incurred by adding fibers has limited the use of FRC to special applications.

when we see in the Ethiopian context at this time we are constructing mega structures, Railway infrastructures are one of them. Those infrastructures we build are for this generation as well as for the next generations to come if we build those infrastructures strong and durable their life span will increase and the maintenance cost will be minimum but if we build them as we build on the railway infrastructure today we will give the next generations infrastructures with short life span and high maintenance cost in order to avoid such kind of disaster we must use SFRC in our railway infrastructures.

CHAPTER III – ASSESEMNET OF SLAB SLEEPERS ON AALRT

CHAPTER III – ASSESEMNET OF SLAB SLEEPERS ON AALRT

3.1. Back ground

The railway was originally developed to have higher load-carrying capacities than the roads. One of the pioneers in the history of railways was G.Stephenson, who built his first steam locomotive in 1813. In the development of the railway a component acting and looking like the sleeper of today was invented quite soon. The demands on the sleepers have increased with the improvement of the railway. In the early railways, the natural choice of material for the sleeper was often wood. One reason for starting to use reinforced concrete sleepers was to get a great reduction in the overall cost of track maintenance, [41]. A reference body of experiments with reinforced concrete sleepers arose as far back as 1880, and reinforced concrete sleepers were used quite extensively in the 1920s and 1930s in countries such as Italy and India. The use of reinforced concrete sleepers increased the structural stiffness and developed unique problems that are not associated with wooden sleepers, such as flexural cracks which could lead to deterioration of the sleepers. This fact, together with shortage of good quality timber during World War II blockades, forced in the development and use of prestressed concrete sleepers. Since then, the use of prestressed concrete sleepers has increased and become standard in the railway tracks of several countries. The development of prestressed concrete sleepers solved the early problems associated with the ordinary reinforced concrete sleepers, [41]. As the pre stressed concrete Steel fiber reinforced concrete also one of the new discoveries that we can use for railway slab sleepers (slab tracks).

Sleepers are members generally laid transverse to the rails on which the rails are supported and fixed, to transfer the loads from rails to the ballast and subgrade below. Sleepers perform the following functions, [41].

- To hold the rails to correct gauge i.e. exact in straight and flat curves, loose in sharp curves and tight in diamond crossings,
- To hold the rails in proper level transverse tilt i.e., level in turnouts, crossovers, etc., and at 1 in 20 tilt in straight tracks, so as to provide a firm and even support to rails,
- To act as elastic medium in between the ballast and rails,

- To distribute the load from the rails to the index area of ballast underlying it or to the girders in case of bridges,
- To support the rails at a proper level in straight tracks and at proper super elevation on curves,
- add to the longitudinal and lateral stability of the permanent track on the whole, and
- To provide means to rectify track geometry during service life.

To fulfill the above functions and for good performance of sleepers an ideal sleeper should possess the following characteristics, [41].

- Should be economical, i.e., they should have minimum possible initial and maintenance costs,
- The fittings should be such that they can be easily adjusted during maintenance operations such as easy lifting, packing, removal and replacement,
- The weight should not be too heavy or excessively light, i.e., they should have moderate weight, for ease of handling, and
- The design should be such that the gauge, alignment of track and levels of the rails can be easily adjusted and maintained.

In this chapter we will discuss about slab track (slab sleepers) on AALRT. As we all know Ethiopia was the first East Africa country to have railway transportation system and infrastructure for about 100 years ago. However, due to different problems the old railway transpiration system and infrastructure collapsed since last two decades. And now in 21st century Ethiopia is building new railway transportation and infrastructure again, AALRT was one of the first projects we build. Those infrastructures we build today are for us (peoples of this generation) and for peoples of the future generation. In order to fulfill our aim / vision we must build our railway infrastructure strong and durable. But as it noticed the Adis Ababa LRT railway project is have some defects located on the bridges slab sleepers i.e. track slab exhibits small cracks. Small cracks today will propagates and become bigger cracks and this will lead in to total failure of the bridge slab sleepers (slab track) and the transportation system. If the total failure of the bridges slabs sleepers and transportation system happens it will put negative impact in our Economy.

3.2. Slab track (Slab sleeper)

Presently all over the world non-ballasted track concepts are being applied, although still at a moderate volume. The great advantages of such structures can be summarized as follows:

- Reduction of structure height,
- Lower maintenance requirements and hence higher availability,
- Increased service life,
- High lateral track resistance which allows future speed increases in combination with tilting technology,
- No problems with churning of ballast particles at high-speed,
- Good damping properties,
- Low noise emission,
- Fast building process,
- Easy dewatering,
- Low weight of the pavement,
- High precision of the rails rectification and
- No geometry deformation under normal conditions.

If the low-maintenance characteristics of slab track on open line are to be retained, great care must be taken to ensure that the subgrade layers are homogenous and capable of bearing the loads imposed. The slabs may be prefabricated or poured on site. The high level of investment required has prevented widespread use of slab track on open line so far. However, on the basis of life cycle costs a different picture is obtained. The greatest savings will be achieved in tunnels and on bridges.

It has been discovered that the response of the sleepers depended on toughness properties and other impacting factors which include relative masses, velocities, contact zone stiffness, frequency of loading, precision of impact, and locally energy-absorbed area, [40].

General considerations on track slab

In supporting and guiding railway rolling stock, the track structure shall be adequate to sustain repeated longitudinal, vertical and lateral forces. Hence, in the design of a concrete slab track system, the concrete slab shall be considered interconnected with other components of the track structure. Items to consider in the design of the concrete slab track system are:

- The concrete slab, rail, fasteners, subbase and subgrade,
- The quality of each component, method of manufacture, installation and maintenance,
- The direction, magnitude and frequency of traffic induced loads, the effect of environmental factors such as temperature and weather,
- The need to adequately support and safely guide railway rolling stock while sustaining repeated longitudinal, vertical and lateral forces and
- Overall economics of installation and maintenance.

3.2.1. Comparison between ballasted and ballast less track

Table 3.1 Comparison of Performances

	Item	**Ballasted**	**Slab**
1	Construction Cost	Low	High
2	Construction Speed	Even	Even
3	Construction Precision	Even	Even
4	Durability	Poor	**Good**
5	Elasticity	Even	Even
6	Maintainability	Even	Even
7	Ballast Scattering	Poor	Good

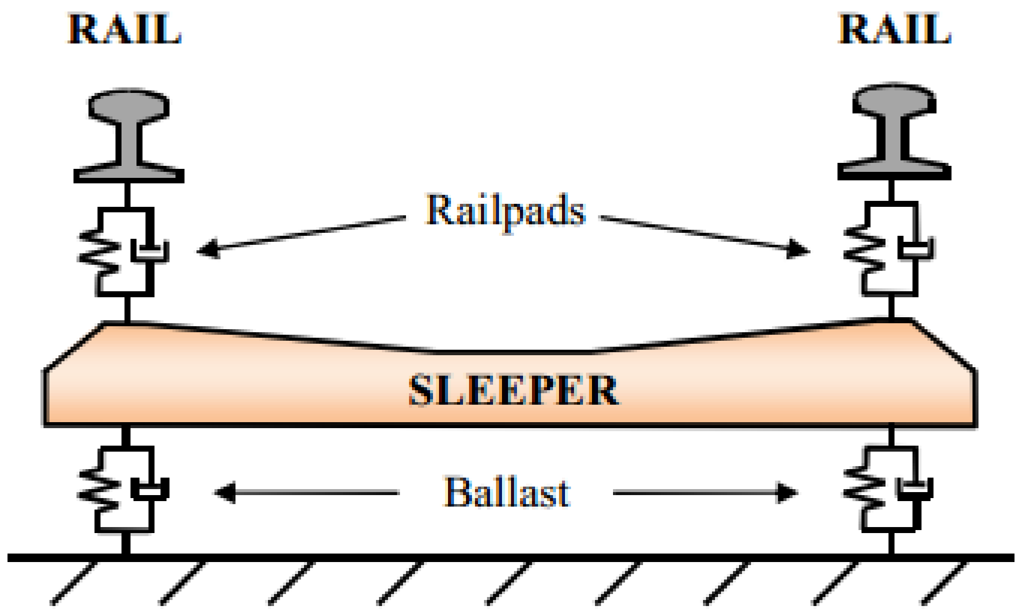


Fig. 3.1 Cross Section of Ballasted Track

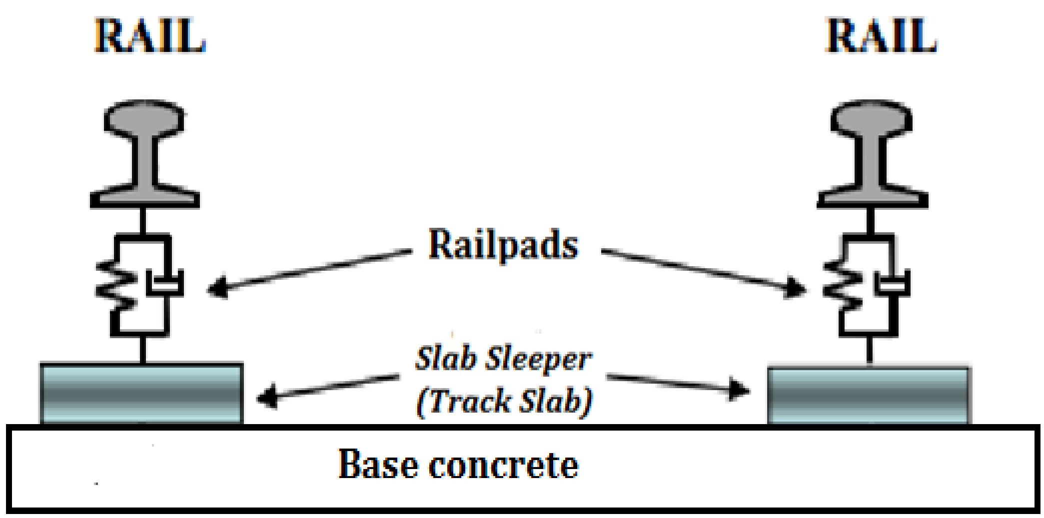


Fig. 3.2 Cross Section of Ballast less Track

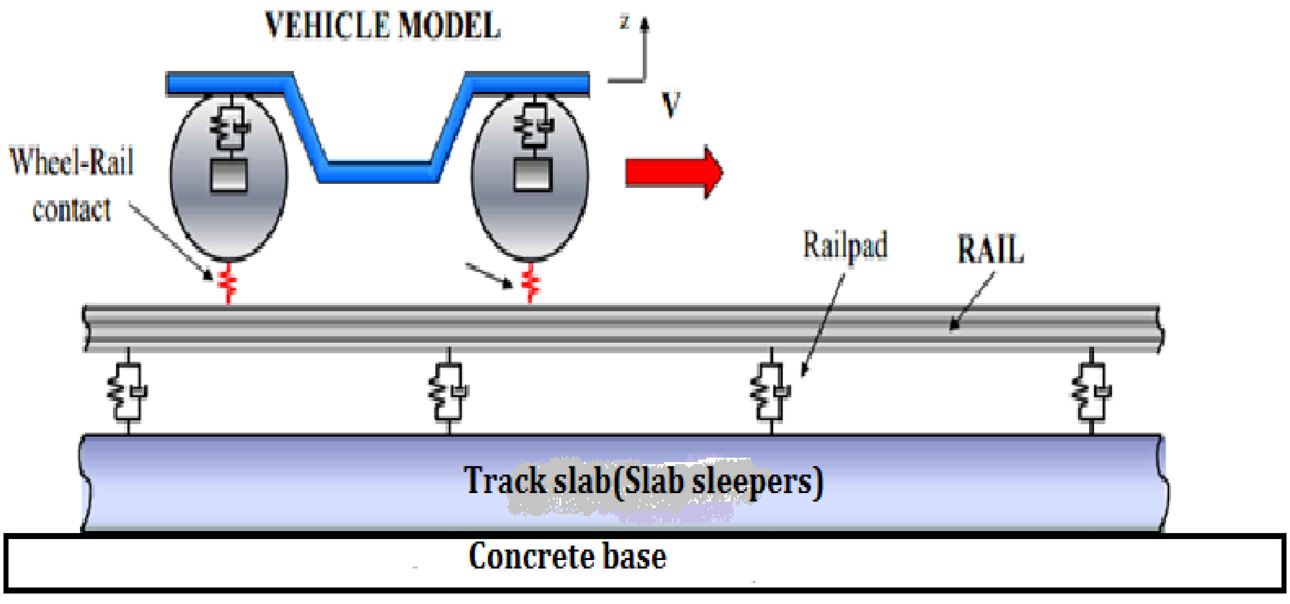


Fig. 3.3 Longitudinal Section of Ballast less Track

3.3. Damages on concrete structure

Damage - physical injury that makes something less useful, valuable or able to function. **Damage of concrete structure** - any defect which can affect the regular performance, serviceability and functionality of the structure. A damage of concrete Structure classification system, allowing users to quantify the damage present was proposed. In accordance with reference [38] damage is classified damage into one of three categories:

- **Minor damage** is defined as concrete with shallow spalls, cracks, and some efflorescence, rust or water stains. Damage at this level does not affect member capacity. Repairs at this stage are for aesthetic or preventative purposes.
- **Moderate damage** includes larger cracks and sufficient spalling or loss of concrete to expose strands. Moderate damage does not affect member capacity. Repairs are intended to prevent further deterioration.
- **Severe damage** is any damage requiring structural repairs. Typical damage at this level includes significant cracking and spalling, corrosion and exposed and broken strands.

There are many common defects that occur on concrete bridges. The following definitions are provided as a guideline for consistency in reporting of defects.

- **Cold joint displacement or deterioration:** is unbounded concrete resulting from intended separate concrete placement or by lack of consolidation.
- **Cracking:** a crack is a linear fracture that may extend partially or completely through the concrete member. When recording cracks, the inspector should describe the type, width, depth, length, direction, location and appearance of the crack as appropriate for the inspection.
- **Freeze-Thaw Damage**: the deterioration of concrete, typically a crack or spall, due to introduction of moisture and the subsequent alternate freezing and thawing of the retained moisture
- **Honeycombs**: Honeycombs are hollow spaces or voids that may be present within the concrete. Honeycombs are caused by improper consolidation during construction, resulting in the segregation of the coarse aggregates from the fine aggregates and cement paste.
- **Pop-Outs**: Pop-outs are conical fragments that break out of the surface of the concrete leaving small holes. Generally, a shattered aggregate particle will be found at the bottom of the hole, with a part of the fragment still adhering to the small end of the pop-out cone.
- **Spalling:** a spall is a roughly circular or oval depression in the concrete. Spalls result from the separation and removal of a portion of the surface concrete, revealing a fracture roughly parallel to the surface. Spalls can be caused by corroding reinforcement and friction from thermal movement. Reinforcing steel is often exposed after spalling.

3.4. Concrete Crack of Ballastless Track Structure

Ballastless track is a track structural style whose roadbed with particulate ballast is replaced by the cement-base materials (concrete or cement asphalt mortar). With the spread of ballastless track technology, the field of application of concrete is expanded in the railway field. It is pity that the concrete crack phenomenon in the ballastless track has appeared widely.

3.4.1. Concrete crack case and its damage in ballastless truck structure

- **Crack in track slab (Slab Sleeper) in AALRT**

Track slab is a kind of precast concrete structure but in the case of Adis Abeba light rail transit the track slab (slab sleepers) are cast insitu . Principle of the design of track slab is no crack design, but some cracks can be found in the track slab due to load action, environmental factor (such as temperature) and creep of concrete as it happens in AALRT. Fig. 3.4 and Fig. 3.5 shows cracks in track slab (slab sleeper) around stadium station at the AALRT. Longitudinal crack which is inducing by the non-homogeneous stress is easy to appear in the range of fastener. There are many cracks is in the inner side of frame track slab, and some cracks run through the total depth of track slab. Some cracks generate form lifting and some generate from curing system of track slab or the structure of track slab

Fig. 3.4 Cracked Slab Track (Slab Sleeper) around Stadium station AALRT/Ethiopia

Fig. 3.5 Cracked Slab Track (slab sleeper) around Stadium station AALRT/Ethiopia

There are two kinds cracks in roadbed slab, one of the cracks appear in the four corner of sleeper, splayed crack universally occurs in the interface between the corner of the sleeper and the roadbed slab concrete see Fig 3.5.

- **Crack in base concrete in AALRT**

As a kind of bulk mass, base concrete must be casted continuously. Fig. 3.6 shows some cracks in the base concrete in AALRT around Mexico station. Crack of base concrete is vertical with the rail. Along the track direction the cracks appear in periodic gap, and the interval is 5-15 m Fig -3.7. Moreover, the depth of crack reaches the whole thickness of base. Some cracks appear parallel and near to the expansion joint and the crack extends down the expansion joint. Cracks can be found in the middle of the track slab, and the width of the crack reaches the total width of track.

Fig. 3.6 Base Crack around Mexico station AALRT/Ethiopia

Fig. 3.7 Base Crack around Mexico station AALRT/Ethiopia

3.4.1.1. Damage of the concrete crack in ballastless track structure

There are two kinds hazard in ballastless track, one is reducing durability of track structure and safety of train travel, the other is inducing insulation inactivation of insulated node. Cracks in the track slab and roadbed slab will become the entryway of the corrosion substances see fig – 3.5. Under the Cl^{-} or CO_2 environment, the steel in the slab will be corrosion, and expansion of the productions of corrosion will aggravate the crack of the concrete, sequentially reducing the durability of the concrete structure. For ballastless track, due to different produce process and deforming property between the preforming sleeper and new filling concrete, binding property of concrete in the joint is poor. Under movable load, concrete of road base slab is easy to disintegrate and the sleeper rap, which affect the safety of the train. No crack should lie in the range of fastener; else the cracks will introduce the fastener loose, thus affect track structure stability. In addition, there may be potential incipient fault of travel, [39].

For ballastless track structure, concrete cracks not only do harms to the crack concrete, but also do harms to the conterminal part. Cracks in the base concrete and HGT will be the pathways to the water. Immersing the water for a long time, the roadbed accelerates falling in, at the same time increase sedimentation value of base, thus affect the stability of base and reduce the durability and bearing capacity of roadbase. Moreover, the cracks in base concrete aggravate corrosion of its steel see Fig- 3.8. Cracks in HBT will become reflect crack which aggravates the crack in road base concrete, [39].

In addition, there are insulation latch hooks around the steel in the slab. Be some cracks in track slab structure, the water is easy to permeate in the inner of the concrete, and the water in the crack evaporates very slowly. So in the rain weather, much water accumulates in the crack, which makes the insulation latch hook in the insulation mode inactivation, insulation property fall down gradually, what may be affect the travel safety for the electrification train.

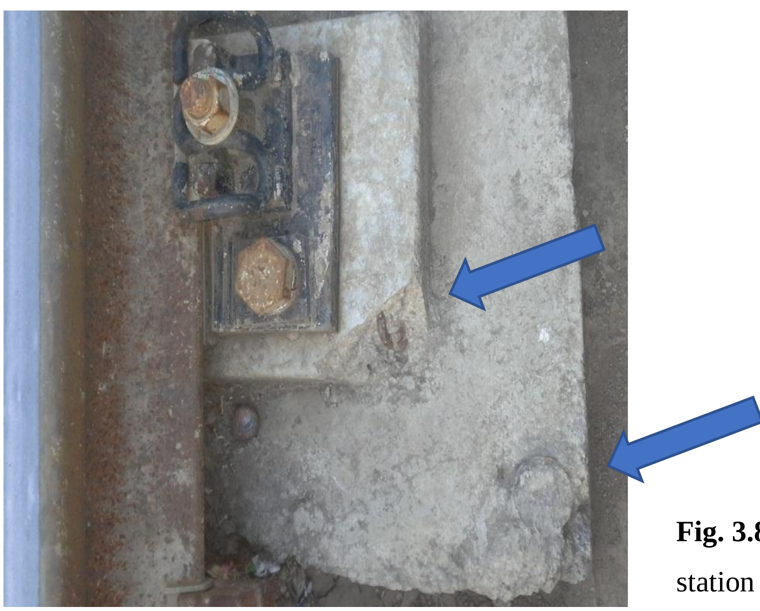


Fig. 3.8 Crashed Slab Track around Mexico station AALRT / Ethiopia

3.4.1.2. Crack cause and its counter measure for ballastless track concrete

- **Crack caused by drying shrinkage**

Crack caused by drying shrinkage is caused by the dry shrinkage deformation of concrete, which often happens after some time of finishing the curing concrete or after finishing concrete casting one week or so even more time. The evaporation of water in the concrete paste will produce dry shrinkage which is a non-reversible process. In the common condition, the dry shrinkage deformation of aggregate is very small, which may be neglect. The dry shrinkage deformation of hardened cement stone is big, which is often several hundred of micron strain, even thousands of micron strain. When the concrete dry shrinkage deformation strength is bigger than stretching resistance of concrete resisting external, the crack will happen in the concrete, [39].

If the dry shrinkage of concrete is reduced, the crack will be reduced or not happen at all. The following solution will reduce the dry shrinkage of concrete:

1. Reducing the cement stone content in the concrete. Cement paste component is be reduced in the concrete system, that is reducing cement and unit of using water and increasing aggregate volume content in the concrete system. Reduction the component in the cementitious material which shrinkages largely when becomes hardened, that is applying the prime mineral admixtures instead of cement or reducing w/cm.
2. The more the elastic modulus ratio of aggregate and hardened cement stone, the smaller the dry shrinkage deformation of the concrete. Therefore, choose the hard texture and high elastic modulus ratio of aggregate as possible as we can. Furthermore, the effective method to reduce the elastic modulus of cement stone is to add prime mineral admixtures, especially the prime fly ash.
3. Reinforce curing. It needs not only in time curing but also sufficiently curing, which means the time of curing must be long enough. Reinforcing curing can guarantee the strength development of the concrete and the hardened cement stone. Moreover sufficiently curing may also put off the time of dry shrinkage and release the degree of the dry shrinkage. The action on both sides makes the dry shrinkage happen after the concrete and the hardened cement stone have enough resistivity, so that the dry shrinkage crack of concrete may be avoided efficiently.

- **Crack caused by change in temperature**

Temperature crack is a kind of crack caused by the temperature changing in the concrete structure or non-uniform temperature distribution. The temperature changing and non-uniform temperature distribution may be divided into interior and exterior temperature difference. The former difference is caused by heat of hydration delivered by hydration action of cementitious material, and the latter is caused by the environmental temperature changes which the ballastless track structure is posited in. The surface cracks in the temperature crack usually appear during the time of construction. The deep and penetrating one often happens two to three months even more after concrete casting, for example, the crack in base structure, which parallels or near with the structural member or the short edge of the structural member, and appears sectional along the track. At the same time the width of the crack changes with the season, and the crack is wide in the winter and narrow in the summer, [39].

- **Crack caused by Plastic shrinkage**

Plastic shrinkage crack form due to water quick lost by many factors, which include atmosphere, temperature of concrete, relative moisture and the surface wind velocity in concrete. Plastic crack can be easily influenced by temperature, wind velocity and moisture. In the condition of high wind velocity, high temperature and the low moisture in the environment, it's easy to form this kind of crack. After concrete initial setting, concrete just form structure and lose flowing power, but its force is very slow. In this period, more water lost will create large plastic shrinkage. Crack will happen in concrete which has no ability of resistance shrinkage stress. Plastic crack is a kind of distribution shape in random and multilateral. These crack in surface is fairly wide, the width of which is from several mm to several cm. Plastic crack in surface of road bed slab, base concrete surface and HGT surface may happen. The influence of plastic crack is not severe for the standstill building, but it's different for the ballastless track structure. The passing train will make plastic crack open and close repeatedly, and lead width of crack to develop continuously, [39].

The solution of reducing the plastic crack in concrete of ballastless track structure is as followings:

1. Reinforcing curing, especially the curing in the early stage, in order to avoid water lost in early stage. Concrete of road bed slab, concrete and base concrete are level face plat.

Because there is big area contacting with the environment, it’s more easily to evaporate for water in concrete. Construction under environment of high temperature and big wind, more effective solution should be taken.

2. Choose proper component of cement or cementations material, and control the time interval between initial set and final set. Before initial set, concrete in shape of flowing can’t create crack, but when it lost flowing power the crack will happen because of strength not enough to resist its shrinkage stress. Therefore, when choose cement, choose short time interval between initial set and final set concrete.

CHAPTER – IV- EXPERIMENTAL TESTING

CHAPTER – IV- EXPERIMENTAL TESTING

4.1. General

The strength of concrete is affected by a number of factors the most important being by the water/cement ratio and the degree of compaction. Other factors include the component materials (cement and aggregate), the age, curing condition. In this study it had done the improvement of the concrete by adding additional material called 3D steel fiber to the ordinary concrete and this concrete called SFRC.

SFRC is used to build structure as the primary function to carry loads as flexural member and must have sufficient strength. SFRC used for such purposes must have strength. This is the reason why the strength of SFRC is commonly considered its most valuable property, although in some cases other characteristics, such as durability and water tightness (or impermeability), may be more important. Nevertheless, strength usually gives an overall picture of the quality of concrete and the steel fiber, and it is considered as good index whether direct or inverse, of most of the other properties.

In this chapter important tests have been conducted on the constituent material to determine the gradation and physical properties of fine and coarse aggregate, chemical composition and other characteristic of cement and properties of steel fibers. After carrying out tests on the fresh concrete, the specimens for the testing of mechanical properties in the hardened state have been tested for compressive strength, flexural strength and flexural toughness.

4.1.1. Composition of SFRC

SFRC is a mixture of Portland cement, steel fiber, water and inert mineral filler known as aggregates. When these materials are mixed, and placed in forms and allowed to cure, the chemical reaction between the water and cement forms a hardened binding medium or cement paste which surrounds and holds together the aggregate by adhering to them to a varying degree.

Since SFRC is made from different materials which form different parts, it is known as a composite material.

The properties of SFRC may be governed by careful selection (design) and control of the constituent materials. The requirements for a fresh and a hardened concrete may vary in a wide range, depending on the type of structure to be casted and the available equipment. These requirements include workability, strength, durability, water tightness etc. For a water tank for instance, the prime requisite is water-tightness, whereas for a structural column, strength and rigidity are the important factors. A mass concrete foundation compacted by vibration, can be casted with large size aggregates and a stiff mixture, whereas narrow heavily reinforced wall compacted by hand must be cast with a flowing mixture containing small size aggregates, [43].

For practical concrete mixes, the cement, steel fiber, water and aggregates should be so proportioned that the resulting concrete has the following properties

a. When freshly mixed, it is workable enough for economical and easy uniform placement, but not excessively fluid.
b. When hardened, it possess strength and durability adequate to the purpose for which it is intended.
c. It involves minimum cost consistent with acceptable quality.

4.1.2. Function of the component materials

In a SFRC mixture, the function of the cement is to react with the water forming a plastic mass when the concrete is fresh, and a solid mass when the concrete is hard.

The function of water, other than enabling the chemical reaction which cause setting and hardening to proceed, is to lubricate the mixture of aggregate and cement in order to facilitate placing. The amount of water mixed with the cement determines the strength of the hardened paste. The use of too much mixing water will thin or dilute the fresh cement paste and weaken its cementing properties when hard. Consequently, it will be readily seen that the strength and quality of concrete depend primarily upon the amount of water mixed with the cement. The relation between the amount of water and cement used in a mixture is called the water cement ratio.

The paste which is the active component of concrete has two functions. Firstly, it fills the voids between the particles of the inert aggregate and provides lubrication of the fresh plastic mass and upon hardening, it acts as a binder cementing the particles of aggregate together in permanent solid mass. Secondly it gives strength (and the strength of normal concrete is determined by that of the paste) and water tightness to the hardened mass. The quality of water used in the mix has marked effect on the fresh as well as the hardened paste. The properties of the hardened paste are also affected by the characteristics of the cement and the completeness of chemical combination between the cement and water.

In a SFRC mixture the aggregate which are generally graded in size from fine sand to pebbles or crushed stones, from the inert mineral filler material which the cement paste binds together. Cement and steel fibre is the most expensive of the materials used to make SFRC. For this reason and because the aggregate provides a relatively cheap filler, it is advisable to use as much aggregates as a given amount of paste will bind together. In addition to being a relatively cheap filler the aggregates reduce the volume changes resulting from the setting and hardening process and from moisture changes in the paste. Obviously, they too have to resist the loads, abrasion, percolation of moisture, and the action of weather, [43].

And the function of steel fiber is to strength the concrete material by mechanism of reinforcing in 3d dimension.

4.1.3. SFRC making materials

SFRC, as pointed out in the previous section, is a composite material made of Portland cement, Steel fibre, water, fine and coarse aggregates. In some cases, admixtures, may be added to give the concrete special properties either when fresh or hardened or both. In this topic, we deal with the properties of the component materials and the requirements they have to fulfill in order to produce good and sound SFRC.

a. Water

Water fit for drinking is generally suitable for making concrete. Substances in water which, if present in large amount, may be harmful are; salt, oil, industrial waste, alkalies, sulphates , organic matter, silt, sewage etc. Tests by the sense of smell, sight or taste should reveal such impurities, however water of doutful quality should be submitted for laboratory analysis and test.

Water used in concrete mixes has two functions, the first is to react chemically with the cement which will finally set and harden, and the second function is to lubricates all other materials and make the concrete workable.

The chemical reaction of cement compounds and water are the same as those shown in the notes on cementing materials, and the cement used in the concrete mix needs less than 30% by weight of water for hydration. However, because of the dual function of water, concrete containing such a small amount of it would be very dry and very difficult to fully compact. The quantity of water used in a concrete mix has, therefore, to be sufficient to fully satisfy both functions, namely the hydration of the cement and the lubrication of the dry materials. For these reasons water used in concrete mixes is usually much greater than the 30% of the cement weight. On the other hand, this extra water, the one needed for lubrication, will not be needed once the concrete is placed and compacted. Since all of it will evaporate when the concrete dries, leaving voids which would make the concrete porous and consequently weak, it is important that this portion of water should be kept to a minimum, [43].

In fact, it should be pointed out that the extra water, and consequential, the total amount of water required per unit volume of fresh concrete depends on the number of factors which are;

1. The desired consistency of the concrete, which may be expressed, as will be seen, by the slump or ball penetration test
2. The maximum size, particle shape and grading of the aggregate.
3. Water reducing or air entraining admixtures

b. Water/cement ratio

Water for a concrete mix is normally added during mixing. It is quite possible, however, that the aggregates are wet and release their surface water when they are mixed. On the other hand, they could be very dry and readily absorb the free water. The relationship between the total free water and the cement is given by what is known as the water/cement ratio of the concrete mix. For a given type of cement and aggregate, the strength and porosity of the paste- structure (cement stone) are dependent almost entirely upon the water cement ratio in the fresh concrete, the less void (for reasons given above) more strength, less drying shrinkage and more durability, meaning, in all a better resulting concrete, [43].

c. Aggregate

Aggregates generally occupy 65-70% of the volume of concrete. Hence due consideration should be given in their selection and proportioning. The term inert mineral fillers is often used to describe aggregates used for making concrete; however, aggregates are not truly inert and their physical, thermal and at times chemical properties influence those of the concrete, [43].

In choosing aggregate for use in a particular concrete attention should be given, among other things, to three important requirements;

- Workability when fresh for which the size and gradation of the aggregate should be such that undue labor in mixing and placing will not be required.
- Strength and durability when hardened – for which the aggregate should;
    - Be stronger than the required concrete strength
    - Contain no impurities which adversely affect strength and durability
    - Not go into undersible reaction with the cement
    - Be resistant to weathering action
- Economy of the mixture – meaning to say that the aggregate should be
    - Available from local and easily accessible deposit or quarry
    - Well graded in order to minimize paste, hence cement requirement

d. Steel fiber

In this study, Steel fibers, will be 1%, 1.5% & 2% (Sec. 2.3) by weight of the total concrete mix. Steel fibers have relatively high strength and modulus of elasticity and are protected from corrosion by the highly alkaline matrix. The fiber-matrix bond can be enhanced by mechanical anchorage through surface roughness or deformation by the mechanism of mechanical anchorage it will increase the mechanical properties of the concrete and Suppliers specification is Annex A.

e. Cement

The cement used in all mixes was the locally manufactured Messebo OPC which was produced in accordance with EN 196 and BS 1370. Chemical composition, physical, mechanical and other characteristic of the cement, as provided by the manufacturer, are presented in Table of Annex 'E'.

f. Chemical Admixtures

To obtain sufficient consistency in the steel fiber reinforced concrete mixes high performance superplasticizing admixture with the commercial name Conplast SP 430 was used in all mixes. Conplast SP430 is a chloride free, superplasticising admixture based on selected sulphonated naphthalene polymers. It is supplied as a brown solution which instantly disperses in water. Conplast SP430 conforms with BSEN 934-2, BS 5075 Part 3 and with ASTM C494 as Type A and Type F, depending on dosage used. Conplast SP 430 has several advantages; some advantages among many worth mentioning are;

- Major increases in strength at early ages without increased cement contents are of particular benefit,
- Makes possible major reductions in water/cement ratio which allow the production of high strength concrete without excessive cement contents, and
- Increased workability levels are maintained for longer than with ordinary sulphonated melamine admixtures.

Based on the product manual for high workability concrete the normal dosage range is from 0.70 to 2.00 liters/100 kg of cementitious material. In this research work 1% of admixture per dosage of cementitious material was used in all mixes. The chemical and physical properties of the superplasticizer used are provided in Table 4.1 and Suppliers specification is Annex B.

Table 4.1 Properties of the Superplasticizer .

Appearance	Brown liquid
Main Component	Sulphonated naphthalene
Specific Gravity	1.18
Water Soluble Chloride	Nil
Alkali Content (Na_2O equivalent/liter of admixture)	55g

4.1.4. Mix Design Considerations for SFRC

By making certain adjustments to conventional concrete practice, it is possible to produce SFRC. The primary concern is to introduce sufficient amount of uniformly distributed fibers in concrete to achieve improvements in mechanical properties, keeping the concrete workable to permit proper mixing, placing, and finishing. Compared to conventional concrete, some SFRC mixtures are characterized by higher cement content, higher fine aggregate content, and decreasing slump with increasing fiber content. There are various procedures for proportioning of SFRC mixtures proposed by different researches. Typical recommended proportions are shown in Table 4.2. To provide better workability of concrete, amount of paste in the mixture should be increased. This requires higher cement content, or moving the ratio of fine aggregates to coarse aggregates upwards. Alternatively pozzolanic admixtures can be used to replace cement. The use of superplasticizers enhance the workability of the concrete however it does not necessarily provide the ability to incorporate higher steel fiber content. Regardless of the mix design, in all cases trial mixes should be prepared to ensure workability and strength properties, [46].

Table 4.2 Range of proportions for normal weight SFRC [46]

Property	9.5mm Maximum Aggregate size	19mm Maximum Aggregate size	38mm Maximum Aggregate size
Cement (kg/m3)	355-590	300-535	280-415
w/c ratio	0.35-0.45	0.4-0.5	0.35-0.55
Fine/coarse aggregate (%)	45-60	45-55	40-55
Entrained air (%)	4-7	4-6	4-5
Fiber content (%) by volume			
Smooth steel	0.4-1.0	0.3-0.8	0.2-0.7
Deformed steel	0.8-2.0	0.6-1.6	0.4-1

4.1.5. Type of mixing

The compressive strength of the concrete is not directly affected by the type of mixer used. Certain types of mixer require a higher degree of workability for efficient operation and this may have an indirect effect on the proportions of the concrete required for a particular value of free-water/cement ratio. However, hand-mixing is likely to produce a lower strength concrete than machine-mixed concrete of similar proportions.

4.1.6. Mixing, Placing and Finishing of SFRC

a) Mixing

Various methods are available for introducing steel fibers to concrete, either with the dry constituents, or to the wet mix. These methods range from charging the aggregate conveyor with fibers sieving directly into the mixer drum, or sieving the fibers and blowing them into the drum. It is very important that the fibers be dispersed uniformly throughout the mixture. For steel fibers, no special mixing technique is required; however adjustments in the mix proportion, mixing sequence, and rate of addition of constituents may be necessary. Regardless of the employed mixing method, the critical factor in successful addition of steel fibers is that the fibers should reach the mixer individually without clumping and be immediately removed from the point of entry by the mixing action. Besides fiber addition rate should be comparable with the mixing speed, [46].

Primary problem encountered in mixing of SFRC is formation of fiber balls. Most fiber balling occurs somewhere before the fibers get into the mixture. Once the fibers get into a mixture ball free, they nearly always stay ball-free. This means that if balls form, it is because fibers were added in such a way that they fell on each other and stacked up (in the mixer, on the belt, on the vanes, etc.) This normally happens when the fibers are added too fast at some point in the procedure. The mixer, whatever type, must carry the fibers away into the mixture as fast as they are added. Balls form by hanging up on a rough loading chute at the back of a mixer truck. Fibers should not be allowed to pile up or slide down the vanes of a partially filled drum; this will form balls, [46].

Other causes of balling are adding too many fibers to a mixture (more than about 2 percent by volume or even 1 percent of a fiber with a high aspect ratio); adding fibers too fast to a harsh mixture (the mixture is not fluid enough or workable enough and the fibers do not get mixed in fast enough; therefore, they pile up on each other in the mixer); adding fibers first to the mixer (the fibers have nothing to keep them apart, they fall on each other, and form balls); and using equipment with worn out mixing blades. The most common causes of wet fiber balls are over mixing and using a mixture with too much coarse aggregate (more than 55 percent of the total combined aggregate by absolute volume), [46].

b) Placing

In most cases SFRC with a proper water-cement ratio appears relatively stiff and unworkable, compared to conventional concrete. However, use of vibrators or high-range water-reducing admixtures (HRWR) and superplasticizers allows easy placing of such seemingly unworkable concrete. The material tends to “hang together” and resist movement during compaction if an attempt is made to handle it without vibration or an HRWR admixture. Also, at the lower end of fiber quantity, some types of fiber allow easy placing without the methods just mentioned. Generally, however, placing of SFRC with no vibration is discouraged because, without compaction, the concrete will be less dense, may have air voids, and may have less bond with any conventional reinforcement, [46].

Water-cement ratios for fibrous mixtures must be carefully controlled. It is very easy to add unnecessary water to the mixture and lose many of the beneficial properties obtained from the addition of fibers. Tests have shown that further addition of water causes an increase in slump without a change in workability under vibration. This water addition reduces the quality of the mixture without improving the place ability and it can give rise to excessive bleeding and segregation, [46].

c) Finishing

SFRC can be finished by using conventional methods and equipment's; however certain refinements in techniques and workmanship are required. For flat-formed surfaces, normally no special attention is needed. The surface will normally be smooth and will not show fibers when the forms are striped. If chamfers or rounds have been provided at the edges and in corners, the ends of fibers will not protrude at these points when forms are removed. To provide added compaction and bury surface fibers, open slab surfaces should first be struck off with a vibrating screed. Magnesium floats can be used to establish a surface and close up any tears or open areas, which are caused by the screed. Throughout all finishing operations, care must be taken not to overwork the surface. Overworking may bring excessive fines to the surface, [46].

4.1.7. Workability

In the fresh mixed plastic SFRC, the aggregate and cement particles are temporarily suspended in water. This separation of the particles and the lubrication effect of the water layer, together with the inter particle forces among the finest particles, make the fresh mixture plastic and possible to place, compact and mold in any shape and hence workable.

Workability of concrete is at times defined as the property or group of properties which determines the ease with which a material can be placed to give a product of the requisite property; at other times, as the combined effect of those properties of fresh concrete that determines the amount of internal work required for placement and compaction and that determines the resistance to aggregation. Workability comprises at least three separate properties as follows;

1. Compatibility or the ease with which the SFRC can be compacted and the air void be removed
2. Mobility or the ease with which SFRC can flow into molds, around reinforcing steel and be remoulded (i.e. that property which is inversely proportional to this internal resistance of the mix to deformation) and

3. Stability or the ability of concrete to remain a stable coherent homogeneous mass during handling and vibration without the constituents aggregating.

Whatever the definition, it must be understood that workability is a relative property which should be seen in relation to the equipment used for mixing, the method of transporting, placing, consolidating, and the size and shape of the mass to be formed. A concrete that is workable under some conditions may not be workable under some other conditions, [43].

4.1.8. Consistence

Consistence is the term used to denote the degree of wetness or fluidity of concrete. Although it doesn't mean the same thing it is closely related to, and is a major factor of workability. By definition it is "the rheological behavior of a material under the condition of stress and strain which either occur in practice or are realized in experimental study" or "that property of a material by which it resist a permanent change of shape and it is defined by the complete flow – force relation".

There seems to exist a disagreement among concrete engineers as to which definition to accept. Nevertheless, it is generally agreed that workability and consistence are not only the most important rheological properties of fresh concrete, but also important factors as far as the finished and hardened product is concerned, since concrete must have a workability such that compaction to maximum density is possible with a reasonable amount of work or with the amount that one is prepared to put in under given conditions.

Experience has shown that wet concretes are more workable than dry (stiff) concrete, but concretes of the same wetness (consistence) may differ in workability. The degree of wetness of a concrete mixture may be classified and described as stiff, plastic, and flowing.

Usually a workable concrete is plastic although under certain conditions of placement stiff concrete are usable and therefore, considered workable, [43].

4.1.9. Curing SFRC

Moisture is necessary for the proper hardening of concrete because the chemical action which results in the setting and hardening of the paste takes place only in the presence of water. It is true that the amount of water normally used at the time of mixing is adequate for this purpose, however, the loss from evaporation from the time concrete is mixed and placed is usually so rapid that there may not be enough of it left for full hydration and hardening. Excessive loss of water due to evaporation may cause the hydration process to stop all together with a consequent reduced strength development. In addition, if concrete dries out too quickly by exposure to sun and wind, it will shrink. This early and usually rapid shrinkage will result in tensile stresses which will lead to surface cracks.

It is important therefore that fresh concrete be kept moist for several days after placing. This process, known as curing should begin soon after the concrete is set and continue preferably for a number of days. There are different methods of curing concrete including sprinkling, ponding with water, or covering with continuously wetted sand.

From the above, the purpose of curing can be summarized as follow;

1. Curing is to prevent formation of surface crack due to rapid loss of water while the concrete is fresh and weak.
2. To assure attainment of strength by providing enough moisture for the hydration of the cement grains throughout the concrete.

Curing is most important in hot climates. In this study we will submerge the specimens on water for 26 days and the water will be changed every seven days with new fresh water.

4.2. Experimental set up

Initially, important tests have been conducted on the constituent material to determine the gradation and physical properties of fine and coarse aggregate, chemical composition and other characteristic of cement and properties of steel fibers. After carrying out tests on the fresh concrete the specimens for the testing of mechanical properties in the hardened state prepared by pouring the concrete into lubricated moulds. For mix of 0%, 1%, 1.5% & 2% of steel fibre, 0%, 4% & 5% glass fiber and mix of steel & glass fiber will cast in three 150mm cubes and three 100x100mm cross section of span 600mm beams, for the respective percentage of fibres. Cubes are used for the determination of compressive strength. And Beam specimens will be used for the determination of flexural tensile strength and flexural toughness.

Comparing the mechanical properties of steel fiber reinforced concrete with glass fibre and mix of glass & steel fibre reinforced concrete in order to select the appropriate type of fibre for the construction of railway sleepers for the Ethiopian practice.

4.2.1. Test on SFRC making materials

Since the selection of material for a particular structural application depends on its mechanical properties, it is important to be familiar with some of the standard tests used to measure these properties and to understand the significance of the information obtained from these tests.

Mechanical tests area those used to examine the performance of materials of construction under the action of external forces. Such tests normally made under conditions approximating those of practice are generally standardized. Standardization is necessary in order to make test results comparable wherever or by whomever they are made, [43].

With reference to the rate and duration of the load application, the following classification may be made;

1. Static test – these are made with gradually increasing load, such as the ordinary tests in tension , compression etc
2. Dynamic tests – these are made with suddenly applied loads as by falling weight or pendulum such as drop – impact test.
3. Wear tests – these are made to determine resistance to abrasion and impact, as in the case of paving materials.
4. Long time tests – these are made with loads applied to the object under test for a long period of time they are used for materials such as concrete in order to measure the response of the concrete with respect of time.
5. Fatigue tests – these are made with fluctuating stresses repeated a large number of times.

In this thesis, Static load application is considered.

With reference to the effect of the test on the specimen the following classification may be made;

1. Destructive test – under these test methods the specimens are either crushed or ruptured and made useless at the end of the tests. Tests to determine the ultimate strength of steel specimens in tension, concrete specimens in compression are examples in this category of test.
2. Non – destructive test – these are usually used to test the strength of members of existing structures without affecting their performance. Strength test of concrete structural members by the rebound hammer test is an example in this group.

4.2.1.1.Test on sand / Fine aggregate

The fine aggregate (river sand) used for this experimental work was brought from Langano, located 200 km East of Addis Ababa, as reported by the suppliers.

Three samples are prepared to test on bulking, Silt content, Specific gravity and sieve analysis. The results found for specimens are listed on the table below and detail procedure and results are placed on Annex 'D'

Table 4.3 Test results of fine aggregate

Type of test	Experimental result	Acceptance range
Average Bulking	28.78	22 – 40%
Average Silt content	3.81	0 – 5%
Average Specific gravity	2.63	2.6 – 2.9
Average water absorption	0.71	
Fineness modules	2.762	2.2 - -2.6 – Fine sand 2.6 – 2.9 – Medium Sand 2.9 – 3.2 – Coarse sand > 3.2 – unusable for concrete

4.2.1.2.Test on coarse aggregate

The Coarse aggregate used for this experimental work was brought from Koye Fech ,in Addis Ababa, as reported by the suppliers.

Two samples are prepared to test on Specific gravity and sieve analysis. The results found for specimens are listed on the table below and detail procedure and results are placed on Annex 'D'

Table 4.4 Test results of fine aggregate

Type of test	Experimental result	Acceptance range
Average Specific gravity	2.7	2.6 – 2.9
Average water absorption	0.89	
Fineness modules	2.618	2.2 - -2.6 – Fine 2.6 – 2.9 – Medium 2.9 – 3.2 – Coarse > 3.2 – unusable for concrete

4.2.2. Test on sleeper elementary and Specimens preparation

Initially a certain amount of water for adjustment obtained from the mix design was added to the measured aggregates and left for a short while to bring the aggregates to the Saturated Surface Dry condition (SSD). The fine aggregate, coarse aggregate and cement were dry mixed for about a minute. The fibers were added during the dry mix as a rainfall very carefully in order to avoid balling effect. This was then followed by the addition of two third of the total mixing water. After two minutes of mixing, remaining mixing water together with superplasticizer was added. Mixing was ceased after four minutes for all mixes.

The specimens for the testing of mechanical properties in the hardened state were casted in two layers using appropriate moulds, wet inside with a release agent. The vibrating procedure was executed in order to obtain a more homogeneous distribution of fibers. For each mix, three 150mm cubes and three 100x100mm cross section beam of 600 mm span were casted. Cubes were used for the determination of 28th day compressive strength. Beam specimens were used for the determination of flexural tensile strength and flexural toughness.

The moulds were left to cure for 24 h. Once hardened, the specimens were carefully demolded and placed in a curing room 28 days for compressive strength tests and 28 days for flexure and impact tests at approximately 95±5% RH and 22±2°C. And the mix proportions are listed in table 4.9 and 4.10.

Table 4.5 Mix proportions for the three mix series per 1m^3 (Annex C)

Mix Designation	Steel fibre in %	Glass fibre in %	Cement Quantity (kg/m^3)	W/C Ratio	Water (liter)	Fine Agg. (kg/m^3)	Coarse Agg. (kg/m^3)	Steel fiber (kg/m^3)	Glass fiber (kg/m3)	Admix. (lit/m^3)
Mix Series I (C-30 with addition steel fiber)										
Control-1	0	0	380.95	0.47	179.05	667.31	1239.3	0	0	3.4
C_1VSF1	1	0	380.95	0.47	179.05	667.31	1239.3	24.59	0	3.4
C_1VSF2	1.5	0	380.95	0.47	179.05	667.31	1239.3	36.885	0	3.4
C_1VSF3	2	0	380.95	0.47	179.05	667.31	1239.3	49.18	0	3.4
Mix Series I (C-30 With addition Glass fiber)										
Control-1	0	0	380.95	0.47	179.05	667.31	1239.3	0	0	3.4
C_1VGF1	0	4	380.95	0.47	179.05	667.31	1239.3	0	98.36	3.4
C_1VGF2	0	5	380.95	0.47	179.05	667.31	1239.3	0	122.95	3.4
Mix Series I (C-30 With addition of glass and steel fiber)										
Control-1	0	0	380.95	0.47	179.05	667.31	1239.3	0	0	3.4
C_1VSGF1	1	2	380.95	0.47	179.05	667.31	1239.3	24.59	49.18	3.4
C_1VSGF2	1.25	2.5	380.95	0.47	179.05	667.31	1239.3	30.74	61.475	3.4
C_1VSGF3	1.5	3	380.95	0.47	179.05	667.31	1239.3	36.885	73.77	3.4

Table 4.6 Mix proportions for the three mix series per one mix(Annex C)

Mix Designation		Steel fibre in %	Glass fibre in %	Cement Quantity (kg/m^3)	W/C Ratio	Water (liter)	Fine Agg. (kg/m^3)	Coarse Agg. (kg/m^3)	Steel fiber (kg/m^3)	Glass fiber (kg/m3)	Admix. (lit/m^3)
Mix Series I (C-30 with addition steel fiber)											
Control-1	0.037	0	0	14.10	0.47	6.62	24.69	45.85	0	0	0.13
C_1VSF1	0.037	1	0	14.10	0.47	6.62	24.69	45.85	0.91	0	0.13
C_1VSF2	0.037	1.5	0	14.10	0.47	6.62	24.69	45.85	1.36	0	0.13
C_1VSF3	0.037	2	0	14.10	0.47	6.62	24.69	45.85	1.82	0	0.13
Mix Series I (C-30 With addition Glass fiber)											
Control-1	0.037	0	0	14.10	0.47	6.62	24.69	45.85	0	0	0.13
C_1VGF1	0.037	0	4	14.10	0.47	6.62	24.69	45.85	0	3.64	0.13
C_1VGF2	0.037	0	5	14.10	0.47	6.62	24.69	45.85	0	4.55	0.13
Mix Series I (C-30 With addition of glass and steel fiber)											
Control-1	0.037	0	0	14.10	0.47	6.62	24.69	45.85	0.00	0.00	0.13
C_1VSGF1	0.037	1	2	14.10	0.47	6.62	24.69	45.85	0.91	1.82	0.13
C_1VSGF2	0.037	1.25	2.5	14.10	0.47	6.62	24.69	45.85	1.14	2.27	0.13
C_1VSGF3	0.037	1.5	3	14.10	0.47	6.62	24.69	45.85	1.36	2.73	0.13

4.2.2.1.Test on fresh concrete

Objective - To determine the relative consistency of freshly mixed steel fibre reinforced concrete by the use of Slump Test

The word workability or workable concrete signifies much wider and deeper meaning than the other terminology consistency often used loosely for workability. Consistency is a general term to indicate the of fluidity or the degree of mobility. The factors helping concrete to have more lubricating effect to reduce internal friction for helping easy compaction are given below:

- Water Content
- Mix Proportions
- Size of Aggregates
- Shape of Aggregates
- Surface Texture of Aggregate
- Grading of Aggregate
- Use of Admixtures.

Slump Test: Slump test is the most commonly used method of measuring consistency of concrete which can be employed either in laboratory or at site of work since in this study steel fibre is added in to the ordinary concrete, the effect on the workability of the concrete is to be observed. It is not a suitable method for very wet or very dry concrete. It does not measure all factors contributing to workability, nor is it always representative of the placability of the concrete. The pattern of slump is shown in Fig. It indicates the characteristic of concrete in addition to the slump value. If the concrete slumps evenly it is called true slump. If one half of the cone slides down, it is called shear slump. In case of a shear slump, the slump value is measured as the difference in height between the height of the mould and the average value of the subsidence.

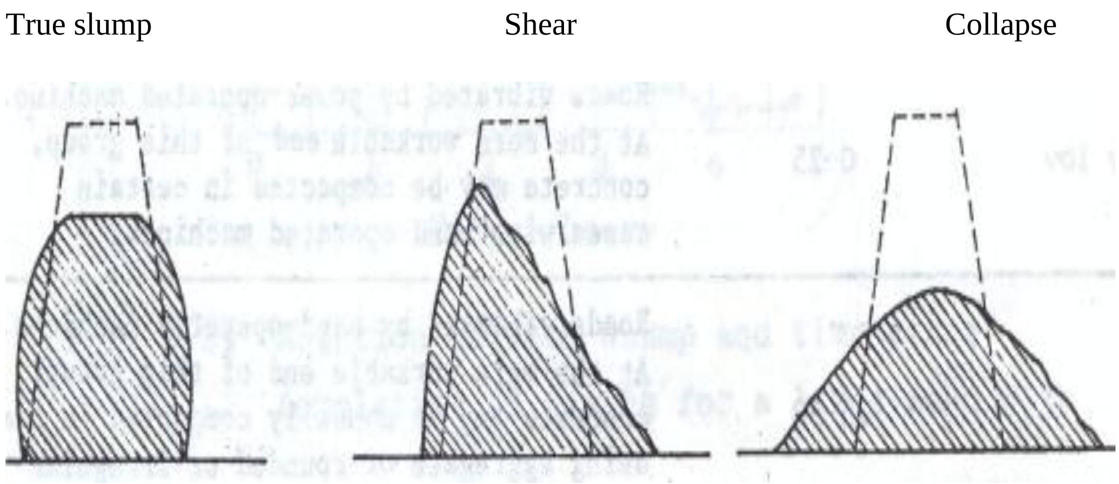


Fig.4.1 Slump test

Table 4.7 Workability and slump of concrete with 19 or 38mm maximum size of aggregate

Degree of Workability	Slump (mm)	Use for which concrete is suitable
Very low	0-25	Roads vibrated by power operated machine. At the more workable end of this group, concrete may be compacted in certain cases with hand- operating machines.
Low	25-50	Roads vibrated by hand operated machines. At the more workable end of the group, concrete may be manually compacted in roads using aggregate of rounded or irregular shape. Mass foundation without vibration or lightly reinforced section with vibration.
Medium	50-100	At the less workable end of this group, manually compacted flat slabs using crushed aggregates. Normal reinforced concrete manually compacted and heavily reinforced section with vibration.
High	100-175	For section with congested reinforcement. Not normally suitable for vibration.

Apparatuses and procedures of slump test is briefed in Annex 'D'

4.2.2.2.Test on 28 days old concrete sleeper elementary

Compressive strength tests were carried out by an oil-pressure machine with a nominal capacity of 3000 KN. Dimension and weight of each specimen were accurately measured before testing. The 28-days compressive strength of each mix were determined in accordance with the Ethiopian standard. The load was applied at a constant rate of 0.442 MPa/s and the compressive strength was measured to the nearest two digits after a decimal. Average of the test results of three specimens belonging to a mix was accepted as a compressive strength of that mix.. Specimens were tested so that the direction of loading was 90° with the direction of casting.

Flexural tensile strength and energy absorption up to failure under flexural loading tests were carried out in ECWC BTCS Material Testing Laboratory, which was equipped with a UTM testing machine with the capability of performing deformation controlled loading. Two point loading was used to determine the flexural tensile strength. Area under the load deflection curve was designated as the energy absorption up to failure and it was calculated using the trapezoidal rule. Average of the test results of three beam specimens belonging to a mix were accepted as the flexural tensile strength and flexural toughness of that mix. Furthermore location of first crack point and energy absorption up to specified deflections were determined according to ASTM C 1018. Specimens were tested so that the direction of loading was 90° with the direction of casting.

4.3. Analysis of test and discussion

4.3.1. Testing of Fresh Concrete

The workability of freshly mixed concrete is a measure of its ability to be mixed, handled, transported, and, most importantly, placed and consolidated with a minimal loss of homogeneity and minimal entrapped air. Among the several tests available the slump test is a common, convenient and inexpensive test. Predicting the workability of SFRC is difficult because of the large number of parameters involved. Two factors which influence significantly the characteristics of SFRC in its fresh state are the aggregate content, and fiber geometry & volume fraction. The influence of aspect ratio and volume fraction of fiber on the properties of fresh concrete is investigated in this study.

All the control mixes (plain concretes) were designed to give a slump value of 10-30 mm. And it was proved to be so for the trial mixes without adding the superplasticizer. Without the presence of the superplasticizer the SFRC appeared to be relatively stiff, unworkable and the materials tend to "hang together" and resist movement compared to the control mixes. It was almost impossible to work with fibers having higher aspect ratio and volume fraction. As a result 1% of SP 430 superplasticizer per cementitious material was added to all mixes in order to improve the workability.

To evaluate the effect of volume fraction of fibers on workability a slump test were performed on the fresh concrete for each mix and the results are reported in Table 4.8. As shown in this table, slump values of concretes vary between 42 and 65 for plain concrete , 28 and 32 mm for mix series II addition of glass fiber and 39 and 45mm for mix series III addition of glass and steel fibre. It can be noted that the presence of the fibers strongly affected the workability of the fresh concrete.

Despite lowest slump value obtained, almost all mixes were workable, had even distribution of fibers without balling effect and responded well to mechanical vibration and could be placed and compacted without much effort. As a result of this it can be concluded that slump test provides little indication of either the workability or the ease with which SFRC can be compacted. Since this test is inadequate and cannot distinguish the effects of fiber inclusion on the consistency of SFRC, as suggested by ACI code to obtain a more reliable measures of workability inverted slump cone test or Vebe test should be used.

Table 4.8 Slump value for the three mix series (Annex 'D')

Mix	Trail mix (m3)	steel fibre in %	Glass fibre in %	W/C Ratio	Water (lit)	Steel fibre (Kg/m3)	Glass fiber (kg/m3)	Admix. (lit/m3)	Slump Value (mm)
Mix Series I (C-30 with addition steel fiber)									
Control-1	0.037	0	0	0.47	6.62	0	0	0.13	65
C_1VSF1	0.037	1	0	0.47	6.62	0.91	0	0.13	54
C_1VSF2	0.037	1.5	0	0.47	6.62	1.36	0	0.13	45
C_1VSF3	0.037	2	0	0.47	6.62	1.82	0	0.13	42
Mix Series II (C-30 With addition Glass fiber)									
Control-1	0.037	0	0	0.47	6.62	0	0	0.13	65
C_1VGF1	0.037	0	4	0.47	6.62	0	3.64	0.13	32
C_1VGF2	0.037	0	5	0.47	6.62	0	4.55	0.13	28
Mix Series III (C-30 With addition of glass and steel fiber)									
Control-1	0.037	0	0	0.47	6.62	0	0	0.13	65
C_1VSGF1	0.037	1	2	0.47	6.62	0.91	1.82	0.13	45
C_1VSGF2	0.037	1.25	2.5	0.47	6.62	1.14	2.27	0.13	42
C_1VSGF3	0.037	1.5	3	0.47	6.62	1.36	2.73	0.13	39

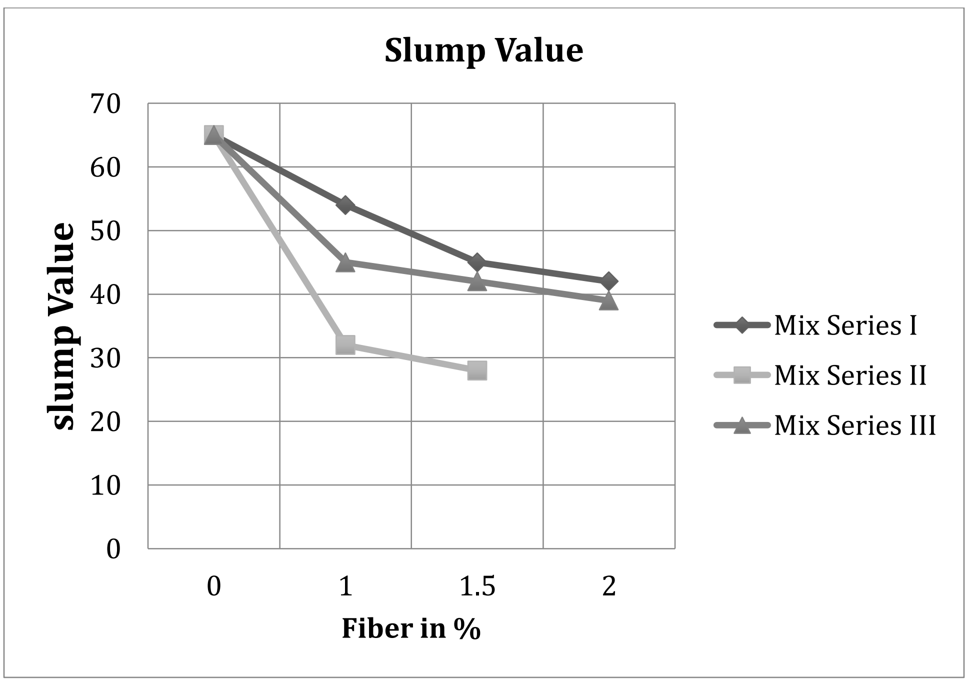


Fig. 4.2 Slump Value

4.3.2. Test on hardened Sleeper elementary

4.3.2.1. Compressive strength

The 28 days compressive strengths were determined as explained in section 4.2.2.2 above. The tables below shows the 28 day compressive strength as the mean of three specimens of two fibre types and one fibre combination tested on the same day along with the the relative strength gain or loss to that of the control mix. The 28 compressive strength results and all raw data are attached in Annex F

A. **Compressive strength of Steel fiber**

As reported in Table 4.9, the 28th day mean compressive strength for the plain control mix is found to be 31.14MPa. In this mix series addition of steel fibers of different volume ranging from 1% to 2% has resulted mean compressive strength values varying from 36.41 MPa to 39.35 MPa with a maximum relative strength gain of 26.37%.

Table 4.9 Compressive strength results of steel fiber (Annex D)

Concrete Grade C-30											
Mix Desig.	Cube No.	Dimensions (cm)			Weight (g)	Volume (cm^3)	Unit Weight (g/cm^3)	Failure Load (kN)	Actual Comp. Strength (MPa)	Corrected Comp. Strength (MPa)	Relative Strength grain (%)
		L	W	H							
Control	C -1	15	15.2	14.7	8253	3351.6	2.46	671.54	29.45	29.85	
	C -2	15	14.9	15	8159	3341.25	2.44	692.13	31.07	30.76	
	C -3	15	15	15	8352	3375	2.47	738.21	32.81	32.81	
Mean					8254.67	3355.95	2.46	700.63	31.11	31.14	
1% SF	SF-11	15	14.9	15	8230	3397.2	2.42	826.66	36.50	36.74	16.93
	SF-12	15	14.8	15	8238	3330	2.47	834.65	37.60	37.10	
	SF-13	15	15.1	14.9	8274	3374.85	2.45	796.37	35.16	35.39	
Mean					8247.33	3367.35	2.45	819.23	36.42	36.41	
1.5% SF	SF-21	15	14.7	15	8002	3351.6	2.39	852.26	38.14	37.88	22.52
	SF-22	15	14.8	15.1	8152	3352.2	2.43	847.05	38.16	37.65	
	SF-23	15	15	15.2	8154	3420	2.38	876	38.93	38.93	
Mean					8102.67	3374.60	2.40	858.44	38.41	38.15	
2% SF	SF-31	15	14.9	15	8411	3374.85	2.49	886.14	39.39	39.38	26.37
	SF-32	15	15	15.1	8325	3397.5	2.45	902.12	40.09	40.09	
	SF-33	15	15.1	14.9	8250	3374.85	2.44	867.8	38.31	38.57	
Mean					8328.67	3382.40	2.46	885.35	39.26	39.35	

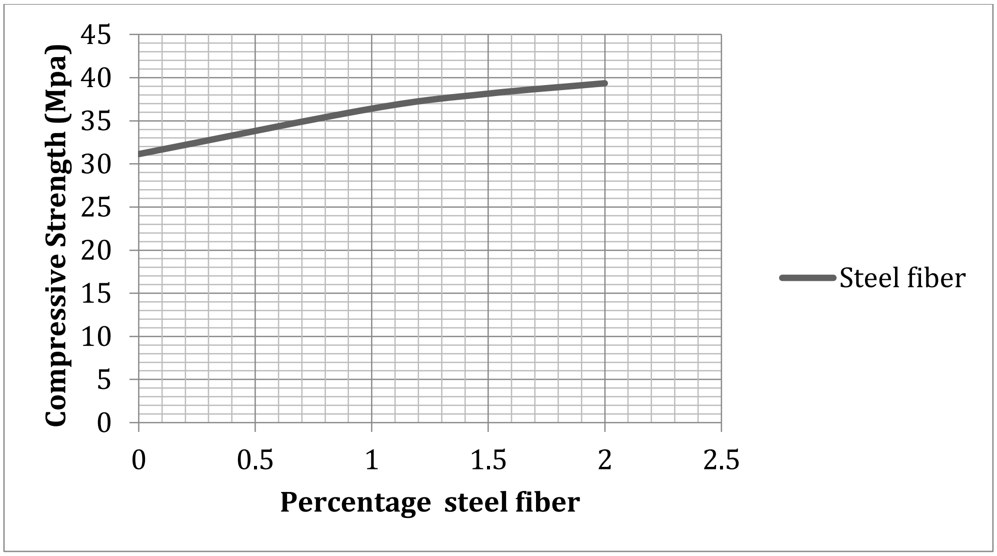


Fig.4.3 Compressive strength of SFRC

B. **. Compressive strength of Glass fiber**

As shown in the tables below 28th day mean compressive strength for the plain control mix is found to be 31.14MPa. In this mix series addition of Glass fibers of different volume 4% and 5% has resulted mean compressive strength values of 33.91 MPa and 34.33 MPa with a maximum relative strength gain of 10.25%.

Table 4.10 Compressive strength results of Glass Fibre (Annex D)

Concrete Grade C-30											
Mix Desig.	Cube No.	Dimensions (cm)			Weight (g)	Volume (cm^3)	Unit Weight (g/cm^3)	Failure Load (kN)	Actual Comp. Strength (MPa)	Corrected Comp. Strength (MPa)	Relative Strength grain (%)
		L	W	H							
Control	C -1	15	15.2	14.7	8253	3351.6	2.46	671.54	29.45	29.85	
	C -2	15	14.9	15	8159	3341.25	2.44	692.13	31.07	30.76	
	C -3	15	15	15	8352	3375	2.47	738.21	32.81	32.81	
				Mean	8254.67	3355.95	2.46	700.63	31.11	31.14	
4% GF	GF-11	15	15	15	8112	3386.18	2.40	769.8	34.10	34.21	8.88
	GF-12	15	15	15	8059	3352.5	2.40	758.82	33.95	33.73	
	GF-13	15	14.8	15	8084	3330	2.43	760	34.23	33.78	
				Mean	8085.00	3356.23	2.41	762.87	34.10	33.91	
5% GF	GF-21	15	15	14.9	8152	3318.98	2.46	770	34.57	34.22	10.25
	GF-22	15	15	14.8	8092	3352.2	2.41	752	33.20	33.42	
	GF-23	15	14.9	14.8	8099	3290.16	2.46	795.22	35.77	35.34	
				Mean	8114.33	3320.44	2.44	772.41	34.51	34.33	

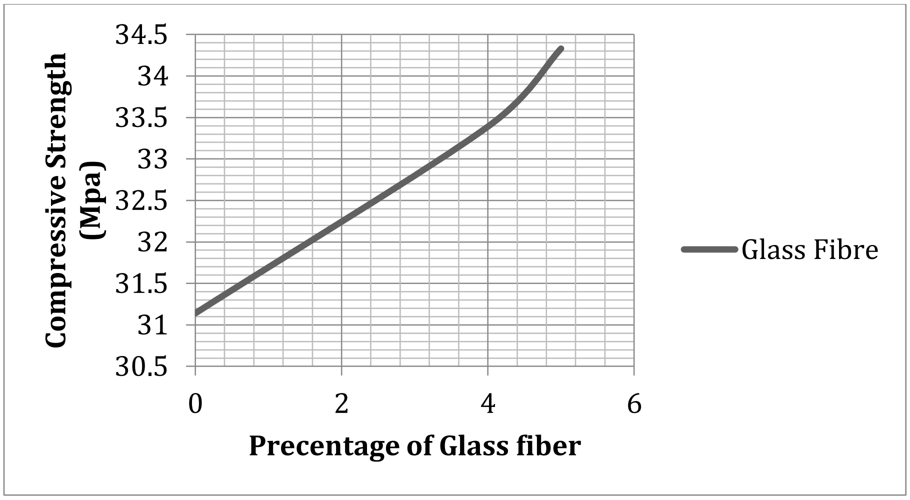


Fig.4.4 Compressive strength of GFRC

C. **Compressive strength of steel and glass fiber mix**

In this mix series addition of steel and glass fibers of different volume has resulted mean compressive strength values varying from 34.19 MPa to 37.63 MPa with a maximum relative strength gain of 20.84% comparing with the control mix mean compressive strength of 31.14Mpa.

Table 4.11 Compressive strength result of steel & glass fiber mix (Annex D)

Concrete Grade C-30											
Mix Desig.	Cube No.	Dimensions (cm)			Weight (g)	Volume (cm3)	Unit Weight (g/cm3)	Failure Load (kN)	Actual Comp. Strength (MPa)	Corrected Comp. Strength (MPa)	Relative Strength grain (%)
		L	W	H							
Control	C -1	15	15.2	14.7	8253	3351.6	2.46	671.54	29.45	29.85	
	C -2	15	14.9	15	8159	3341.25	2.44	692.13	31.07	30.76	
	C -3	15	15	15	8352	3375	2.47	738.21	32.81	32.81	
				Mean	8254.67	3355.95	2.46	700.63	31.11	31.14	
1% SF & 2% GF	SGF-11	15	14.9	15	8425	3352.5	2.51	768.89	34.40	34.17	10.75
	SGF-12	15	15	15	8324	3352.5	2.48	780.3	34.91	34.68	
	SGF-13	15	15	14.8	8198	3352.2	2.45	778.65	34.38	34.61	
				Mean	8315.67	3352.40	2.48	775.95	34.56	34.49	
1.25% SF & 2.5% GF	SGF-21	15	14.7	14.9	8298	3329.26	2.49	824	36.88	36.62	18.7152
	SGF-22	15	15	14.8	8200	3296.7	2.49	841.25	37.77	37.39	
	SGF-23	15	15	14.8	8250	3330	2.48	830	36.89	36.89	
				Mean	8249.33	3318.65	2.49	831.75	37.18	36.97	
1.5% SF & 3% GF	SGF-31	15	14.7	15	8465	3285.45	2.58	835	38.12	37.11	20.8442
	SGF-32	15	15	15.1	8354	3397.5	2.46	846	37.60	37.60	
	SGF-33	15	15	14.9	8350	3352.5	2.49	859	38.18	38.18	
				Mean	8389.67	3345.15	2.51	846.67	37.97	37.63	

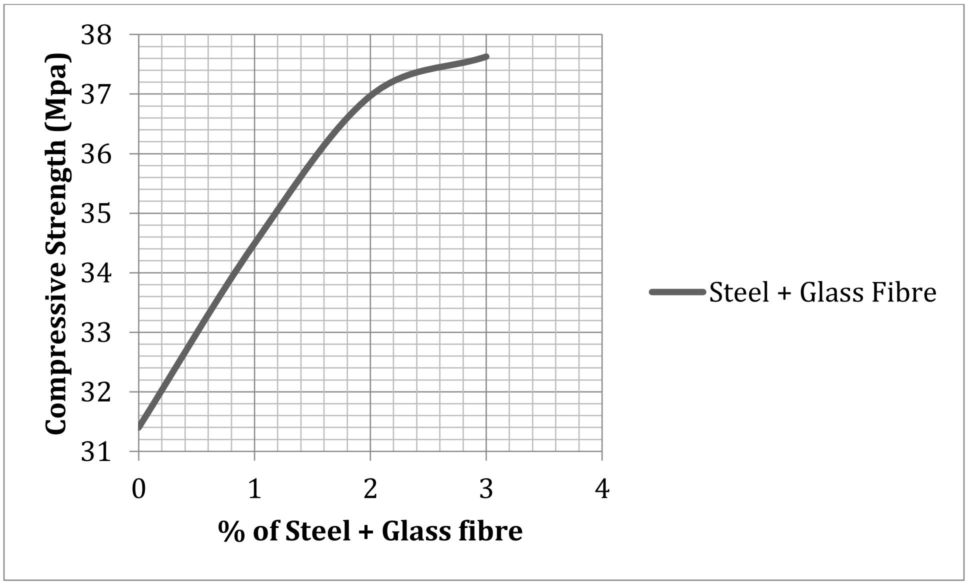


Fig.4.5 Compressive strength mix of steel glass fibre

Generally, among the 27 mixes there is no decrease in compressive strength rather than increasing the strength. The inclusion of fibers in concrete is very much advantageous in delaying the materials failure and increasing the strain at the peak in the stress strain curves for steel fiber reinforced concrete in compression. This occurrence is also confirmed by the examination of the specimens after testing. For the plain concrete specimens a sudden ejection of materials was observed at the collapse, while for SFRC a more ductile collapse was observed.

The results obtained in this study regarding the compressive strength are very much in harmony with the experimental results reported in the literature review. In fact, values illustrated in Table 4.9 confirm the experimental results reported in the literature (shah suendra & Ragan[34]) where compressive strength of concrete seems unaffected by the presence of steel fibers despite their geometry and volume fraction. In addition, comparing these results with those reported in section 2.3.1.1 and 2.4.2 the slight increase in compressive strength with respect to unreinforced concrete is confirmed and the relative strength gains are also in a range reported in section 2.4.2.

4.3.2.2. Flexural Strength

Basically there are two commonly adopted forms of the flexure test; the two point loading and center point loading. The two point loading is generally preferred for many materials, but the center point loading is often used where greater testing simplicity is required. In this Study the flexural tensile strength of all mixes was determined as clarified in Chapter 2 using a two point loading. This method is preferred over center point loading for the different advantages it possesses. In this test the concrete beam to be tested is supported at its ends and loaded at its interior location by gradually increasing load to failure. The failure load (loading value at which the concrete cracks heavily) is then recorded and used to determine the tensile at which the member failed, i.e. its tensile strength. The mean flexural tensile strength for all mix series are presented in Tables 4.12, 4.13 and 4.14 for steel , glass, steel & glass fibres respectively along with the relative flexural strength gain to that of the control mix. Apparently fiber inclusion of two aspect ratio and volume fractions resulted in substantial increase in flexural tensile strength values as discussed below

A. **Flexural strength of Steel fiber**

The 28th day mean flexural strength for the plain control mix is 8.87MPa. In this mix series addition of steel fibers of different volume ranging from 1% to 2% has resulted mean flexural strength values varying from 9.83MPa to 14.74MPa with a maximum relative strength gain of 66.2% as shown in table 4.12.

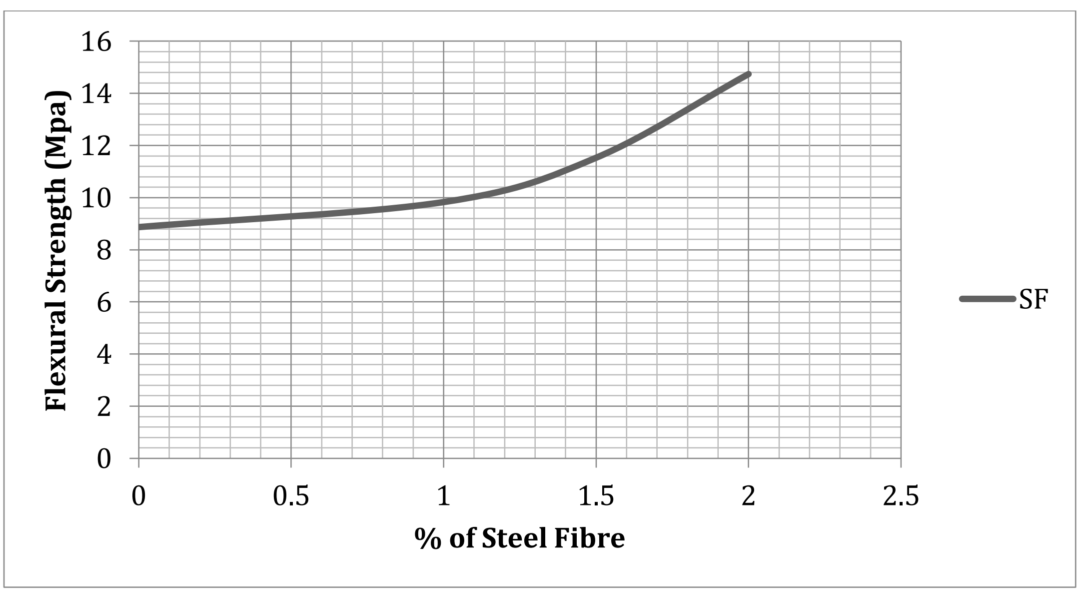


Fig.4.6 Flexural strength of SFRC

Table 4.12 Flexural strength results of steel fiber (Annex D)

Concrete Grade C-30										
Mix Desig.	Beam No.	Dimensions (cm)			P (kN)	M (N.m)	I (m^4)	C (mm)	σ (MPa)	σ Gain (%)
		L	W	H						
Control	C -1	60	10	10	14.75	147.5	833.33	50	8.85	
	C -2	60	10	10	15	150	833.33	50	9.00	
	C -3	60	10	10	14.6	146	833.33	50	8.76	
				Mean	14.78	147.83	833.33	50	8.87	
1% SF	SF-11	60	10	10	15	150	833.33	50	9.00	10.8
	SF-12	60	10	10	17.95	179.5	833.33	50	10.77	
	SF-13	60	10	10	16.2	162	833.33	50	9.72	
				Mean	16.38	163.83	833.33	50	9.83	
1.5% SF	SF-21	60	10	10	18.6	186	833.33	50	11.16	33.46
	SF-22	60	10	10	19.3	193	833.33	50	11.58	
	SF-23	60	10	10	19.73	197.3	833.33	50	11.84	
				Mean	19.21	192.10	833.33	50	11.53	
2% SF	SF-31	60	10	10	24	240	833.33	50	14.40	66.20
	SF-32	60	10	10	25	250	833.33	50	15.00	
	SF-33	60	10	10	24.71	247.1	833.33	50	14.83	
				Mean	24.57	245.70	833.33	50	14.74	

B. **Flexural strength of Glass fiber**

As reported in Table 4.13, the 28th day mean flexural strength for the plain control mix is found to be 8.87MPa. In this mix series addition of glass fibers of different volume 4% and 5% has resulted mean flexural strength values 8.91MPa and 8.95MPa with a maximum relative strength gain of 3.16%.

Table 4.13 Flexural strength results of glass fiber(Annex D)

Concrete Grade C-30										
Mix Desig.	Beam No.	Dimensions (cm)			P (kN)	M (N.m)	I (m^4)	C (mm)	σ (MPa)	σ Gain (%)
		L	W	H						
Control	C -1	60	10	10	14.75	147.5	833.33	50	8.85	
	C -2	60	10	10	15	150	833.33	50	9.00	
	C -3	60	10	10	14.6	146	833.33	50	8.76	
				Mean	14.78	147.83	833.33	50	8.87	
4% GF	GF-11	60	10	10	15	150	833.33	50	9.00	0.5
	GF-12	60	10	10	14.8	148	833.33	50	8.88	
	GF-13	60	10	10	14.75	147.5	833.33	50	8.85	
				Mean	14.85	148.50	833.33	50	8.91	
5% GF	GF-21	60	10	10	14.5	145	833.33	50	8.70	3.16
	GF-22	60	10	10	15	150	833.33	50	9.00	
	GF-23	60	10	10	15.25	152.5	833.33	50	9.15	
				Mean	14.92	149.17	833.33	50	8.95	

Fig.4.7 Flexural strength of GFRC

C. **Flexural strength of steel and glass fiber mix**

Addition mix of steel and glass fibers of different volume has resulted mean flexural strength values varying from 9.46MPa to 10.24MPa with a maximum relative strength gain of 15.45% comparing with the mean felexural strength control mix 8.87Mpa.

Table 4.14 Flexural strength results of steel & glass fiber mix (Annex D)

Concrete Grade C-30										
Mix Desig.	Beam No.	Dimensions (cm) L	W	H	P (kN)	M (N.m)	I (m4)	C (mm)	σ (MPa)	σ Gain (%)
Control	C -1	60	10	10	14.75	147.5	833.33	50	8.85	
	C -2	60	10	10	15	150	833.33	50	9.00	
	C -3	60	10	10	14.6	146	833.33	50	8.76	
				Mean	14.78	147.83	833.33	50	8.87	
1% SF & 2% GF	SGF-11	60	10	10	15	150	833.33	50	9.00	6.7
	SGF-12	60	10	10	16.52	165.2	833.33	50	9.91	
	SGF-13	60	10	10	15.8	158	833.33	50	9.48	
				Mean	15.77	157.73	833.33	50	9.46	
1.25% SF & 2.5% GF	SGF-21	60	10	10	16.5	165	833.33	50	9.90	9.58
	SGF-22	60	10	10	17	170	833.33	50	10.20	
	SGF-23	60	10	10	16.2	162	833.33	50	9.72	
				Mean	16.57	165.67	833.33	50	9.94	
1.5% SF & 3% GF	SGF-31	60	10	10	17.3	173	833.33	50	10.38	15.45
	SGF-32	60	10	10	16.9	169	833.33	50	10.14	
	SGF-33	60	10	10	17	170	833.33	50	10.20	
				Mean	17.07	170.67	833.33	50	10.24	

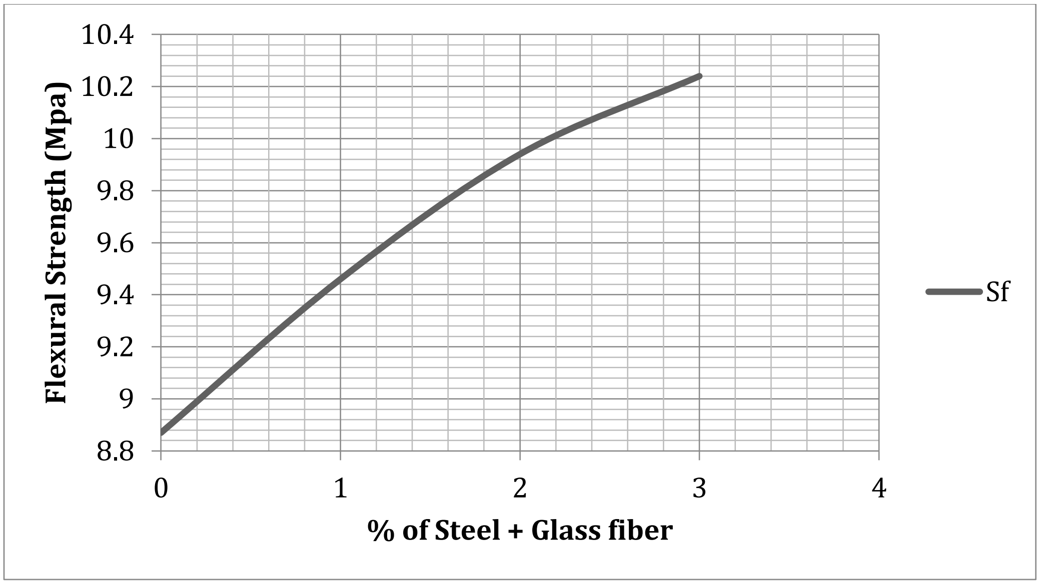


Fig.4.8 Flexural strength mix of steel and glass fibre

From the test results it can be noted that lowest values of tensile strength were obtained in glass fibers, whereas, highest values were recorded in steel fibre reinforced concrete. This can be explained by the fact that failure in flexure for fiber reinforced concrete is mainly due to fiber pull out and tensile strength of the fibre. And also it is possible to observe that addition of steel fibers appreciably improved the flexural tensile strength of concrete compared to the compressive strength. Increases in the flexural strength of SFRC are substantially greater than compression because ductile behavior of the SFRC on the tension side of a beam alters the normally elastic distribution of stress and strain over the member depth

The results obtained in this study regarding the flexural strength are very much in harmony with the experimental results reported in the literature review. In fact, values illustrated in Table 4.12 confirm the experimental results reported in the literature [34].

4.3.2.3. Flexural Toughness

Flexural toughness is energy absorptions of the concrete structure up to failure under flexural loading for all mixes were calculated as explicated in Chapter 2. Area under the load deflection curve was designated as the energy absorption up to failure and it was calculated using the trapezoidal rule. Mean of the test results of three beam specimens belonging to a mix were accepted as flexural toughness of that mix.

Since determination of first crack point is not a concern and stability problems encountered right after the first crack do not affect the obtained results significantly in JSCE Standard method, this method was preferred over ASTM C 1018 method to determine the flexural toughness. In this method the area under the load deflection curve up to a deflection of span/150 (4mm in this case) is obtained and the calculated values together with the relative energy absorption gain for all mix series are presented in Table 4.15. The Averaged load deflection curves from which the energy absorption values are calculated are shown in Fig. 4.10, 4.11 and 4.12.

As reported in the literature review part, the main effect of the steel fibers is to prevent and control the crack propagation; as a consequence the flexural behavior is characterized by a residual strength in the post cracking stage with a significant improvement of the material toughness. As expected and shown in Fig. 4.9, the failure in flexure for all SFRC specimens was due to fiber pull out. In the experiment it was observed that all control plain beams broke suddenly in two halves, and the load versus deflection curve of the control mixes made a closed loop instantly after the first crack was observed. This clearly shows the typical brittleness of plain concrete, which makes this material unsuitable for a reliable structural use without tensile reinforcement. Apparently steel fiber inclusion prevented sudden and brittle failure. Fiber inclusion of all volume of fraction greatly enhanced the flexural toughness up to failure compared with the plain control mixes.

Fig.4.9 Sample beam failed by fibre pullout under flexure

Table 4.15 Calculating mean energy absorption

Steel fibre			Glass fibre			Steel and Glass fibre		
Mix series	Energy absorption (Joule)	Relative energy gain (%)	Mix series	Energy absorption (Joule)	Relative energy gain (%)	Mix series	Energy absorption (Joule)	Relative energy gain (%)
control	11.824		control	11.824		control	11.824	
1% SF	22.932	93.94	4% GF	13.365	13.03	1% SF + 2% GF	21.29	80.06
1.5% SF	28.815	143.70	5% GF	14.174	19.87	1.25% SF + 2.5% GF	24.03	103.23
2% SF	44.19	273.73				1.5% SF + 3% GF	26.46	123.78

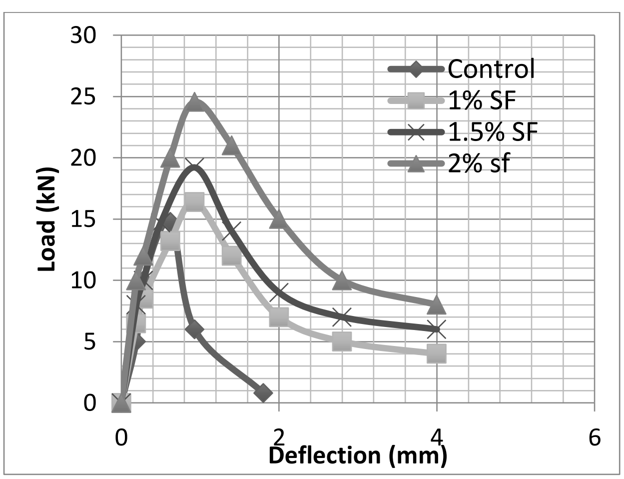


Fig.4.10 Load versus deflection curve of mix of steel fibre

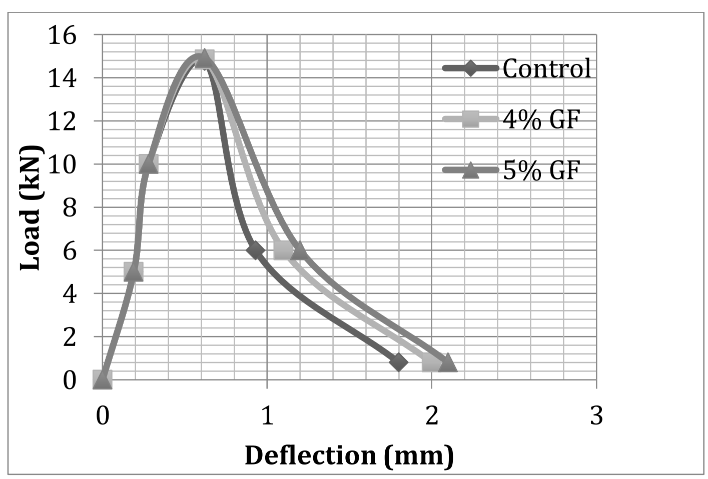


Fig.4.11 Load versus deflection curve of mix of Glass fibre

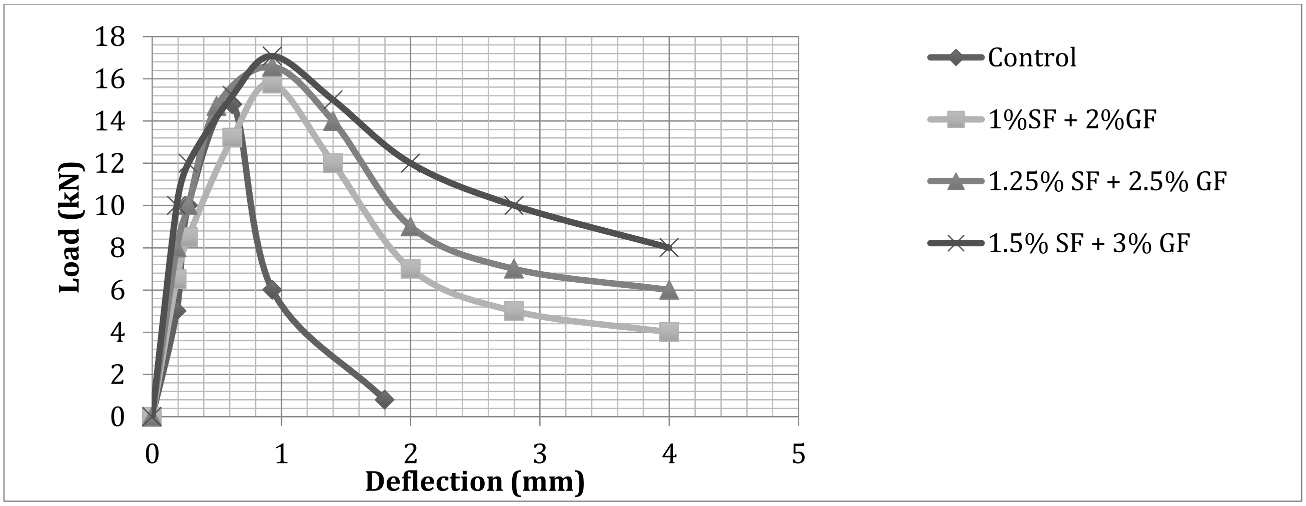


Fig.4.12 Load versus deflection curve of mix of steel fibre and glass fibre

From Table 4.15 it can be noted that flexural energy absorption of the plain control mix is 11.824 Joule. However, steel fiber inclusion has resulted energy absorption with a maximum and minimum value of 44.19 and 22.932 Joule with a relative energy absorption gain of 273.73% and 93.94%, respectively. Addition of 4 and 5% of glass fiber has increased the energy absorption by 1.52 and 2.334 Joule respectively. Also the inclusion mix of glass and steel fibre resulted energy absorption with a minimum and maximum value of 21.29 and 26.46 Joule respectively and the maximum a relative energy absorption gain is 123.78%.

4.3.3. Comparison of steel and glass fibre

From table 4.16, we can noted that the slump test results are much lower on glass fibre reinforced concrete that means the concrete mix was very stiff comparing to the control and other fibre mixes this is because of the glass fibre has much higher aspect ratio and water absorption than the other fibres.

The 28th day mean compressive strength for the plain control mix is found to be 31.14MPa. In mix series addition of steel, glass and mix of glass & steel fibers of different volume has resulted mean compressive strength values 37.97, 34.12 and 36.36Mpa respectively. And mean Flexural strength for the plain control mix is 8.87MPa. In mix series addition of steel, glass and mix of glass & steel fibers of different volume has resulted mean Flexural strength values 12.03, 8.93 and 9.88Mpa respectively. This results shows as the compressive and Flexural strength of SFRC is much better than the GFRC and SGFRC.

Table 4.16 Comparison of the three mix series

Mix design	Slump (mm)	Steel Fiber		Glass Fiber		Steel + Glass Fiber	
		Comp. Strength (Mpa)	Flexural Strength (Mpa)	Comp. Strength (Mpa)	Flexural Strength (Mpa)	Comp. Strength (Mpa)	Flexural Strength (Mpa)
Control	65	31.14	8.87				
1% SF	54	36.41	9.83				
1.5% SF	45	38.15	11.53				
2% SF	42	39.35	14.74				
	Mean	37.97	12.03				
4% GF	32			33.91	8.91		
5% GF	28			34.33	8.95		
	Mean			34.12	8.93		
1% SF + 2% GF	45					34.49	9.46
1.25% SF + 2.5% GF	42					36.97	9.94
1.5% SF + 3% GF	39					37.63	10.24
	Mean					36.36	9.88

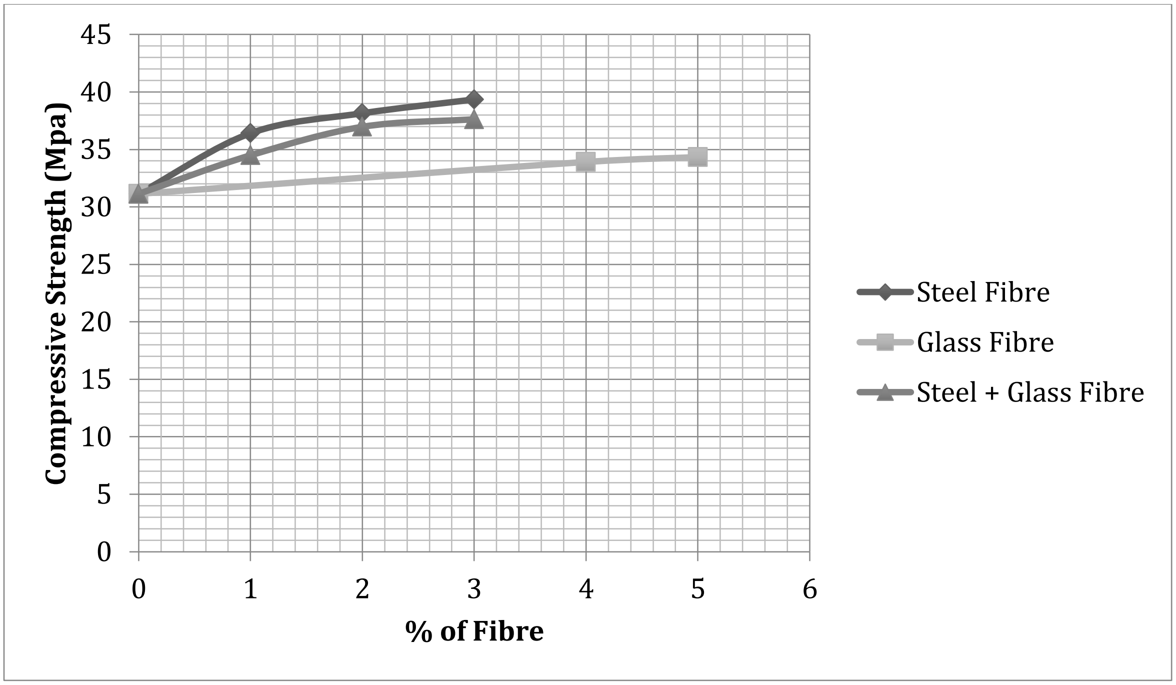


Fig.4.13 Comparison of Compressive strength

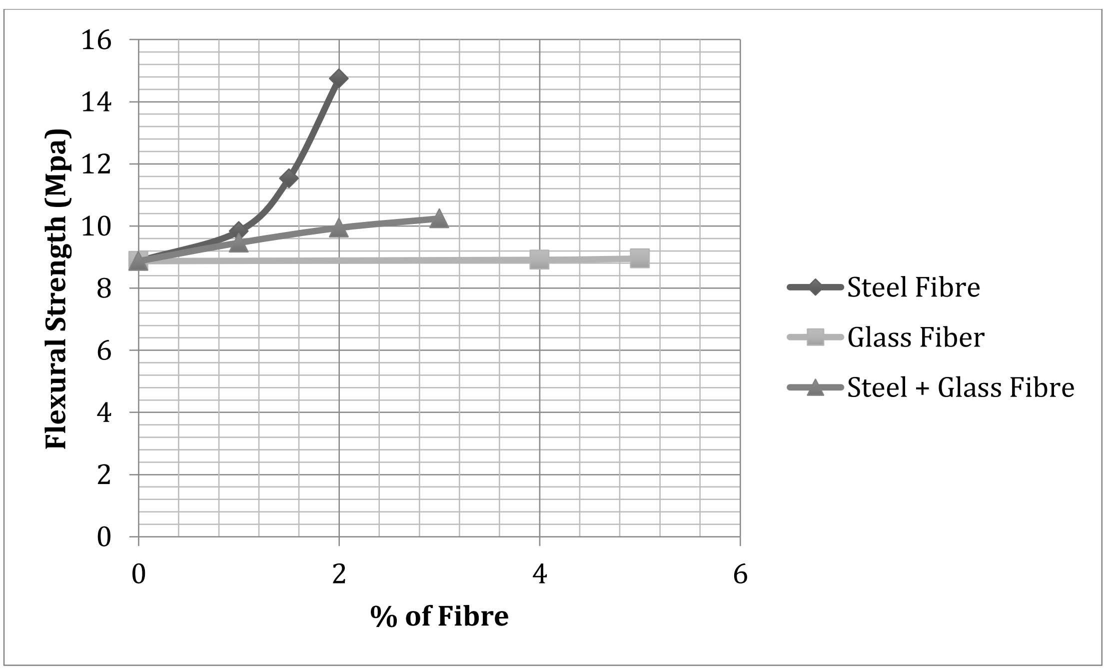


Fig.4.14 Comparison of Flexural strength

CHAPTER V - ANALYSIS AND DESIGN OF SFRC SLAB TRACK (SLAB SLEEPER)

CHAPTER V- ANALYSIS AND DESIGN OF SFRC SLAB TRACK (SLAB SLEEPER)

5.1.General

Presently all over the world ballastless track concepts are in practice, although at a moderate volume. The pattern of slab track use seems to rise by the time due to the higher demands for high speed railways and heavy freight trains. The slab may be cast-in-situ, resulting in a continuous length of concrete, or it may be constructed in discrete precast sections laid end to end. The main advantages of such structures are [42];

- Lower maintenance requirements
- Increased service life of the track
- No track maintenance like tamping and aligning
- No problems with churning of ballast particles at high-speed
- Very high lateral and longitudinal track stability.

Slab track can be constructed in three ways [42];

a. Using a slab with reinforcement at the neutral line. Since the bending stiffness of such slab is very poor massive soil improvements are required which makes such slab structure financially less attractive.
b. Using a slab with reinforcement at the top and at the bottom of the slab, this improves the bending strength of the track structure.
c. Using bridge or bridge like structures as a substructure in slab track design. The influence of bending of the bridge has a restricted influence on the bending stresses in the track slab

According Ethiopian national railway program (ENRP)

- 5000km of national railway line
- Standard gauge of 1435mm
- Electric traction
- High capacity 25 ton/ axle
- High speed (120-160 km/hr for passenger and 80-120km/hr for freight)
- Concrete sleeper
- 34km of fully electrified LRT for Adis Abeba

5.2.Analysis of Ballastless Track Slab

Rails are the horizontal member running throughout the track which is supported by the fastening systems. Figure below shows the Profile UIC60 in accordance with IRS-T12. The height of the UIC60 type rail system is 172 mm. The mass and section of the rail is 60.34 kg/m and 7686 mm^2

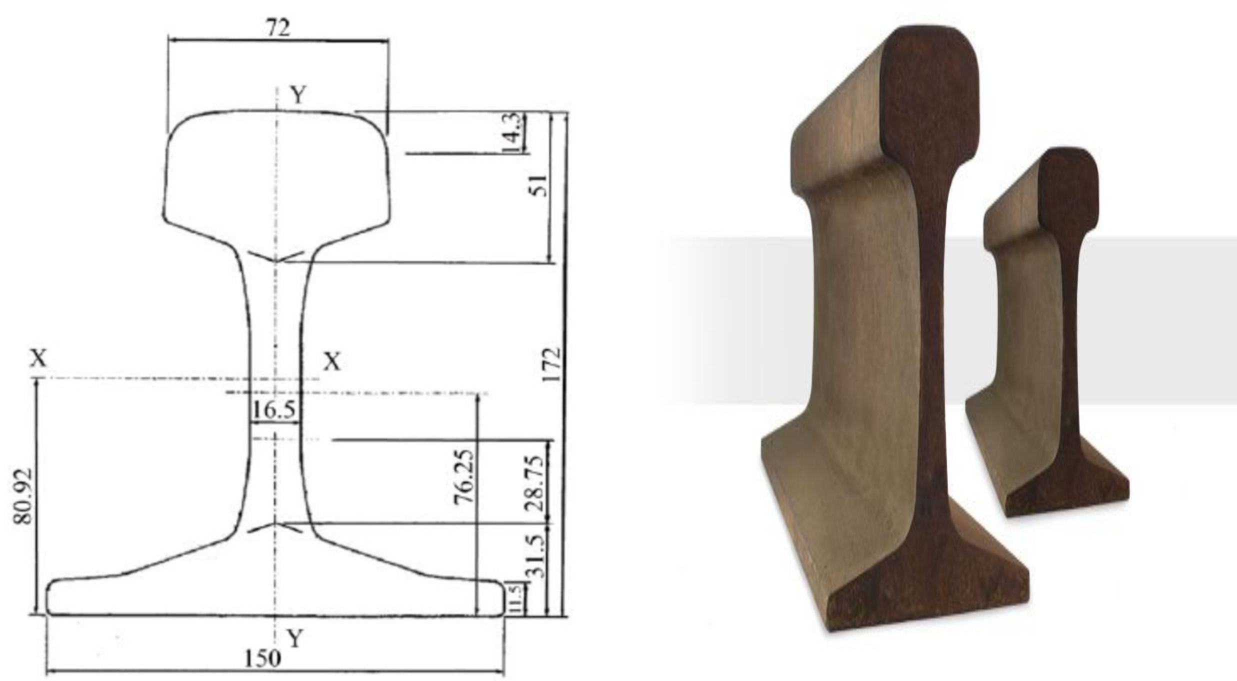


Fig. 5.1 Example of rail profile UIC60 with measurements

Fastening system is used to hold the rail element with the slab element. The fastening system shall have 4 anchor bolts at each rail seat. The spacing between each fastener is 0.65m, in straight alignment as well as curves. The approximated weight of a fastener is 20 kg per fastening system. The maximal longitudinal restraint per fastening system is 13 kN [43].

Slab track model

A. Support Conditions

The ballastless track consists of a continuous slab of concrete where rails are supported on the upper surface of the slab. The support spring stiffness representing Hydraulic Bounding Layer (HBL) is taken with corresponding to the maximum tolerable deflection of 5mm. The maximum axle load of 224 kN is considered. The spring stiffness for the rail with respect to the fastening system of 26 kN/mm is applied throughout the running beam element and the stiffness 34 kN/mm for slab with respect to HBL is acting throughout the plate element [42].

B. Load Calculations as per EN code

The loads to be taken into account in the slab track modeling are presented in the following sections and the loads summary is shown in Table 5.1. Some of them are applied vertically to the structure, other horizontally. The axis (X, Y, Z) are shown in Figure below [42].

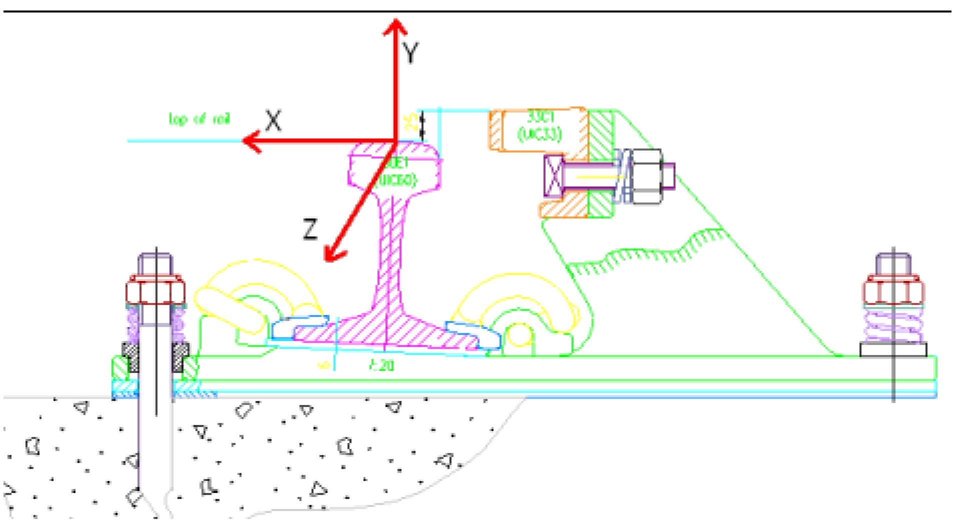


Fig. 5.2 Axis convention at the top of rail

The various types of horizontal and vertical loads acting on the structure are:

- Dead Load (DL)
- Super Imposed Dead Load (SIDL)
- Live Load (LL)
- Dynamic / Impact Load (IL)
- Lurching Force (LF)
- Earthquake Load (EQ)
- Traction & Braking Load (T&B)
- Racking Force (RF)
- Long Welded Rail (LWR)
- Temperature (TR)

As per EN code, vertical wheel loads are distributed to fasteners under load at 50 % and to adjacent fasteners at 25 %. Horizontal wheel loads are distributed to fasteners under load at 70 % and to adjacent fasteners at 18 %. The diagrammatic representation of the bogie details are shown in Figure below [42].

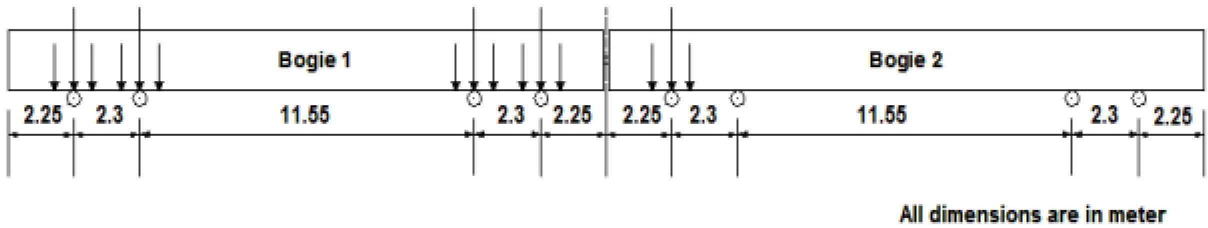


Fig. 5.3 Diagrammatic representation of bogie details

1. Dead Load: This is the self-weight of the track structure, mainly reinforced concrete which is given by its volumetric weight.

$$DL = Track\ width * Thickness * Volumetric\ Concrete$$
$$= 2.54 * 0.265 * 24$$
$$= 16.15\ kN/m$$

2. Super Imposed Dead Load: SIDL is considered for the running rail portion.

$$SIDL = \frac{Rail}{fastener} + \frac{Fastening\ system\ load}{fastener}$$
$$= 0.6 + \frac{0.2}{0.6} = 0.93\frac{kN}{m}$$

3. Live Load: According to the axle load value at the maximum capacity, as per EN Code, the train live load is

$$LL = 224\ kN. LL\ per\ wheel\ is\ 112\ kN.$$

4. Impact Load: As per Modern Railway Track by Coenraad Esveld, the impact load is dependent of the train speed and train quality. The dynamic factor can therefore b calculated by Eisenmann formula:

$$\gamma_{dyn} = t * \varphi\left(1 + \frac{V - 60}{140}\right) = 2 * 0.2 * \left(1 + \frac{80 - 60}{140}\right) = 0.46$$

$$Impact\ Load = Dynamic\ factor * LL$$
$$= 0.46 * 112 = 51.52\ kN/wheel$$

5. Racking Force: Racking force is a nose force which is produced due to the lateral movement. The nosing force shall be acting horizontally at the top of the rails, Perpendicular to the center-line of track. It shall be applied on both straight track and curved track. As per EN code Bridge Rules [47], the racking force is considered as 5.88 kN/m. Racking force per fastener is given by;

$$Racking\ Force\ =\ 5.88 * 0.65\ =\ 3.82\ kN/fastener$$

6. Traction & Braking Force: Traction and braking force is frictional force acting between the rails and the trails. It is a longitudinal force of 18 % of the live load

$$T\&B\ Force\ =\ 0.18 * 112\ =\ 20.16\ kN/wheel$$

7. Lurching Force: Lurching forces are caused by the train rotating slightly about its axis. This causes a moment at rail level corresponding to 6 % of the maximum axle load multiplied by the distance between rails.

$$Lurching\ Force\ =\ (0.06 * 224) * 1.435\ =\ 19.29kN/wheel$$

8. Long welded rail Load: LWR load is a part of the rail steel expansion from rail to fastener to slab. The maximum longitudinal force induced on slab by the LWR force is limited to the longitudinal restraint capacity of the fastening system which is LWR = 13 kN/m. LWR per fastener is,

$$LWR\ =\ 13/0.65\ =\ 20\ kN/fastener$$

9. Earthquake Load: As per EN Bridge Rules [47], the seismic force shall be computed as follows. This force should be considered on both vertical and horizontal direction. Earthquake force

$$Horizontal\ Force\ =\ 0.09 * Wm(Live\ load)\ =\ 0.09\ *\ 122.63\ =\ 11.04\ kN/wheel$$

$$Vertical\ Force\ = \frac{(Horizontal\ force)x\ 1.81}{track\ width} = \frac{11.04\ x\ 1.81}{1.435} =\ 13.925kN/wheel$$

Table 5.1 Load summary

Load	Symbol	Description	Description of load (KN/fastener)	
			Horizontal loads	Vertical loads
Dead load	DL	Self-weight of Concrete material	16.15	
	SIDL	Self-weight of track material	---	0.93KN/m
Live load	LL	Live load	---	112
	IL	Impact load	---	51.52
	RF	Racking force	3.82	---
	T & B	Traction & braking force	20.16	---
	LF	Lunching force	---	19.29
Other loads	LWR	LWR load	20	---
	EQ	Earthquake	11.04	13.925
	TR	Temperature	15	

C. Load Combinations

The following load combinations LC1, LC2 & LC3 are proposed for track structures based on realistic configurations for a track structure. The factors are inspired from IRS Concrete Bridge Code

- LC1: Loads combination for normal condition
- LC2: Earthquake with Live Load condition
- LC3: Loads combination with Temperature and LWR forces.

The loads to be taken in each combination with appropriate load factors are shown in Table 3.3 [42].

Table 5.2 Loads to be taken in each combination with appropriate load factors

Loads	Limit state	Load factors		
		LC1	LC2	LC3
DL	ULS	1.25	1.25	1.25
	SLS	1	1	1
SIDL	ULS	2	2	2
	SLS	1.2	1.2	1.2
Live load Traction & Braking Lurching Racking	ULS	1.75	1.4	1.4
	SLS	1	1	1
Earthquake load	ULS		1.25	
	SLS		1	
LWR	ULS			1.5
	SLS			1
Temperature	ULS			1.5
	SLS			1

The load combinations considered for the analysis are,

- 1.25DL + 2SIDL + 1.75*(RF+LF+T&B+LL+IL)
- 1.25DL + 2SIDL + 1.4*(RF+LF+T&B+LL+IL) + 1.25EQ
- 1.25DL + 2SIDL + 1.4*(RF+LF+T&B+LL+IL) + 1.5LWR + 1.5TR
- DL + 1.2SIDL + 1*(RF+LF+T&B+LL+IL)
- DL + 1.2SIDL + 1*(RF+LF+T&B+LL+IL) + 1EQ
- DL + 1.2SIDL + 1*(RF+LF+T&B+LL+IL) + 1LWR + 1TR
- DL + SIDL
- DL + SIDL + 1T&B + 1LL + 1IL
- 1LL + 1IL + 1 TR

D. SAP results

SAP model is analyzed with above conditions and results obtained are figured below. The isometric view of the model is shown in Figure 5.4.

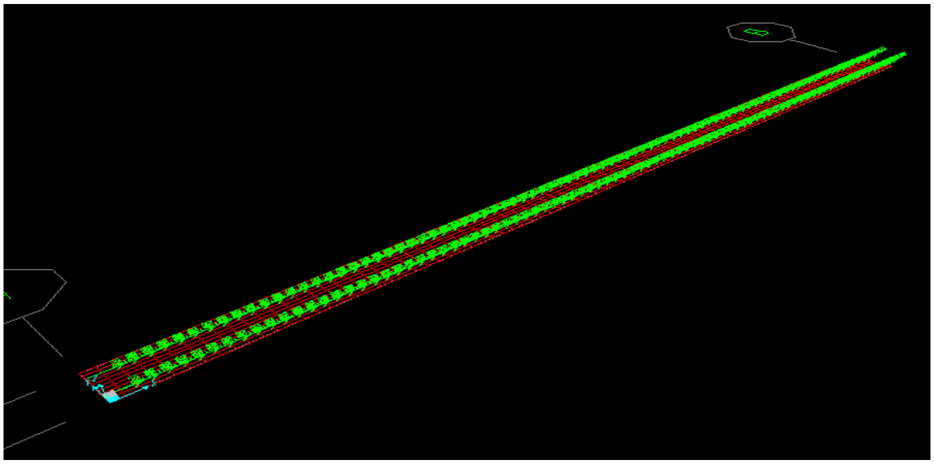


Fig. 5.4 Isometric view of the design

The track slab is modeled for all combination of vertical loads and horizontal forces in SLS & ULS conditions and the model are shown in following figures. Figures 5.5 and 5.6 show the stress contour of load combinations with temperature & LWR force and loads with normal conditions respectively.

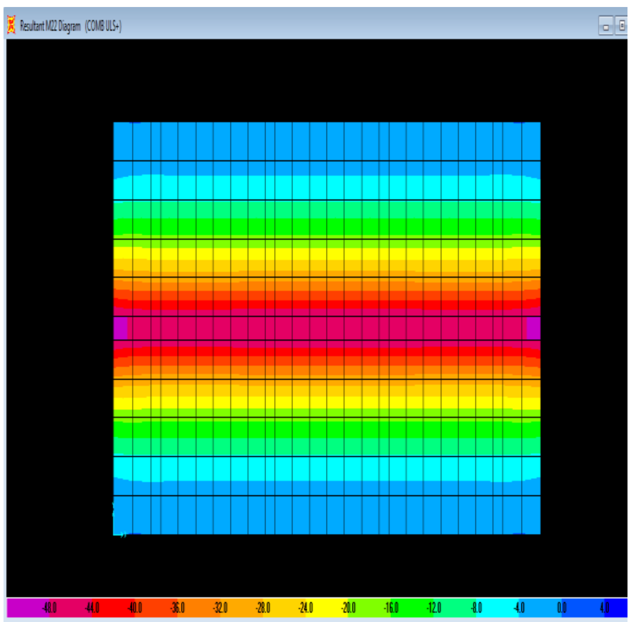


Fig. 5.5 stress contour of load combinations with temperature & LWR force

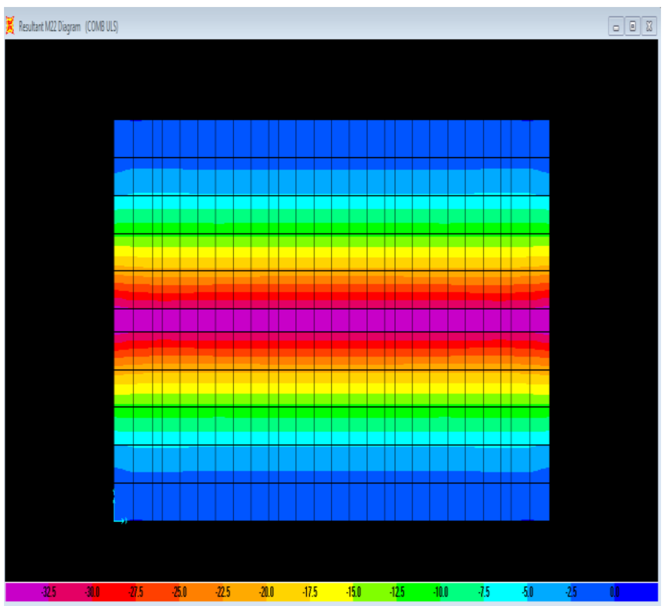


Fig. 5.6 stress contour of loads with normal conditions

E. Design Moments

The Negative and positive moments are obtained from the ultimate loading combinations as shown in Table 5.3;

Table 5.3 Design summary (Annex 'F')

Design moment (kNm)	Negative moments	Positive moments
M_{design}	48.92	0

5.3. Design of Ballastless Track Slab

The purpose of this calculation is to design the main reinforcement (conventional reinforcement) required in SFRC track slab:

(i) Longitudinal reinforcement in track slab

(ii) Transverse reinforcement in track slab

The calculations will be carried out with respect to the requirements of EN code for Serviceability Limit State (SLS) and for Ultimate Limit State (ULS). The reinforcement details are as follows:

$Grade\ of\ steel\ (fy) = 500\ Mpa$

$Grade\ of\ concrete\ (fck) = 39.35\ Mpa$

$Width\ of\ Section\ b = 1000\ mm$

$Depth\ of\ Section\ (End\ section)\ D = 250\ mm$

$(Mid\ section)\ Dm = 250\ mm$

$Max.dia\ bar\ provided\ dx = 12\ mm$

$dz = 12\ mm$

$Clear\ cover\ bottom\ reinforcement\ Cb = 50\ mm$

$Clear\ cover\ top\ reinforcement\ Ct = 50\ mm$

$Effective\ depth\ of\ section:$

$$Longitudinal\ bottom\ Reinforcement\ =\ D - Cb - \left(\frac{dx}{2}\right) =\ 250 - 50 - \left(\frac{12}{2}\right)\ =\ 194\ mm$$

$$Tra.bottom\ Reinforcement\ =\ Dm - Cb - dz - \left(\frac{dx}{2}\right) =\ 250 - 50 - 12 - \left(\frac{12}{2}\right)\ =\ 182\ mm$$

Longitudinal and transversal reinforcement

$$M_u = 0.87 * fy * Ast * d * \left(1 - \frac{Ast * fy}{bdfck}\right) = 0.87 * 500 * Ast * 194 * \left(1 - \frac{Ast * 500}{1000 * 194 * 39.35}\right)$$

$$48.92 * 10^6 = 84390Ast\left(1 - \frac{500Ast}{7633900}\right)$$

$$Ast^2 - 15260.4\ Ast + 88446292.9 = 0\ , \qquad Ast_{req}\ = 603.62mm^2$$

$$Provide\ 12\ diameters\ with\ 250mm\ spacing\ in\ both\ direction\ and\ Ast_{pro}\ will\ be\ 720mm^2$$

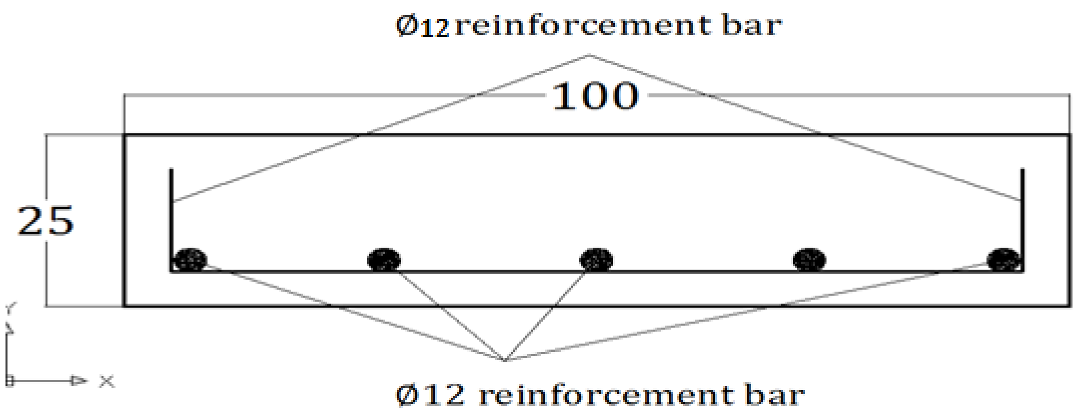


Fig. 5.7 Reinforcement details of track slab

CHAPTER VI- CONCLUSION AND RECOMMENDATION

CHAPTER VI- CONCLUSION AND RECOMMENDATION

6.1 Conclusions

In this study, the experimental work carried out to evaluate the fresh and hardened properties of SFRC as well as GFRC in order to use in railway slab track. On the basis of results obtained by slump tests, compression tests and flexural tests the following conclusions are drawn:

1. Without the presence of the superplasticizer (SP 430) the SFRC appeared to be relatively stiff, unworkable and the materials tend to "hang together" and resist movement compared to the control mixes. It is almost impossible to work with fibers having higher aspect ratio and volume fraction like glass fibre. Therefore the use of admixture is a must to attain a satisfactory workability and a more uniform distribution of fiber.
2. The incorporation of steel and glass fibers strongly affected the workability of the fresh concrete. The test results indicated that as the fiber length and the volume of fraction increase the workability tend to decrease significantly. In addition it can be realized that when the glass fibers are longer than 40mm and the fiber volumes are 4% and higher, it becomes relatively difficult to obtain to consolidate it and consequently, to produce a good fibers dispersion within the cement matrix.
3. A relative compressive strength gain ranging from 19.93 – 26.37%, 8.88 – 10.25% and 10.75 – 20.84%, for steel, glass and mix of glass & steel fiber respectively, was obtained by introducing fibers of different property and volume to the concrete. From the results acquired it is possible to conclude that it is unlikely to achieve considerable improvements in compressive strength by glass fiber inclusion and the ultimate strength is only slightly affected by the presence of glass fibers. If what is desired is a strength increase, it is clearly much easier (and much cheaper) simply to redesign the plain concrete mix, primarily by reducing the w/c ratio and by changing the cement type but in the case of steel fiber there are much noticeable changes on the compressive strength of the concrete that we can use on our railway slab tracks even if it is possible to achieve the compressive strength of the concrete by w/c ratio proportion the addition of steel fibre will be increase the mechanical properties of the concrete mix.

4. Fiber inclusion of different volume fractions resulted in substantial increase in flexural tensile strength values. A similar pattern was exhibited in all mix series with regard to increment in flexural tensile strength when both the percentage of steel and glass fibres increased. Compared to the control mix the relative flexural tensile strength gain by glass fiber is not as such appreciable due to its low tensile strength but a relative flexural tensile strength gain ranging form 10.8 – 66.20% was obtained by introducing steel fiber of different percentage in volume to the concrete. From the result it is possible to conclude that introducing steel fiber to concrete on railway slab track is one of the best solutions in order to avoid or minimizing the cracks.

5. Energy absorption under flexural loading was not satisfactory in case of glass fiber inclusion but on the case of steel fibre it shows very good improvements with the relative energy absorption gain of 273.73% compared with the plain concrete. This kind of improvements in concrete is difficult to get with addition of admixtures or by adjusting the mix proportion. Form this we can conclude that introducing steel fibre in to a concrete is one of the best ways to increase the life time of a railway structures.

6. From the results obtained it is possible to deduce that an increase in energy absorption up to specified points of deflection and the residual strength after cracking can be observed when the volume of fibre increase.

7. Most of the test results obtained from this study confirms the experimental results reported in the literature.

6.2 Recommendations

Based on the investigation made the following recommendations are forwarded for studies in purpose of future excellence;

1. Slump test is inadequate and cannot satisfactorily distinguish the effects of fiber inclusion on the consistency of SFRC. Methods employing dynamic consolidation such as inverted slump cone test or Vebe test should be used in order to attain a clearer view of the effects of fiber inclusion.
2. Since material properties of steel fiber reinforced concrete depend, to a relevant extent, on the bond between the fibers and the matrix, direct or indirect fiber pull out test should be carried out in order to attain a comprehensible view on the behavior of pulling out of a fiber from a matrix already reinforced with steel fiber.
3. Since results from flexural tests on concrete beams are prone to significant experimental errors due to spurious support displacements, machine stiffness, load rate and rocking of specimen on its support it is recommended to use a yoke along with resistive clip gauge.
4. In this study 3D dramix steel fibre was used but if we use much improved type of steel fibre for example 4D and 5D steel fibres with much tensile strength, wire ductility and anchorage strength we will get much improved results from this study.
5. Further research is proposed in the following areas;
    i. Development of rational design procedures to incorporate the properties of SFRC to replace stirrups provided for shear in load carrying beams
    ii. Use of SFRC to replace the minimum reinforcement recommended on track slab on bridge and tunnel for shrinkage and temperature.

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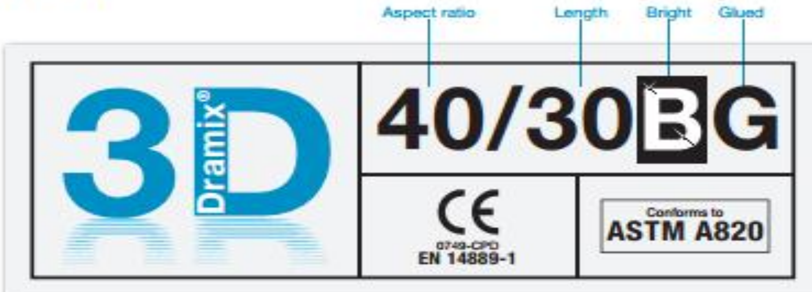
ANNEX 'A' – STEEL FIBER

Dramix®

BEKAERT
better together

Data Sheet



DRAMIX® 3D

Dramix® 3D is the reference in steel fibre reinforcement. Combining high performance, durability and ease-of-use, 3D provides you with a time-saving and cost-efficient solution for most common applications.

> original anchorage
> standard tensile strength

Dramix® 3D is a cost efficient solution for
> flooring
> tunnel applications
> precast
> residential applications

Bekaert supplies all of the support you need for your project. We help you determine the most suitable fibre types, calculate optimal dosages, select the right concrete quality. Contact your local support.

Go to www.bekaert.com/dosingdramix for our recommendations on handling, dosing and mixing.

Modifications reserved.
All details describe our products in general form only.
For detailed information, product specifications available on request.

PERFORMANCE

Material properties

Tensile strength: $R_{m,nom}$: 1.225 N/mm²
Tolerances: ± 7,5% Avg
Young's Modulus: ± 210.000 N/mm²

Geometry

Fibre family	3D	
Length (l)	30 mm	
Diameter (d)	0,75 mm	
Aspect ratio (l/d)	40	80 65 55 40

Fibre network

8,7 km per m³ (for 30 kg/m³)
9.096 fibres/kg

Dramix® range

	5D	4D	3D
Tensile strength			
Wire ductility			
Anchorage strength			

PRODUCT CERTIFICATES

CE
0749-CPD
EN 14889-1

Conforms to
ASTM A820

Dramix® is certified for structural use according to EN 14889-1 (system '1'). Detailed information is available on request.

SYSTEM CERTIFICATES

All Dramix® plants are ISO 9001 and ISO 14001 certified.

PACKAGING

BAGS 20 kg   BIG BAG 1100 kg

STORAGE

ANNEX 'B' – SUPPERPLAS

24
Sept 2014

FOSROC
constructive solutions

Fosroc® Conplast SP430

High performance superplasticising admixture

Uses

- To provide excellent acceleration of strength gain at early ages and major increases in strength at all ages by significantly reducing water demand in a concrete mix.
- Particularly suitable for precast concrete and other high early strength requirements.
- To significantly improve the workability of site mixed and precast concrete without increasing water demand.
- To provide improved durability by increasing ultimate strengths and reducing concrete permeability.
- In screeds it reduces the water content required to give suitable workability for placing and compaction.

Advantages

- Major increases in strength at early ages without increased cement contents are of particular benefit in precast concrete, allowing earlier stripping times.
- Makes possible major reductions in water:cement ratio which allow the production of high strength concrete without excessive cement contents.
- Use in production of flowing concrete permits easier construction with quicker placing and compaction and reduced labour costs without increasing water content.
- Increased workability levels are maintained for longer than with ordinary sulphonated melamine admixtures.
- Improved cohesion and particle dispersion minimises segregation and bleeding and improves pumpability.
- Chloride free, safe for use in prestressed and reinforced concrete.
- In screed material, the lower water content leads to quicker drying times

Standards compliance

Conplast SP430 complies with BS 5075 Part 3 and with ASTM C494 as Type A and Type F.

Description

Conplast SP430 is a chloride free, superplasticising admixture based on selected sulphonated napthalene polymers. It is supplied as a brown solution which instantly disperses in water.

Conplast SP430 disperses the fine particles in the concrete mix, enabling the water content of the concrete to perform more effectively. The very high levels of water reduction possible allow major increases in strength to be obtained.

CE 0086	
Fosroc Limited Drayton Manor Business Park, Coleshill Road,Tamworth,UK. B78 3XN **14** **DoP UK9-64** **0086-CPR-473151**	
Conplast SP430	
High Range water reducing/Superplasticizing Admixture EN 934-2:T3.1/3.2	
Water Reduction	≥ 12% compared with Reference mix
Increase of consistence	Increase ≥ 120mm from initial slump or Increase ≥ 160mm from initial flow
Retention of Consistence	At 30 mins ≥ Reference mix at initial
Compressive Strength	Fulfilled
Air Content:	Fulfilled
Corrosion Behaviour	Contains components only from EN934-1: Annex A.1
Dangerous Substances	NPD
Durability	NPD

Properties

Appearance:	Brown liquid
Specific gravity:	Typically 1.20 at 20°C
Chloride content:	Nil to BS 5075
Air entrainment:	Typically less than 2% additional air is entrained at normal dosages.
Alkali content:	Typically less than 72.0 g. Na_2O equivalent/litre of admixture. A fact sheet on this subject is available.

Technical support

Fosroc provides a technical advisory service for on-site assistance and advice on admixture selection, evaluation trials and dispensing equipment. Technical data and guidance can be provided for admixtures and other products for use with fresh and hardened concrete.

Typical dosage

The optimum dosage of Conplast SP430 to meet specific requirements should always be determined

Page 1

ANNEX 'C' – DOE MIX DESIGN

Table A.C.1 Mix design

Mix Design Data Sheet for (C-30)				
Stage	**Item**		**Reference or Calculation**	**Values**
1	1.1	Characteristic strength	Specified	Compressive 30 N/mm^2 at 28 days Proportion defective 5 Percent
	1.2	Standard deviation	Fig. 3	- N/mm^2 or no data 8 N/mm^2
	1.3	Margin	C1	(k = 1.64) 1.64 x 8 = 13.12 N/mm^2
	1.4	Target mean strength	C2	30 + 13.12 = 43.12 N/mm^2
	1.5	Cement type	Specified	PPC
	1.6	Aggregate Type: Coarse		Crushed
		Aggregate Type: Fine		Uncrushed
	1.7	Free-water/cement ratio	Table 2, Fig 4	0.47 Use the lower value
	1.8	Maximum Free water/cement ratio		0.5
2	2.1	Slump or V-B	Specified	Slump 10-30 mm or V-B 6-12 s
	2.2	Maximum aggregate Size	Specified	20 mm
	2.3	Free-water Content	Table-3	179 kg/m^3
3	3.1	Cement Content	C3	179 ÷ 0.47 = 380.85Kg/m^3
	3.2	Maximum cement content	Specified	_____ kg/m^3
	3.3	Minimum cement content	Specified	_____ kg/m^3 Use if greater than item 3.1 and calculate item 3.4
	3.4	Modified free-water/cement ratio		_____
4	4.1	Relative density of aggregate (SSD)		2.70
	4.2	Concrete density	Fig. 5	2459 kg/m^3
	4.3	Total aggregate content	C4	2459 – 380.85- 179= 1899.15 kg/m^3
5	5.1	Grading of fine aggregate	BS 882	Zone 2
	5.2	Proportion of fine aggregate Fine aggregate content	Fig. 6	35 percent
	5.3	Coarse aggregate content		1899.15 x 0.35 = 664.7kg/m^3
	5.4			1899.15 – 664.7 = 1234.45kg/m^3

Quantities	**Cement (kg)**	**Water (kg or lit)**	**Fine Aggregate (kg)**	**Coarse Aggregate (kg)**
Per m^3 (to the nearest 5 Kg)	380.85	179	664.7	1234.45
Per trial mix of **0.037** m^3	14.1	6.623	24.6	45.67

ANNEX 'D' – TEST PROCEDURES AND RESULTS

Test 1 - Determination of bulking of fine aggregate

Objective - To determine bulking of a given sample of fine aggregate

Theory – Free moisture forms a film around each particle. This film of moisture exerts what is known as surface tension which keeps the neighboring particles away from it. Similarly, the force exerted by surface tension keeps every particle away from each other. Therefore, no point contact is possible between the particles. This causes bulking of the volume. It is interesting to note that the bulking increases with the increase in moisture content up to a certain limit and beyond that the further increase in the moisture content results in the decrease in the volume and at a moisture content representing saturation point, the fine aggregate shows no bulking.

Apparatus - Measuring jar, Taping rod etc

Procedure –

1. Put sufficient quantity of the sand loosely into a container. Level off the top of the sand and pushing a steel rule vertically down through the sand at the middle to the bottom, measure the height. Suppose this is h1 in cm.
2. Empty the sand out of the container into another container where none of it will be lost. Half fill the first container with water. Put back about half the sand and rod it with a steel rod, about 6 mm in diameter, so that its volume is reduced to a minimum. Then add the remainder of the sand and rod it in the same way.
3. The percentage of bulking of the sand due to moisture shall be calculated from the formula:

$$precentage\ bulking = \left(\frac{h}{h1} - 1\right) * 100$$

Table A.D.1 Bulking results of fine aggregate

No	Descriptions	Sample		
		I	II	III
1	Volume of loss sand (h),ml	200	200	200
2	Volume of saturated sand (h1),ml	153	158	155
3	$precentage\ bulking = \left(\frac{h}{h1} - 1\right) * 100$	30.72	26.58	29.03
	Average value	28.78		

Test -2 - Determination of silt content in fine aggregate

Objective - To determine silt content in a given sample of fine aggregate by sedimentation method.

Apparatus

- Graduated measuring jar
- Sand sample on its natural state
- Observation shit for recording the results

Chemical - A solution of 1% of sodium chloride (Nacl) prepared by adding 1 gram of sodium chloride in to 100ml of water.

Procedure

1. Take 50ml of 1% Nacl solution into prepared graduate measuring jar,
2. Add sample sand until the level on the measuring jar reaches 100ml,
3. Add more 50ml of 1% Nacl solution into prepared graduate measuring jar until the level reaches 150ml,
4. By covering the opening on the measuring jar shake it well in order to mix the Nacl solution with the sample sand,
5. Allow the contents on the jar to settle for 3hrs,
6. Record the total volume of the silt and the sand,
7. Finally, the silt content will calculate by:

$$Precentage\ of\ silt = \frac{Volume\ of\ silt}{Total\ volume\ of\ sand\ sample}\ x\ 100$$

Table A.D.2 Silt content results of fine aggregate

No	Descriptions	Sample		
		I	II	III
1	Volume of sample sand (A),ml	97	96	96
2	Volume of silt content after 3 hr (B),ml	3	4	4
3	$Precentage\ of\ silt = \frac{B}{A}\ x\ 100$	3.09	4.17	4.17
	Average value	3.81		

Test -3- Determination of specific gravity and water absorption of fine aggregate

Objective to determine specific gravity of a given sample of fine aggregate

Apparatus Pycnometer, A 1 000-ml measuring cylinder, well-ventilated oven, Taping rod, Filter papers and funnel, etc.

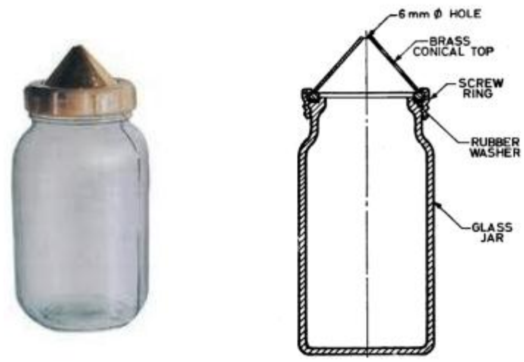


Fig. A.D.1 Pycnometer

Procedure

1. A sample of about 500 g shall be placed in the tray and covered with distilled water at a temperature of 22 to 32°C. Soon after immersion, air entrapped in or bubbles on the surface of the aggregate shall be removed by gentle agitation with a rod. The sample shall remain immersed for 24 ± l/2 hours.
2. The water shall then be carefully drained from the sample, by decantation through a filter paper, any material retained being return& to the sample. The fine aggregate including any solid matter retained on the filter paper shall be exposed to a gentle current of warm air to evaporate surface moisture and the material just attains a free-running‘ condition. The saturated and surface-dry sample shall be weighed (A).
3. The aggregate shall then be placed in the pycnometer which shall be filled with distilled water. Any trapped air shall be eliminated by rotating the pycnometer on its side, the hole in the apex of the cone being covered with a finger. The pycnometer shall be dried on the outside and weighed (weight B).

4. The contents of the pycnometer shall be emptied into the tray, care being taken to ensure that all the aggregate is transferred. The pycnometer shall be refilled with distilled water to the same level as before, dried on the outside and weighed (C).
5. The water shall then be carefully drained from the sample by decantation through a filter paper and any material retained returned to the sample. The sample shall be placed in the oven in the tray at a temperature of 100 to 110°C for 24 f l/2 hours, during which period it shall be stirred occasionally to facilitate drying. It shall be cooled in the air-tight container and weighed (weight D).
6. Calculations— Specific gravity, apparent specific gravity and water &sorption shall be calculated as follows.

Observation sheet

Table A.D.3 Specific gravity & water absorption Results for Fine Aggregate

No	Description	Sample	
		I	II
1	Weight of sample in gram	2000	2000
2	Weight of vessel + sample + water (A) in gram	1821	1823
3	Weight of vessel + water (B) in gram	1514	1514
4	Weight of saturated and surface dry sample (C) in gram	500	500
5	Weight of oven dry sample (D) in gram	497	496
6	$specfice\ gravity = \left(\frac{D}{C-(A-B)}\right)x100$	2.58	2.6
7	$Apparent\ specfice\ gravity = \left(\frac{D}{D-(A-B)}\right)x100$	2.62	2.65
8	$Water\ absorption, percentage\ dry\ weight = \left(\frac{C-D}{D}\right)x100\ ,\ \%$	0.60	0.81
9	Average value of specific gravity	2.59	
10	Average of apparent specific gravity	2.63	
11	Average of water absorption	0.71	

Test - 4 - Sieve analysis on fine aggregate

Objective - To determine fineness modulus of fine aggregate

Theory - This is the name given to the operation of dividing a sample of aggregate into various fractions each consisting of particles of the same size. The sieve analysis is conducted to determine the particle size distribution in a sample of aggregate, which we call gradation. Many a time, fine aggregates are designated as coarse sand, medium sand and fine sand. These classifications do not give any precise meaning. What the supplier terms as fine sand may be really medium or even coarse sand. To avoid this ambiguity fineness modulus could be used as a yard stick to indicate the fineness of sand. The following limits may be taken as guidance: Fine sand : Fineness Modulus : 2.2 - 2.6, Medium sand : F.M. : 2.6 - 2.9, Coarse sand : F.M. : 2.9 - 3.2 Sand having a fineness modulus more than 3.2 will be unsuitable for making satisfactory concrete.

Apparatus - Test Sieves conforming to IS: 460-1962 Specification of 4.75 mm, 2.36 mm, 1.18 mm, 600 micron, 300 micron, 150 micron, Balance, Gauging Trowel, Stop Watch, etc

Procedure

1. The sample shall be brought to an air-dry condition before weighing and sieving. The air-dry sample shall be weighed and sieved successively on the appropriate sieves starting with the largest. Care shall be taken to ensure that the sieves are clean before use.
2. The shaking shall be done with a varied motion, backward sand forwards, left to right, circular clockwise and anti-clockwise, and with frequent jarring, so that the material is kept moving over the sieve surface in frequently changing directions.
3. Material shall not be forced through the sieve by hand pressure. Lumps of fine material, if present, may be broken by gentle pressure with fingers against the side of the sieve.
4. Light brushing with a fine camel hair brush may be used on the 150-micron and 75-micron IS Sieves to prevent aggregation of powder and blinding of apertures.
5. On completion of sieving, the material retained on each sieve, together with any material cleaned from the mesh, shall be weighed.

Observation

Table A.D.4 Sieve Analysis Results for Fine Aggregate

Sieve No	Sieve Size (mm)	Weight of Sieve (g)	Wt. of Sieve & Retained (g)	Weight Retained (g)	Percentage Retained (%)	Cumulative Coarser (%)	Cumulative Passing (%)	Lower Limit (%)	Upper Limit (%)
1	9.5	586	586	0	0	0	100	100	
2	4.75	567	593	26	5.2	5.2	94.8	95	100
3	2.36	521	558	37	7.4	12.6	87.4	80	100
4	1.18	529	650	121	24.2	36.8	63.2	50	85
5	0.06	506	680	174	34.8	71.6	28.4	25	60
6	0.03	478	610	132	26.4	98	2	10	30
7	0.015	462	470	8	1.6	99.6	0.4	2	10
8	Pan	423	425	2	0.4	100	0		
Total		4072	4572	500	100		276.2		
FM=2.762									

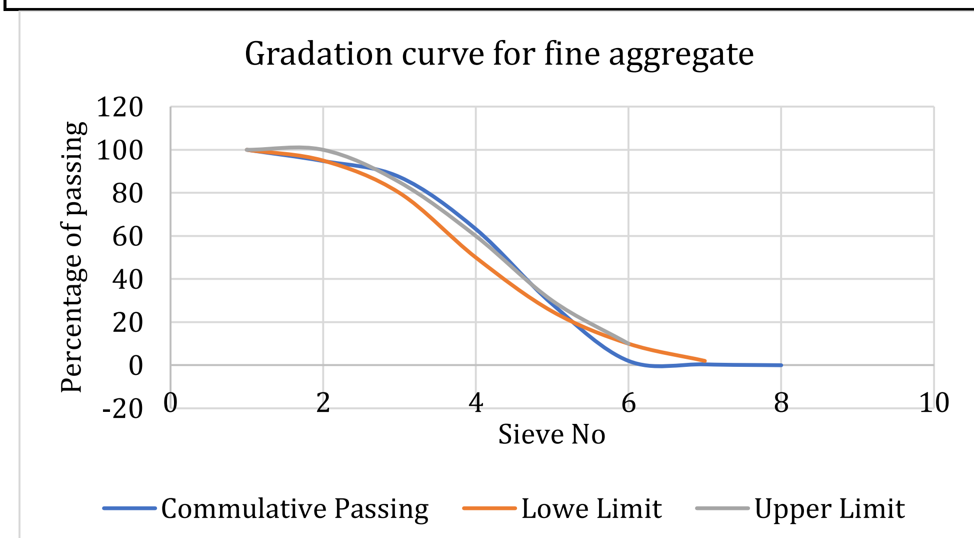


Fig. A.D.2 Gradation Curve for fine aggregate

Fineness modulus is an empirical factor obtained by adding the cumulative percentages of aggregate passing on each of the standard sieves ranging from 4.75 mm to 150 micron and dividing this sum by an arbitrary number 100.

$$Finess\ Modulus, FM = \left(\frac{Total\ cumulative\ precentage\ of\ pass}{100}\right) = \frac{276.2}{100} = 2.762$$

Test – 5 - Particle Size Distribution Of course Aggregates

Objective To determination of particle size distribution of coarse aggregates by sieving or screening.

Theory - Grading refers to the determination of the particle-size distribution for aggregate. Grading limits and maximum aggregate size are specified because grading and size affect the amount of aggregate used as well as cement and water requirements, workability, pumpability, and durability of concrete. In general, if the water-cement ratio is chosen correctly, a wide range in grading can be used without a major effect on strength. When gap-graded aggregate are specified, certain particle sizes of aggregate are omitted from the size continuum. Gap-graded aggregate are used to obtain uniform textures in exposed aggregate concrete. control of mix proportions is necessary to avoid segregation

Apparatus

Test Sieves conforming to IS : 460-1962 Specification of 80 mm, 40 mm, 20 mm, 10 mm, 4.75 mm, Balance, Gauging Trowel, Stop Watch, etc.

Procedure

1. The sample shall be brought to an air-dry condition before weighing and sieving. This may be achieved either by drying at room temperature or by heating at a temperature of 100 to 110°C. The air-dry sample shall be weighed and sieved successively on the appropriate sieves starting with the largest. Care shall be taken to ensure that the sieves are clean before use.
2. Each sieve shall be shaken separately over a clean tray until not more than a trace passes, but in any case, for a period of not less than two minutes. The shaking shall be done with a varied motion, backward sand forwards, left to right, circular clockwise and anti-clockwise, and with frequent jarring, so that the material is kept moving over the sieve surface in frequently changing directions.
3. Material shall not be forced through the sieve by hand pressure. Lumps of fine material, if present, may be broken by gentle pressure with fingers against the side of the sieve.
4. On completion of sieving, the material retained on each sieve, together with any material cleaned from the mesh, shall be weighed.

Observation

Table A.D.5 Sieve Analysis Results for Coarse Aggregate(Annex 'D')

Sieve No	Sieve Size (mm)	Weight of Sieve (g)	Wt. of Sieve & Retained (g)	Weight Retained (g)	Percentage Retained (%)	Cumulative Coarser (%)	Cumulative Passing (%)	Lower Limit (%)	Upper Limit (%)
1	37.5	1188	1188	0	0	0	100	100	
2	19	1419	1440	21	0.42	0.42	99.58	90	100
3	12.5	1166	4000	2834	56.68	57.1	42.9	40	80
4	9.5	1171	2356	1185	23.7	80.8	19.2	20	55
5	4.75	1194	2147	953	19.06	99.86	0.14	0	10
6	Pan	1060	1067	7	0.14	100	0	0	5
Total		7198	12198	5000	100		261.82		
FM=2.6182									

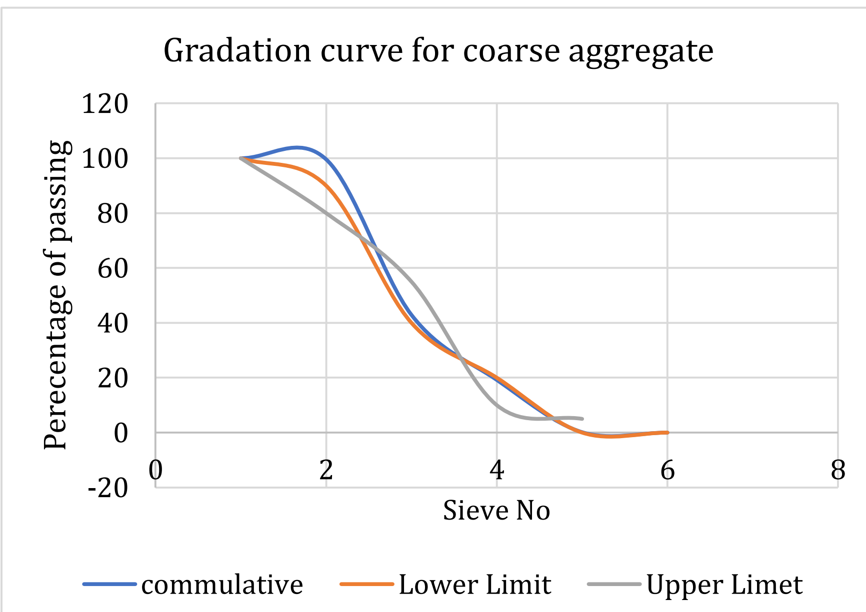


Fig. A.D.3 Gradation Curve for Coarse aggregate

$$Finess\ Modulus, FM = \left(\frac{Total\ cumulative\ precentage\ of\ pass}{100}\right) = \frac{261.82}{100} = 2.62$$

Test -6 - Determination of Specific Gravity and water absorption of Course Aggregate

Objective To determine specific gravity of a given sample of course aggregate

Apparatus A wire basket of not more than 6-3 mm mesh, A stout watertight container in which the basket may be freely suspended, well-ventilated oven, Taping rod, An airtight container of capacity similar to that of the basket, etc

Fig. A.D.4 Wire basket and weight balance

Procedure

1. A sample of not less than 2000 g of the aggregate shall be thoroughly washed to remove finer particles and dust, drained and then placed in the wire basket and immersed in distilled water at a temperature between 22°C to 32°C with a cover of at least 5 cm of water above the top of the basket.
2. Immediately. after immersion the entrapped air shall be removed from the sample by lifting the basket containing it 25 mm above the base of the tank and allowing it to drop 25 times at the rate of about one drop per second. The basket and aggregate shall remain completely immersed during the operation and for a period of 24 ± l/2 hours afterwards.
3. The basket and the sample shall then be jolted and weighed in water at a temperature of 22°C to 32°C (weight A1).
4. The basket and the aggregate shall then be removed from the water and allowed to drain for a few minutes, after which the, aggregate shall be gently emptied from the basket on to one of the dry clothes, and the empty basket shall be returned to the water and weighed in water (weight A2).

5. The aggregate placed on the dry cloth shall be gently surface dried with the cloth, transferring it to the second dry cloth when the first will remove no further moisture. The aggregate shall then be weighed (weight B).
6. The aggregate shall then be placed in the oven in the shallow tray, at a temperature of 100 to 110°C and maintained at this temperature for 24 ± l/2 hours. It shall then be removed from the oven, cooled in the airtight container and weighed (weight C).
7. Calculations— Specific gravity, apparent specific gravity and water &sorption shall be calculated as follow

Observation sheet

Table A.D.6 Specific gravity & water absorption Results for Coarse Aggregate (Annex 'D')

No	Description	Sample	
		I	II
1	Weight of sample in gram	1000	1000
2	Weight of vessel + sample + water (A) in gram	3371	3374
3	Weight of vessel + water (B) in gram	2754	2754
4	Weight of saturated and surface dry sample (C) in gram	990	992
5	Weight of oven dry sample (D) in gram	981	983.5
6	$specfice\ gravity = \left(\frac{D}{C-(A-B)}\right)x100$	2.63	2.64
7	$Apparent\ specfice\ gravity = \left(\frac{D}{D-(A-B)}\right)x100$	2.7	2.71
8	$Water\ absorption, percentage\ dry\ weight = \left(\frac{C-D}{D}\right)x100$, %	0.92	0.86
9	Average value of specific gravity	2.64	
10	Average of apparent specific gravity	2.7	
11	Average of water absorption	0.89	

Conclusion / Result

I. The Specific Gravity of a given sample of course aggregate is found to be 2.7 and The Water Absorption of a given sample of course aggregate is found to be 0.89 %

Test -7- Slump test

Apparatuses;

The Slump Cone apparatus for conducting the slump test essentially consists of a metallic mould in the form of a frustum of a cone having the internal dimensions as under: Bottom diameter : 20 cm, Top diameter : 10 cm, Height : 30 cm and the thickness of the metallic sheet for the mould should not be thinner than 1.6 mm. Weights and weighing device, Tamper (16 mm in diameter and 600 mm length), Ruler, Tools and containers for mixing, or concrete mixer etc.

Procedure

1. Dampen the mold and place it on a flat, moist, nonabsorbent (rigid) surface. It shall be held firmly in place during filling by the operator standing on the two foot pieces. Immediately fill the mold in three layers, each approximately one third the volume of the mold.
2. Rod each layer with 25 strokes of the tamping rod. Uniformly distribute the strokes over the cross section of each layer.
3. In filling and rodding the top layer, heap the concrete above the mold before rodding start. If the rodding operation results in subsidence of the concrete below the top edge of the mold, add additional concrete to keep an excess of concrete above the top of the mold at all time.
4. After the top layer has been rodded, strike off the surface of the concrete by means of screeding and rolling motion of the tamping rod.
5. Remove the mold immediately from the concrete by raising it carefully in the vertical direction. Raise the mold a distance of 300 mm in 5 ± 2 sec by a steady upward lift with no lateral or torsional motion.
6. Immediately measure the slump by determining the vertical difference between top of the mold and the displaces original center of the top surface of the specimen. Complete the entire test from the start of the filling through removal of the mold without interruption and complete it within 2½ min.
7. If a decided falling away or shearing off of concrete from one side or portion of the mass occurs, disregard the test and make a new test on another portion of the sample. If two consecutive tests on a sample of concrete show a falling away or shearing off of a portion

of concrete from the mass of specimen, the concrete lacks necessary plasticity and cohesiveness for the slump test to be applicable.

8. After completion of the test, the sample may be used for casting of the specimens for the future testing.

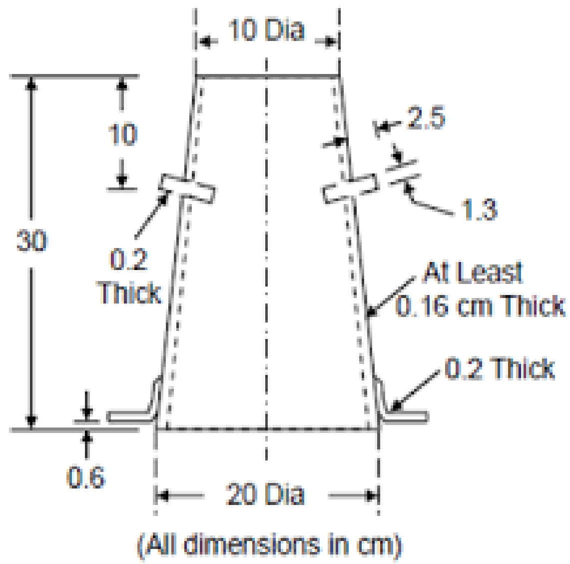


Fig. A.D.5 Slump test equipment

Title -8 - Determine compressive strength of cubic SFRC specimens

Objective – The test method covers determination of compressive strength of cubic SFRC specimens. It consists of applying a compressive axial load to molded cubes at a rate which is within a prescribed range until failure occurs

Theory - Of the various strength properties of concrete, it is generally the compressive strength which attracts the greatest interest since it is this property which is made use of in designing structural units or simple load bearing quality. In addition, it has a great practical and economic significance because the sections and size of the concrete structures are determined by it.

Since most concrete structures are designed to resist compressive stress, it is this property which is usually prescribed by code or standards in terms of either ultimate strength of working stress which is taken as a percentage of the crushing strength as determined by standard cube or cylinder test.

The strength of concrete is affected by a number of factors the most important being by the water/cement ratio and the degree of compaction. Other factors include the component materials (cement and aggregate), the age, curing condition and in this study it had done the improvement of the concrete by adding additional material called 3D steel fiber to the ordinary concrete.

The compression Test - Many engineering materials such as concrete stone and bricks are used in construction to support primary compressive forces. In general engineering materials, may be divided into two general classes according to their manner of failure in compression. These are;

a) Ductile (plastic or viscous) materials which include those Which will flow without showing any other indication of failure, such as wrought iron and soft steel.
b) Brittle materials which include those which will crush to power, or crumbles to places, or fail by shearing on definite angles under a compressive load, such as cast iron, concrete, bricks and stone.

Age at Test - Tests shall be made at recognized ages of the test specimens, the most usual being 7 and 28 days. Where it may be necessary to obtain the early strengths, tests may be made at the ages of 24 hours ±½ hour and 72 hours ± 2 hours. The ages shall be calculated from the time of the addition of water to the dry ingredients. But in this study we only make test for the concrete sample at the age 28 days.

Number of Specimens - At least three specimens from each percentage of (0%, 1%, 1.5% & 2%) steel fiber, (4% & 5%) glass fiber and mix of glass with steel fiber that means we will have 27 specimens, preferably from different batches, shall be made for testing at each

Apparatus – Testing Machine - The testing machine may be of any reliable type, of sufficient capacity for the tests and capable of applying the load at the rate specified in 5.5. The permissible error shall be not greater than ± 2 percent of the maximum load. Cube Moulds - The mould shall be of 150 mm size

Procedure –

1. Sampling of Materials - Samples of aggregates for each batch of concrete shall be of the desired grading and shall be in an air-dried condition. The cement samples, on arrival at the laboratory, shall be thoroughly mixed dry either by hand or in a suitable mixer in such a manner as to ensure the greatest possible blending and uniformity in the material.
2. Proportioning - The proportions of the materials, including water, in concrete mixes used for determining the suitability of the materials available, shall be similar in all respects to those to be employed in the work.
3. Weighing - The quantities of cement, each size of aggregate, and water for each batch shall be determined by weight, to an accuracy of 0.1 percent of the total weight of the batch.
4. Mixing Concrete - The concrete shall be mixed by hand, or preferably, in a laboratory batch mixer, in such a manner as to avoid loss of water or other materials. Each batch of concrete shall be of such a size as to leave about 10 percent excess after moulding the desired number of test specimens.
5. Mould - Test specimens cubical in shape shall be 15 × 15 × 15 cm. If the largest nominal size of the aggregate does not exceed 2 cm, 10 cm cubes may be used as an alternative. Cylindrical test specimens shall have a length equal to twice the diameter.
6. Compacting - The test specimens shall be made as soon as practicable after mixing, and in such a way as to produce full compaction of the concrete with neither segregation nor excessive laitance.
7. Curing - The test specimens shall be stored in a place, free from vibration, in moist air of at least 90 percent relative humidity and at a temperature of 27° ± 2°C for 24 hours ± ½ hour from the time of addition of water to the dry ingredients.

8. Placing the Specimen in the Testing Machine - The bearing surfaces of the testing machine shall be wiped clean and any loose sand or other material removed from the surfaces of the specimen which are to be in contact with the compression platens.
9. In the case of cubes, the specimen shall be placed in the machine in such a manner that the load shall be applied to opposite sides of the cubes as cast, that is, not to the top and bottom.
10. The axis of the specimen shall be carefully aligned with the center of thrust of the spherically seated platen. No packing shall be used between the faces of the test specimen and the steel platen of the testing machine.
11. The load shall be applied without shock and increased continuously at a rate of approximately 140 kg/sq. cm/min until the resistance of the specimen to the increasing load breaks down and no greater load can be sustained.
12. The maximum load applied to the specimen shall then be recorded and the appearance of the concrete and any unusual features in the type of failure shall be noted

Fig. A.D.6 Compressive strength testing Machine

Test -9 - Determine Flexural Strength of Cubic SFRC Specimens

Objective This clause deals with the procedure for determining the flexural strength of moulded SFRC flexure test specimens

Theory - Many members in structures are subjected to force acting transvers to their longitudinal axis. Such members are said to be subjected to bending or flexural. In competing the stress-strain properties of a material in bending flexure, a load deflection diagram is first obtained using either the center – point loading or the two-point loading

Either or both types of bending tests are recommended by national such as the Ethiopian, ASTM and British standards. Two-point loading is considered as a more accurate measure of bending properties.

In the center point test, it is only the mid span section which is under maximum moment. Furthermore, with two-point loading, bending stresses free transverse shear stresses are produced for an appreciable length of the specimen.

During a bending test the load is applied by a universal or similar testing machine while the deflection is measured by a deflectometer which is placed on or under the specimen usually at the center. Load and deflection are measured to failure at predetermined increments of load which gives a load deflection diagram.

Ductile and brittle materials behave differently under bending. In general specimens made of ductile materials continue to deform without failure and fracture does not occur. For this reason, properties in the plastic range cannot be determined for such materials. In the case of brittle materials such as cast iron, wood and various plastics on the other hand, the load deflection diagram can be determined to fracture so that all the properties can be evaluated.

Age at Test - Tests shall be made at recognized ages of the test specimens, the most usual being 7 and 28 days. Where it may be necessary to obtain the early strengths, tests may be made at the ages of 24 hours ± ½ hour and 72 hours ± 2 hours. The ages shall be calculated from the time of the addition of water to the dry ingredients. But in this paper, we only make test for the concrete sample at the age 28 days.

Number of Specimens - - At least three specimens from each percentage of steel fiber (0%, 1%, 1.5% and 2%) that means we will have 12 specimens, preferably from different batches, shall be made for testing at each

Apparatus-

Testing Machine - The testing machine may be of any reliable type, of sufficient capacity for the tests and capable of applying the load at the rate specified in 5.5. The permissible error shall be not greater than ± 2 percent of the maximum load.

Beam Moulds - The beam moulds shall conform to IS: 10086-1982. The standard size shall be 15 × 15 × 60 cm. Alternatively, if the largest nominal size of the aggregate does not exceed 19 mm, specimens 10 × 10 × 60 cm may be used. Weights and weighing device, Tools and containers for mixing, Tamper (square in cross section) etc

Procedure –

1. Sampling of Materials - Samples of aggregates for each batch of concrete shall be of the desired grading and shall be in an air-dried condition. The cement samples, on arrival at the laboratory, shall be thoroughly mixed dry either by hand or in a suitable mixer in such a manner as to ensure the greatest possible blending and uniformity in the material.
2. Proportioning - The proportions of the materials, including water, in concrete mixes used for determining the suitability of the materials available, shall be similar in all respects to those to be employed in the work.
3. Weighing - The quantities of cement, each size of aggregate, and water for each batch shall be determined by weight, to an accuracy of 0.1 percent of the total weight of the batch.
4. Mixing Concrete - The concrete shall be mixed by hand, or preferably, in a laboratory batch mixer, in such a manner as to avoid loss of water or other materials. Each batch of concrete shall be of such a size as to leave about 10 percent excess after moulding the desired number of test specimens.
5. Mould - The standard size shall be 15 × 15 × 60 cm. Alternatively, if the largest nominal size of the aggregate does not exceed 19 mm, specimens 10 × 10 × 50 cm may be used.
6. Compacting - The test specimens shall be made as soon as practicable after mixing, and in such a way as to produce full compaction of the concrete with neither segregation nor excessive laitance.
7. Curing - The test specimens shall be stored in a place, free from vibration, in moist air of at least 90 percent relative humidity and at a temperature of 27° ± 2°C for 24 hours ± ½ hour from the time of addition of water to the dry ingredients.

8. Placing the Specimen in the Testing Machine - The bearing surfaces of the supporting and loading rollers shall be wiped clean, and any loose sand or other material removed from the surfaces of the specimen where they are to make contact with the rollers.
9. The specimen shall then be placed in the machine in such a manner that the load shall be applied to the uppermost surface as cast in the mould, along two lines spaced 20.0 or 13.3 cm apart.
10. The axis of the specimen shall be carefully aligned with the axis of the loading device. No packing shall be used between the bearing surfaces of the specimen and the rollers.
11. The load shall be applied without shock and increasing continuously at a rate such that the extreme fibre stress increases at approximately 7 kg/sq cm/min, that is, at a rate of loading of 400 kg/min for the 15.0 cm specimens and at a rate of 180 kg/min for the 10.0 cm specimens.
12. The load shall be increased until the specimen fails, and the maximum load applied to the specimen during the test shall be recorded. The appearance of the fractured faces of concrete and any unusual features in the type of failure shall be noted.

Calculation

The flexural strength of the specimen shall be expressed as the modulus of rupture fb, which, if ‘a‘ equals the distance between the line of fracture and the nearer support, measured on the center line of the tensile side of the specimen, in cm, shall be calculated to the nearest 0.5 kg/sq cm as follows:

$$fb = \frac{Pxl}{axd^2}$$

When ‘a’ is greater than 20cm for 15cm specimen, or greater than 13.3cm for a 10cm specimen or

$$fb = \frac{3Pxa}{bxd^2}$$

when ‘a‘ is less than 20.0 cm but greater than 17.0 cm for 15.0 cm specimen, or less than 13.3 cm but greater than 11.0 cm for a 10.0 cm specimen where;

b = measured width in cm of the specimen

d = measured depth in cm of the specimen at the point of failure

l = length in cm of the span on which the specimen was supported and

P = maximum load in kg applied to the specimen.

ANNEX 'E' – PROPERTIES OF CEMENT

Table A.E.1 Chemical, Physical and Mechanical Properties of the Cement [Source: Messebo Cement Factory, August 2009].

Chemical properties	**(%)**
SiO_2	29.14
Al_2O_3	5.91
CaO	6.76
MgO	55.86
SO_3	1.52
Sulfur content	2.46
Chloride content	0.01
Loss on Ignition (LOI)	2.31
Percentage of Pozzolana	25
Physical and Mechanical Properties	
Specific gravity (g/cm^3)	-
Specific Surface Area (cm^2/g)	2970
Initial Setting time (min)	155
Final Setting time (min)	195
Soundness (mm)	1.25
Compressive strength (N/mm^2) 2 day	13.8
28 day	36.6
Heat of Hydration (Kj/Kg) 3 day	153
28 day	258

ANNEX 'F' – SAP OUTPUT

ShellType	OutputCase	M11	M22	M12	MMax	MMin
Text	Text	KN-m/m	KN-m/m	KN-m/m	KN-m/m	KN-m/m
Shell-Thin	COMB1	-1.2812	-11.398	-0.0033	-1.2812	-11.398
Shell-Thin	COMB1	-1.3457	-11.3951	-0.0033	-1.3457	-11.3951
Shell-Thin	COMB1	-1.3457	-11.3951	0.0033	-1.3457	-11.3951
Shell-Thin	COMB1	-1.2812	-11.398	0.0033	-1.2812	-11.398
Shell-Thin	COMB2	-1.204	-10.7111	-0.0031	-1.204	-10.7111
Shell-Thin	COMB2	-1.2646	-10.7083	-0.0031	-1.2646	-10.7083
Shell-Thin	COMB2	-1.2646	-10.7083	0.0031	-1.2646	-10.7083
Shell-Thin	COMB2	-1.204	-10.7111	0.0031	-1.204	-10.7111
Shell-Thin	COMB3	-1.204	-10.7111	-0.0031	-1.204	-10.7111
Shell-Thin	COMB3	-1.2646	-10.7083	-0.0031	-1.2646	-10.7083
Shell-Thin	COMB3	-1.2646	-10.7083	0.0031	-1.2646	-10.7083
Shell-Thin	COMB3	-1.204	-10.7111	0.0031	-1.204	-10.7111
Shell-Thin	COMB4	-0.8806	-7.8339	-0.0023	-0.8806	-7.8339
Shell-Thin	COMB4	-0.9249	-7.8319	-0.0023	-0.9249	-7.8319
Shell-Thin	COMB4	-0.9249	-7.8319	0.0023	-0.9249	-7.8319
Shell-Thin	COMB4	-0.8806	-7.8339	0.0023	-0.8806	-7.8339
Shell-Thin	COMB5	-0.8806	-7.8339	-0.0023	-0.8806	-7.8339
Shell-Thin	COMB5	-0.9249	-7.8319	-0.0023	-0.9249	-7.8319
Shell-Thin	COMB5	-0.9249	-7.8319	0.0023	-0.9249	-7.8319
Shell-Thin	COMB5	-0.8806	-7.8339	0.0023	-0.8806	-7.8339
Shell-Thin	COMB6	-0.8806	-7.8339	-0.0023	-0.8806	-7.8339
Shell-Thin	COMB6	-0.9249	-7.8319	-0.0023	-0.9249	-7.8319
Shell-Thin	COMB6	-0.9249	-7.8319	0.0023	-0.9249	-7.8319
Shell-Thin	COMB6	-0.8806	-7.8339	0.0023	-0.8806	-7.8339
Shell-Thin	COMB7	-0.6214	-5.5281	-0.0016	-0.6214	-5.5281
Shell-Thin	COMB7	-0.6527	-5.5267	-0.0016	-0.6527	-5.5267
Shell-Thin	COMB7	-0.6527	-5.5267	0.0016	-0.6527	-5.5267
Shell-Thin	COMB7	-0.6214	-5.5281	0.0016	-0.6214	-5.5281
Shell-Thin	COMB8	-0.8278	-7.364	-0.0021	-0.8278	-7.364
Shell-Thin	COMB8	-0.8694	-7.3621	-0.0021	-0.8694	-7.3621
Shell-Thin	COMB8	-0.8694	-7.3621	0.0021	-0.8694	-7.3621
Shell-Thin	COMB8	-0.8278	-7.364	0.0021	-0.8278	-7.364
Shell-Thin	COMB9	-0.1959	-1.7425	-0.0005051	-0.1959	-1.7425
Shell-Thin	COMB9	-0.2057	-1.742	-0.0005051	-0.2057	-1.742
Shell-Thin	COMB9	-0.2057	-1.742	0.0005051	-0.2057	-1.742
Shell-Thin	COMB9	-0.1959	-1.7425	0.0005051	-0.1959	-1.7425
Shell-Thin	COMB ULS	-3.6893	-32.8202	-0.0095	-3.6893	-32.8202
Shell-Thin	COMB ULS	-3.875	-32.8116	-0.0095	-3.875	-32.8116

Shell-Thin	COMB ULS	-3.875	-32.8116	0.0095	-3.875	-32.8116
Shell-Thin	COMB ULS	-3.6893	-32.8202	0.0095	-3.6893	-32.8202
Shell-Thin	COMB SLS	-2.6418	-23.5018	-0.0068	-2.6418	-23.5018
Shell-Thin	COMB SLS	-2.7748	-23.4957	-0.0068	-2.7748	-23.4957
Shell-Thin	COMB SLS	-2.7748	-23.4957	0.0068	-2.7748	-23.4957
Shell-Thin	COMB SLS	-2.6418	-23.5018	0.0068	-2.6418	-23.5018
Shell-Thin	COMB ULS+	-5.3344	-47.4547	-0.0138	-5.3344	-47.4547
Shell-Thin	COMB ULS+	-5.6028	-47.4424	-0.0138	-5.6028	-47.4424
Shell-Thin	COMB ULS+	-5.6028	-47.4424	0.0138	-5.6028	-47.4424
Shell-Thin	COMB ULS+	-5.3344	-47.4547	0.0138	-5.3344	-47.4547
Shell-Thin	COMB SLS+	-4.2869	-38.1363	-0.0111	-4.2869	-38.1363
Shell-Thin	COMB SLS+	-4.5026	-38.1264	-0.0111	-4.5026	-38.1264
Shell-Thin	COMB SLS+	-4.5026	-38.1264	0.0111	-4.5026	-38.1264
Shell-Thin	COMB SLS+	-4.2869	-38.1363	0.0111	-4.2869	-38.1363
Shell-Thin	COMB1	-1.4762	-11.4323	0.0001503	-1.4762	-11.4323
Shell-Thin	COMB1	-1.4787	-11.4335	0.0001503	-1.4787	-11.4335
Shell-Thin	COMB1	-1.4787	-11.4335	-0.0001503	-1.4787	-11.4335
Shell-Thin	COMB1	-1.4762	-11.4323	-0.0001503	-1.4762	-11.4323
Shell-Thin	COMB2	-1.3873	-10.7433	0.0001413	-1.3873	-10.7433
Shell-Thin	COMB2	-1.3895	-10.7444	0.0001413	-1.3895	-10.7444
Shell-Thin	COMB2	-1.3895	-10.7444	-0.0001413	-1.3895	-10.7444
Shell-Thin	COMB2	-1.3873	-10.7433	-0.0001413	-1.3873	-10.7433
Shell-Thin	COMB3	-1.3873	-10.7433	0.0001413	-1.3873	-10.7433
Shell-Thin	COMB3	-1.3895	-10.7444	0.0001413	-1.3895	-10.7444
Shell-Thin	COMB3	-1.3895	-10.7444	-0.0001413	-1.3895	-10.7444
Shell-Thin	COMB3	-1.3873	-10.7433	-0.0001413	-1.3873	-10.7433
Shell-Thin	COMB4	-1.0146	-7.8575	0.0001033	-1.0146	-7.8575
Shell-Thin	COMB4	-1.0163	-7.8583	0.0001033	-1.0163	-7.8583
Shell-Thin	COMB4	-1.0163	-7.8583	-0.0001033	-1.0163	-7.8583
Shell-Thin	COMB4	-1.0146	-7.8575	-0.0001033	-1.0146	-7.8575
Shell-Thin	COMB5	-1.0146	-7.8575	0.0001033	-1.0146	-7.8575
Shell-Thin	COMB5	-1.0163	-7.8583	0.0001033	-1.0163	-7.8583
Shell-Thin	COMB5	-1.0163	-7.8583	-0.0001033	-1.0163	-7.8583
Shell-Thin	COMB5	-1.0146	-7.8575	-0.0001033	-1.0146	-7.8575
Shell-Thin	COMB6	-1.0146	-7.8575	0.0001033	-1.0146	-7.8575
Shell-Thin	COMB6	-1.0163	-7.8583	0.0001033	-1.0163	-7.8583
Shell-Thin	COMB6	-1.0163	-7.8583	-0.0001033	-1.0163	-7.8583
Shell-Thin	COMB6	-1.0146	-7.8575	-0.0001033	-1.0146	-7.8575
Shell-Thin	COMB7	-0.716	-5.5448	0.00007291	-0.716	-5.5448
Shell-Thin	COMB7	-0.7172	-5.5453	0.00007291	-0.7172	-5.5453
Shell-Thin	COMB7	-0.7172	-5.5453	-0.00007291	-0.7172	-5.5453
Shell-Thin	COMB7	-0.716	-5.5448	-0.00007291	-0.716	-5.5448
Shell-Thin	COMB8	-0.9538	-7.3861	0.00009712	-0.9538	-7.3861

Shell-Thin	COMB8	-0.9553	-7.3869	0.00009712	-0.9553	-7.3869
Shell-Thin	COMB8	-0.9553	-7.3869	-0.00009712	-0.9553	-7.3869
Shell-Thin	COMB8	-0.9538	-7.3861	-0.00009712	-0.9538	-7.3861
Shell-Thin	COMB9	-0.2257	-1.7477	0.00002298	-0.2257	-1.7477
Shell-Thin	COMB9	-0.226	-1.7479	0.00002298	-0.226	-1.7479
Shell-Thin	COMB9	-0.226	-1.7479	-0.00002298	-0.226	-1.7479
Shell-Thin	COMB9	-0.2257	-1.7477	-0.00002298	-0.2257	-1.7477
Shell-Thin	COMB ULS	-4.2508	-32.9189	0.0004329	-4.2508	-32.9189
Shell-Thin	COMB ULS	-4.2578	-32.9224	0.0004329	-4.2578	-32.9224
Shell-Thin	COMB ULS	-4.2578	-32.9224	-0.0004329	-4.2578	-32.9224
Shell-Thin	COMB ULS	-4.2508	-32.9189	-0.0004329	-4.2508	-32.9189
Shell-Thin	COMB SLS	-3.0439	-23.5725	0.00031	-3.0439	-23.5725
Shell-Thin	COMB SLS	-3.0489	-23.575	0.00031	-3.0489	-23.575
Shell-Thin	COMB SLS	-3.0489	-23.575	-0.00031	-3.0489	-23.575
Shell-Thin	COMB SLS	-3.0439	-23.5725	-0.00031	-3.0439	-23.5725
Shell-Thin	COMB ULS+	-6.1462	-47.5975	0.0006259	-6.1462	-47.5975
Shell-Thin	COMB ULS+	-6.1563	-47.6025	0.0006259	-6.1563	-47.6025
Shell-Thin	COMB ULS+	-6.1563	-47.6025	-0.0006259	-6.1563	-47.6025
Shell-Thin	COMB ULS+	-6.1462	-47.5975	-0.0006259	-6.1462	-47.5975
Shell-Thin	COMB SLS+	-4.9393	-38.2511	0.000503	-4.9393	-38.2511
Shell-Thin	COMB SLS+	-4.9474	-38.2551	0.000503	-4.9474	-38.2551
Shell-Thin	COMB SLS+	-4.9474	-38.2551	-0.000503	-4.9474	-38.2551
Shell-Thin	COMB SLS+	-4.9393	-38.2511	-0.000503	-4.9393	-38.2511

TABLE: Vehicles 3 - General Vehicles 2 - Loads							
VehName	**LoadType**	**UnifLoad**	**UnifType**	**AxleLoad**	**AxleType**	**AxleWidth**	**MinDist**
Text	Text	KN/m	Text	KN	Text	m	m
TRAIN	Leading Load	120	Lane Width	0	Two Points	1	
TRAIN	Fixed Length	0	Lane Width	28	Two Points	1.435	1.65
TRAIN	Fixed Length	0	Lane Width	56	Two Points	1.435	0.6
TRAIN	Fixed Length	0	Lane Width	28	Two Points	1.435	0.6
TRAIN	Fixed Length	0	Lane Width	28	Two Points	1.435	1.1
TRAIN	Fixed Length	0	Lane Width	56	Two Points	1.435	0.6
TRAIN	Fixed Length	0	Lane Width	28	Two Points	1.435	0.6
TRAIN	Fixed Length	0	Lane Width	28	Two Points	1.435	10.35
TRAIN	Fixed Length	0	Lane Width	56	Two Points	1.435	0.6
TRAIN	Fixed Length	0	Lane Width	28	Two Points	1.435	0.6
TRAIN	Fixed Length	0	Lane Width	28	Two Points	1.435	1.1
TRAIN	Fixed Length	0	Lane Width	56	Two Points	1.435	0.6
TRAIN	Fixed Length	0	Lane Width	28	Two Points	1.435	0.6
TRAIN	Fixed Length	0	Lane Width	28	Two Points	1.435	3.3
TRAIN	Fixed Length	0	Lane Width	56	Two Points	1.435	0.6
TRAIN	Fixed Length	0	Lane Width	28	Two Points	1.435	0.6
TRAIN	Fixed Length	0	Lane Width	28	Two Points	1.435	1.1
TRAIN	Fixed Length	0	Lane Width	56	Two Points	1.435	0.6
TRAIN	Fixed Length	0	Lane Width	28	Two Points	1.435	0.6
TRAIN	Fixed Length	0	Lane Width	28	Two Points	1.435	10.35
TRAIN	Fixed Length	0	Lane Width	56	Two Points	1.435	0.6
TRAIN	Fixed Length	0	Lane Width	28	Two Points	1.435	0.6
TRAIN	Fixed Length	0	Lane Width	28	Two Points	1.435	1.1
TRAIN	Fixed Length	0	Lane Width	56	Two Points	1.435	0.6
TRAIN	Fixed Length	0	Lane Width	28	Two Points	1.435	0.6
TRAIN	Trailing Load	120	Lane Width				

ANNEX 'F' – PHOTOGRAPHIC PRESENTATION

Fig. A.F.1 Measuring glass fibre

Fig. A.F.2 Measuring Steel fibre

Fig. A.F.3 Measuring cement

Fig. A.F.4 Measuring water

Fig. A.F.5 Slump test

Fig. A.F.6 Glass fibre

Fig. A.F.7 Leveling SFRC sample beams

Fig. A.F.8 Vibrating Glass fiber concrete

Fig. A.F.9 Curing specimens

Fig. A.F.10 Weight measurement sp.

Fig. A.F.11 Specimens under flexure test

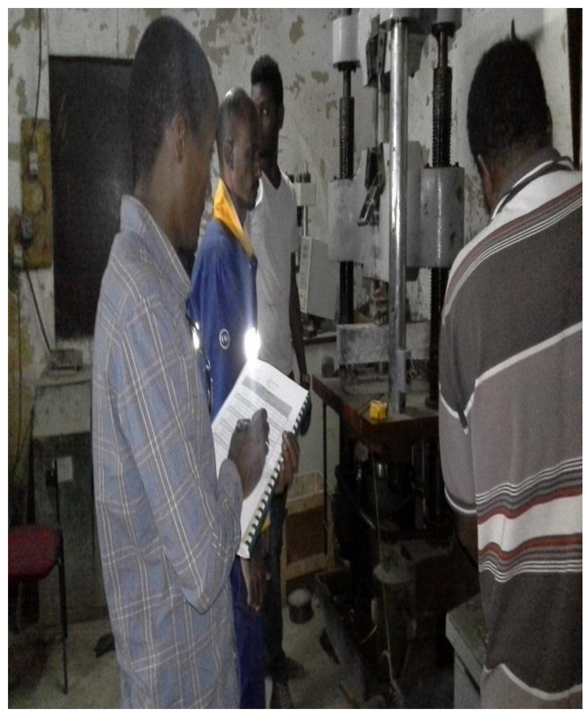


Fig. A.F.12 Recording flexural data

Fig. A.F.13 Specimens under compression test

Fig. A.F.14 Recording compression data