FEBRUARY 2023 M.Sc in Civil Engineering AHMAD HAYDAR AWRAHMAN

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DIRECT SHEAR STRENGTH OF FIBER REINFORCED SELF COMPACTING CONCRETE UNDER ACID AND SULFATE ATTACK

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AHMAD HAYDAR AWRAHMAN

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in

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Supervisor

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Prof. Dr. Azad Abdulkadir MOHAMMED

by

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ABSTRACT

DIRECT SHEAR STRENGTH OF FIBER REINFORCED SELF COMPACTING CONCRETE UNDER ACID AND SULFATE ATTACK

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This thesis shows an experimental investigation on the shear strength of self-compacting concrete (SCC) reinforced by steel fibres (SF) as well as polypropylene fibres (PPF). Also, the fresh and some other mechanical properties were investigated in three different environmental conditions the air, sulfate ($MgSO_4$ with a concentration of 5%) and acid (H_2SO_4 with a concentration of 5%). Five different mixtures were created: SCC without fibre as the control mix, SCC with the addition of SF with 0.1% and 0.2% volume fractions and PPF with varying volume fractions of 0.1% and 0.2%. Shear strength, compressive strength and splitting tensile strength were conducted on FRSCC specimens after exposing them to previous environments after 30 days of exposure. For workability, it was concluded that PPF decreased the workability of SCC badly. So special care must be taken when selecting its volume fraction. However, SF slightly affects workability and does not decrease it compared with PPF. It was found that generally shear strength of SCC mixes enhanced with increasing SF and PPF volume fraction. Compression strength did not improve by PPF, but tensile strength achieved some improvements. However, with SF, they significantly improved. It was found that both fibres have some good durability effects, and they resist aggressive environmental conditions.

Key Words: Fiber Reinforced Self-Compacting Concrete, Polypropylene Fiber, Steel Fiber, Direct Shear Strength, Workability.

ÖZET

LİF TAKVİYELİ KENDİNDEN YERLEŞEN BETONUN ASİT VE SÜLFAT ATAĞI ALTINDA DOĞRUDAN KESME MUKAVEMETİ

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Bu tez, çelik lifler (SF) ve polipropilen lifler (PPF) ile güçlendirilmiş kendiliğinden yerleşen betonun (SCC) kayma mukavemeti üzerine deneysel bir araştırmayı göstermektedir. Ayrıca taze ve diğer bazı mekanik özellikler hava, sülfat (%5 konsantrasyonda MgSO4) ve asit (%5 konsantrasyonda H2SO4) olmak üzere üç farklı çevre koşulunda incelenmiştir. Beş farklı karışım oluşturuldu: kontrol karışımı olarak lifsiz SCC, %0,1 ve %0,2 hacim fraksiyonlarına sahip SF ilaveli SCC ve %0,1 ve %0,2'lik değişen hacim fraksiyonlarına sahip PPF. 30 gün maruz kaldıktan sonra önceki ortamlara maruz bırakıldıktan sonra FRSCC numuneleri üzerinde kesme mukavemeti, basınç mukavemeti ve yarma gerilme mukavemeti uygulandı. İşlenebilirlik için, PPF'nin SCC'nin işlenebilirliğini kötü bir şekilde azalttığı sonucuna varılmıştır. Bu nedenle, hacim oranını seçerken özel dikkat gösterilmelidir. Ancak SF işlenebilirliği biraz etkiler ve PPF'ye kıyasla azaltmaz. Genel olarak SCC karışımlarının kayma direncinin, artan SF ve PPF hacim fraksiyonu ile arttığı bulunmuştur. Basma mukavemeti PPF ile iyileşme göstermedi, ancak çekme mukavemetinde bazı iyileşmeler sağlandı. Ancak, SF ile önemli ölçüde iyileştiler. Her iki elyafın da bazı iyi dayanıklılık etkilerine sahip olduğu ve agresif çevre koşullarına karşı dirençli olduğu bulundu.

Anahtar Kelimeler: Elyaf Takviyeli Kendiliğinden Yerleşen Beton, Polipropilen Elyaf, Çelik Elyaf, Doğrudan Kayma Dayanımı, İşlenebilirlik.

''Dedicated to my family''

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TABLE OF CONTENTS

Page

LIST OF TABLES

Page*

LIST OF FIGURES

Page*

LIST OF SYMBOLS

P	Testing machine's maximum applied load (N)
T	Splitting tensile strength (MPa)
d	Diameter (mm)
π	Pi
l	Length (mm)
Pu	maximum applied load at failure of the specimen
τ	shear stress
d & b	size dimensions of the shear plane

LIST OFABBREVIATIONS

ACI	American Concrete Institute
ASTM	American Society for Testing and Materials
CVC	Conventional Vibrated Concrete
ECC	Engineered Cementitious Composite
EFNARC	European federation of national trade associations representing for concrete
EN	European Standards
FA	Fly Ash
FRC	Fiber Reinforced Concrete
FRSCC	Fiber Reinforced Self-Compacting Concrete
HRWRA	High Range Water Reducing Admixture
HSC	High Strength Concrete
HSFRC	High Strength Fiber Reinforced Concrete
NSC	Normal Strength Concrete
OPC	Ordinary Portland Cement
PP	Polypropylene
PPF	Polypropylene Fiber
PPFRSCC	Polypropylene Fiber Reinforced Self-Compacting Concrete
SCC	Self-Compacting Concrete
SF	Steel Fiber
SFRC	Steel Fiber Reinforced Concrete
SFRSCC	Steel Fiber Reinforced Self-Compacting Concrete
SP	Superplasticizer
VC	Vibrated Concrete
VSI	Visual Stability Index

CHAPTER I
INTRODUCTION

1.1 Background

Shear transfers are used to describe shear forces that cross a particular shear plane. Such circumstances include precast RC connections, corbels, brackets, members of shear span smaller than the effective depth, in which pure and direct shear is far more likely to occur, as well as column footing connections exposed to significant shear forces. This force could be of great importance in so many types of RC members. (ACI Committee 318., 2011; Edward Nawy, 2008; C.-K. Wang et al., 2007). In some circumstances, a fracture already occurs in the shear plane prior to the application of any shear force as a result of thermal deformation or the presence of tension forces brought on by restrained shrinkage (Nilson et al., 2016).

Due to the enormous rise in population, and hazardous waste in metropolitan areas, recent research on the durability of RC have concentrated heavily on chemical attacks (Mohammedameen et al., 2019). Investigators are aware of the issue of conventional concrete deterioration in the presence of chemical attacks, and continuing investigations aim to stop this from happening. Structures are vulnerable to axial force, shear stresses, and bending moments along with chemical attacks, particularly in seismic zones. Structures in such an environment are subject to seismic loads following the loss of mechanical strength brought on by chemical attack, and failure of the structures is unavoidable inevitable (Mohammedameen et al., 2019).

Self-consolidating concrete (SCC) is a brand-new, high-performance concrete that spreads easily into the area under its weight and fills confined spaces. Even in structures with densely packed reinforcement, without mechanical consolidation or significant material constituent separation (Sarsam et al., 2014).

The use of SCC can improve productivity in structural applications such as repair and facilitate the filling of restricted sections. Such concrete has been widely used to facilitate construction operations, especially in sections presenting special difficulties to casting and vibration such as bottom sides of beams and girders (Khayat, 1999).

Better compressive strength, rigidity, low electrical and thermal conductivity, low combustibility, and low toxicity are all characteristics of the SCC. Its employment is constrained by two qualities: brittle and weak under tension (Sarsam et al., 2014). However, the FR composites (FRC) advancements have offered a technical foundation for addressing these shortcomings (V. C. Li et al., 1998). Tiny particles of reinforcing material called fibers are added to a concrete mix that typically includes cement, water, fine and coarse aggregate, and fibers. Steel, glass, asbestos, carbon, and polypropylene are some of the more popular fibers. Cracks would spread, sometimes quickly, when the strain placed on concrete approaches for failure. Concrete fibers offer a way to stop the spread of cracks. If the fiber's elastic modulus is high compared to the elastic modulus of the concrete or mortar binder, the fibers contribute to carrying the load and increasing the material's tensile strength (Sarsam et al., 2014). Compared to CVC, FRSCC can increase durability and mechanical performance (Siddique, 2019). The tensile strength and toughness of concrete are improved by fibers. Additionally, they lessen concrete shrinkage and creep strain (Ganesh & Pavan, 2004).

1.2 Research significance

In reinforced concrete (RC) structures, a failure because of direct shear occurs close to supports (where shear stresses are high or when an earlier crack surface has developed into the depth of the element) and at joints (when the shear span is smaller than approximately half the effective depth of a member) (Ross, 1986). Additionally, this sort of failure can happen in RC structures under strong, brief-duration dynamic stress; in other words, direct shear failure occurs when a member experiences such force and does not have time to behave in the bending mode (Lavenhagen, 2012). In order to determine the material's failure limits for the purpose of safe design, it is important to examine the material for these types of tests. Research on the shear behaviour of self-consolidating concrete made using steel fibre, and polypropylene needs to be well documented (Simalti & Singh, 2020).

1.3 Problem statement

Past reports of some initial issues, such as bond & shear behaviors of SCC, have been made. Aggregate interlock was anticipated to play less role than VC because of the lower aggregate composition, which could lead to decreased bond and shear strength (Khayat & de Schutter, 2014).

Poor engineering science problem knowledge or a lack of theoretical knowledge may result in inadequate design and potentially expensive repair costs. For subsurface engineering applications, including tunnel linings and defect correction, the developing of shear strength characteristics of concrete subjected to sulfate attack is critical. In terms of direct shear tests, it is essential to understand the sulfate-damage process on cement-based products correctly (Zhang et al., 2020).

However, the fiber contribution to SCC also needs further research about which fiber is more reliable and the ratio of that fiber, as well as the contribution of different types of fiber for shear strength properties. Also, the benefits of different fiber types for enhancement of durability.

1.4 Objective of the research

The main objectives behind this study are:

1) To investigate and compare the shear strength of self-compacting concrete containing steel fiber and polypropylene fiber in different environmental exposures.
2) In addition to investigate and compare some other hardened properties of self-compacting concrete including compressive strength, tensile strength containing different fiber, in different conditions.
3) To investigate the workability of fresh self-compacting concrete with and without fibers.
4) To investigate the effect of different ratios of fibers added to self-consolidating concrete on the mentioned properties.

1.5 Thesis Structure

There are five chapters and an Abstract in this thesis:

Chapter 1: Includes the aims, problems and objectives of the research along with a general introduction to the topic.

Chapter 2: Includes an overview of the literature and background information on shear strength, self-compacting concrete, steel fibers, polypropylene fibers, durability and studies done in the past on fiber-reinforced concrete.

Chapter 3: Describes the experimental strategy used in the current research. It provides a thorough description of the various ingredients employed, mixing processes, sample preparation techniques, and testing methodologies.

Chapter 4: Presents the outcomes of the testing program while outlining the results. In this chapter, tables of experiment results and Figures are shown and discussed.

Chapter 5: highlights the findings of the current investigation, offers suggestions for more research, and outlines the limitations of the study.

CHAPTER II

LITERATURE REVIEW

2.1 Introduction

Concrete shear strength is described as one layer's resistant to slippage at the common surface of contacts while taking into account the other layers. The shear failure, especially the situation when it suddenly develops, is the most unwelcome failure (Q Madhlom et al., 2021). Due to this form of fast failure, many efficient designs for reinforced concrete members have been investigated (Birkeland & Birkeland, 1966).

Elements' dimensions, the absence as well as the presence of axial forces, the reinforcement ratio, compressive and tensile strengths, loadings, cross-sectional shape, a shear span/depth, proportion (a/d), and fibre-reinforced concrete toughness properties are the primary factors that influence the shear strength of structural concrete (Cuenca & Serna, 2013)In a zone where a significant shear force is available in combination with the bending moment, a shear crack hinge forms. Shear crack hinge also has substantially higher rotational performance than flexural crack hinge if a member has enough shear capacity to prevent shear failure (Siddique, 2019). Only flexural cracks appear at low shear forces. The elongation of the flexural cracks will bend and then become shear cracks with just an incline in the direction of the applied load when the shear stress inside the beam meets the shear crack stress (Siddique, 2019).

The shear strength can be explained by a mixture of three load-carrying methods, including cohesion or adhesion, shear-friction, and shear reinforcement, according to literary works on "shear-friction" (F. Chen et al., 2019; Haskett et al., 2011; X. Liu et al., 2019; Santos & Júlio, 2012; Soetens & Matthys, 2017; C. Wang et al., 2019; Y. Zhao et al., 2019).

The chemical bonding connections that give rise to the adhesion and cohesion component are also known as "aggregate interlocking". The normal stress at the shear interface and surface roughness impacts the second component, shear friction, which is connected to the contribution from the longitudinally relative slip(Zhang et al., 2020). The final one, shear reinforcement, has to do with how well the shear reinforcement contributes flexural strength along the interface. Another name for this was "dowel action" (Zhang et al., 2020).

The production process facilitates the manufacture of particularly thin members when fibres are added to CVC or SCC in place of shear reinforcement. By improving the bearing capacity, reducing the size effect in shear, or ensuring the minimal shear reinforcement required by the present codes, fibres can delay the appearance of the shear failure mechanism and prevent the creation of a single critical shear cracking (fib Bulletin, 2010; Minelli et al., 2014). According to ACI Committee 544, (1988), the following are the contributions of fibres to shear:

- Fibres can significantly raise the first crack strength & overall tensile strength of plain concrete.
- Minimizing crack width results in an enhancement in the shear transfer between both sides of the crack.
- Fibres are much closer to one another than stirrups, thereby successfully slowing down the growth of cracks.

2.2 Fibers

In the past ten years, FR-SCC has been employed in a variety of wholly and partly structural applications, such as roof elements, slabs on grade, tunnel segments, overlays, sheet piles, precast prestressed beams (Carlswärd & Emborg, 2007; Dhonde et al., 2007; Ferrara & Meda, 2006; Groth & Nemegeer, 1999; Grünewald, 2004). The classification of fibres is shown in Figure 2.1. The qualities of several fibre types that can be employed in concrete production are shown in Table 2.1.

FRSCC is a novel form of concrete that frequently consists of a substance developed for a particular application. The three aspects of strength, fibre dose, and flowability are the main ways it differs from conventional compacted concrete (Siddique, 2019). By using FRSCC, maximum performance can be attained. Potential advantages for each differentiator with the FRSCC's modified mix design in comparison to CVC are listed in Table 2.2.

Table 2.1 General Fiber Properties (Johnson and Colin, 1980)

Fibers	Diameter (µm)	Specific Gravity	Modulus of Elasticity (GPa)	Tensile Strength (GPa)	Elongation to Failure (%)
Chrysotile Asbestos	0.02-20	2.55	164	3.1	2-3
Crocidolite Asbestos	0.1-20	2.55	196	3.5	2-3
E-Glass	9-15	2.56	77	2-3.5	2-3.5
AR-Glass	9-15	2.71	80	2-2.8	2-3
Fibrillated Polypropylene	20-200	0.91	5	0.5	20
Steel	5-500	7.84	200	1-3	3-4
Stainless Steel	5-500	7.84	160	2.1	3
Carbon Type I	3	1.90	380	1.8	0.5
Carbon Type II	9	1.90	230	2.6	1.0

Table 2.2 Potential advantages of using FRSCC (Siddique, 2019).

Plus, Strength	Plus, Fibers	Plus, Flowability
–Tensile strength ↑ –Compressive strength ↑ –Modulus of elasticity ↑ –Durability ↑ –Mechanical properties ↑ –Material volume ↓ –Service life ↑ –Weight of structure ↓ –Grow early-age strength ↑	–Post cracking strength ↑ –Tensile strength ↑ –Replacement reinforcement –Crack width ↓ –Combine with reinforcement –Durability ↑ –Mechanical properties ↑ –Material volume ↓ –Slender element –Weight structure ↓ –Thin element	–Casting of complex shape –Remote casting – SCC mix design permits using more fiber. – densely reinforced casting – The aesthetics have improved. –Production efficiency ↑ – FR orientation can be advantageous or customized.

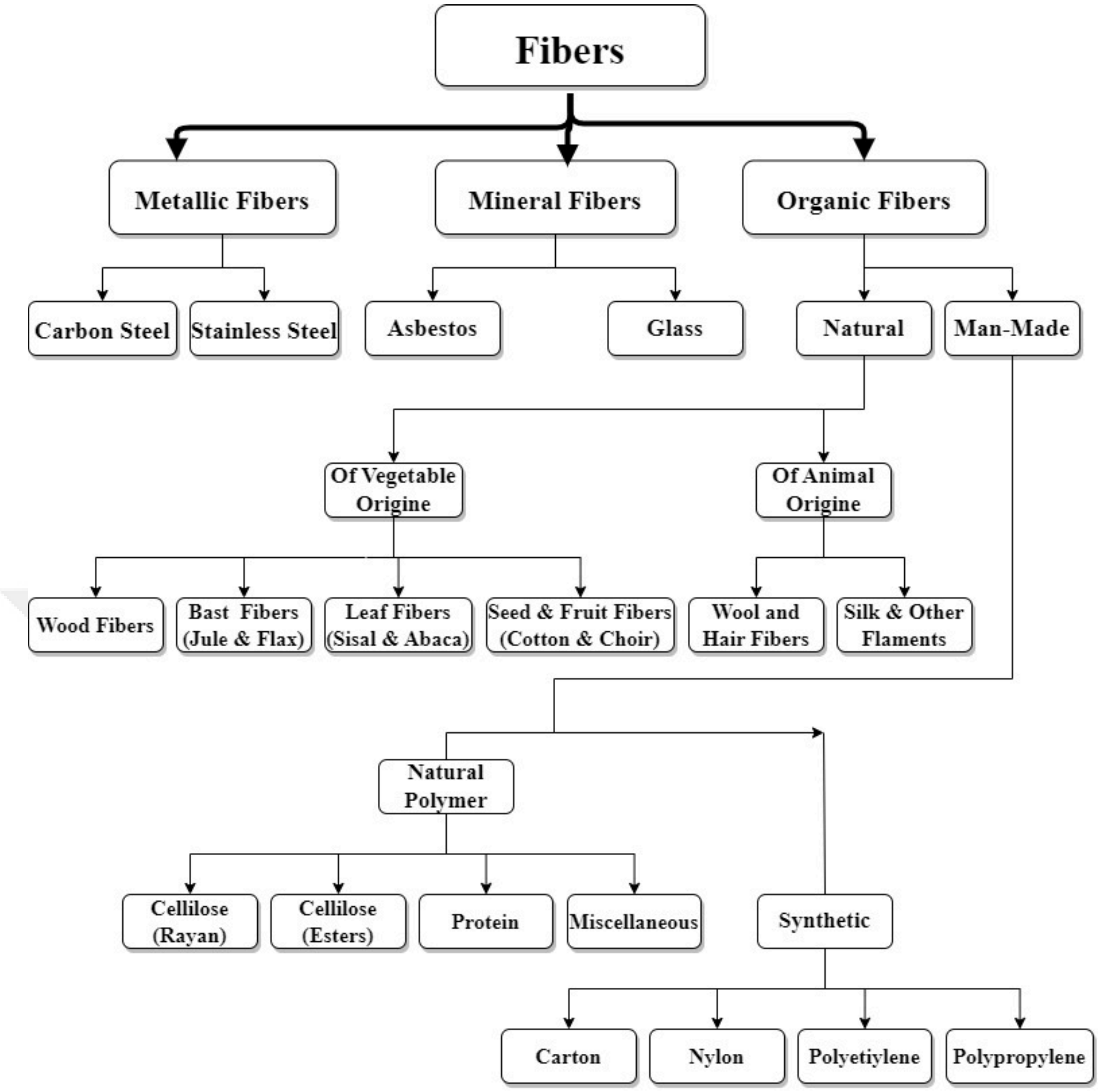


Figure 2.1 Classification of fibres (James Patrick and Maina Mwangi, 1985)

The minimization of vibration used to compact the concrete, as well as the improvement of the SCC matrix's stability, are the main benefits of using fibres in SCC (Khayat & de Schutter, 2014). As a result, structural features that are unaffected by both the downward settlement & segregation of the fibres experience a uniform, random distribution of the fibres (Ferrara, 2003; Ferrara & Meda, 2006; Ozyurt et al., 2007). The efficient structural performance of parts constructed using fiber-reinforced cementitious composites depends heavily on this requirement. The random dispersion of fibres within structural components may be affected by improper compaction and placement, which is worsened further by the damaging effect of fibres on workability (Bayasi & Soroushian, 1992), Reduced or absent fibre dosage of an area in concrete causes faults that lead to early failure and the activation of unexpected mechanisms, which affects the structural performance and load-bearing capacity (Khayat & de Schutter, 2014).

2.2.1 Steel fiber

Porter initially proposed using steel fibers in concrete in 1910 (Naaman, 1985). Nevertheless, the first American scientific study on FRC was conducted in 1963 (Romualdi & Baston, 1963). Traditional hydraulic cement, water, fine and coarse aggregates, and steel fibers are used to create SFRC. ACI 544.1R, (1996) identifies steel fibers as separate, small strips of steel with an aspect ratio (which is length to diameter proportion) in the range between 20 to 100 and any of the varied cross-sections that are small sufficient to be freely and randomly distributed in the fresh mix of concrete utilizing traditional mixing techniques (Behbahani et al., 2011). high range water reducers (chemical admixtures) can also be included in the concrete mix to improve the SFRC's workability and stability.

The majority of applications to date (of SFR-SCC) have used steel fibres. There have been reports of the usage of various steel fibre kinds with rectangular, circular, or even elliptic cross-sections (straight shown in Figure 2.2, crimped, hooked-end, etc.)(Khayat & de Schutter, 2014).

Figure 2.2 Copper coated straight steel fibers.

2.2.1.1 Steel fiber benefits

Numerous variables, including type, length, shape, strength, cross-section, fibre content, mix design, matrix strength, as well as concrete mixing, affect the positive effects of steel fibres in concrete. Figure 2.3 displays normal load-deflection curves for fibre-reinforced concrete and without fibre (ACI 544.1R, 1996). Including steel fibres in ordinary RC members provide several benefits, including:

1- Seel fibres improve the concrete's flexural capacity by enhancing the composite's tensile strength.

2- 2-The post-cracking strength, as well as restraint of the fractures in the concrete, resulting from the crack-bridging action of Steel fibres and their ability to transfer stresses equally throughout the matrix.

3- Make the concrete more ductile.

4- SFRC is more serviceable and long-lasting than traditional RC (Grzybowski, 1989; Grzybowski & Shah, 1990; Rapoport et al., 2002)

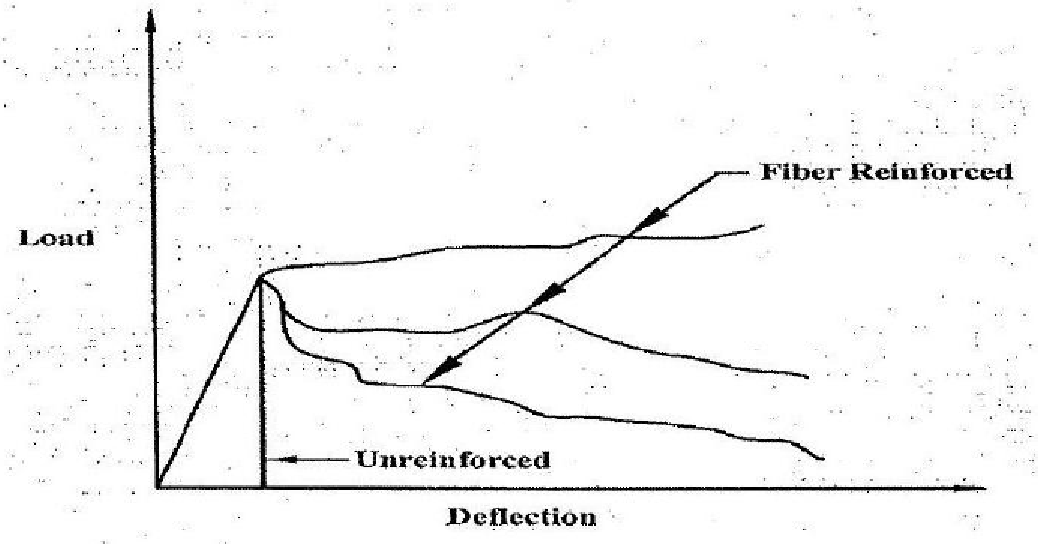


Figure 2.3 Load-Deflection Curves for Fibrous Concrete and Plain Concrete (ACI 544.1R, 1996)

2.2.1.2 Workability

The only drawback of steel fibre-reinforced concrete is that it requires more vibration to make it workable, which reduces its workability and accelerates the rigidity of fresh concrete caused by the addition of Steel fibres. The employment of newly created high-range superplasticizers, which not only improve the workability of steel fibre-reinforced concrete but also preserve the plasticity of the mixture for a more extended period, could help to solve this problem partially (Behbahani et al., 2011).

Hooked end and Straight steel fibres were employed in Sahmaran et al., (2005) studies, which were conducted in both fresh and hardened conditions. They discovered that a fibre content of 60 kg/m3 can result in appropriate Self-consolidating concrete workability.

The workability, fracture characteristics, and mechanical behaviour of hybrid SF-reinforced self-consolidating concrete were studied by Akcay & Tasdemir, (2011) Two distinct volume ratio of (0.75 per cent & 1.5 per cent of the overall quantity of concrete) of three various types of steel fibers, each with hooked ends and without it, were putted to the mixtures. The results of the experiments showed that Self-consolidating concrete the workability was slightly reduced after adding fibres as shown in Figure 2.4. Moreover, the shape of the long fibres is the critical element affecting workability and flowability. With the addition of fibre, the flowability was observed to decrease. However, the flowability of the final product did not significantly change for the fibre contents specifically used in the study.

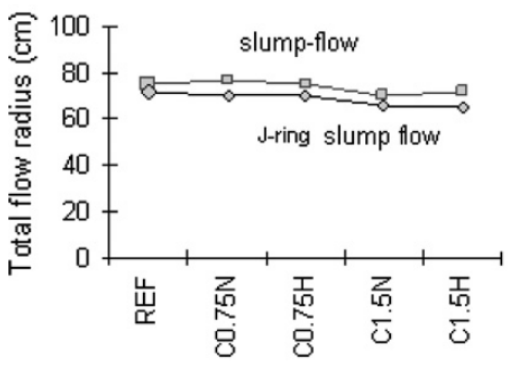


Figure 2.4 Results of slump flow and J-ring tests for total flow radius (Akcay & Tasdemir, 2011).

2.2.1.3 SFRSCC mechanical properties

Concrete material constituents (cement, water quantities, and), as well as SF characteristics (amount and aspect ratio, SF type), have an impact on the mechanical properties of steel fibre self-consolidating concrete. The concrete industry is already familiar with how the components of concrete affect SRF-SCC mechanical strength. However, more research is needed to determine how steel fibres affect the mechanical strength of concrete (Anil, 2018).

2.2.1.3.1 Compressive Strength

According to research by (Dixon & Mayfield, 1971) and (Johnston, 1974), adding up to 1.5% by volume of Steel fibres enhances compressive strength capacity from Zero to 15%. Figure 2.5 illustrates the increased spalling resistance, ductility, and toughness of Steel fibres reinforced by the gradual slope in the descending region of the stress-strain curves (Padmarajaiah & Ramaswamy, 2002).

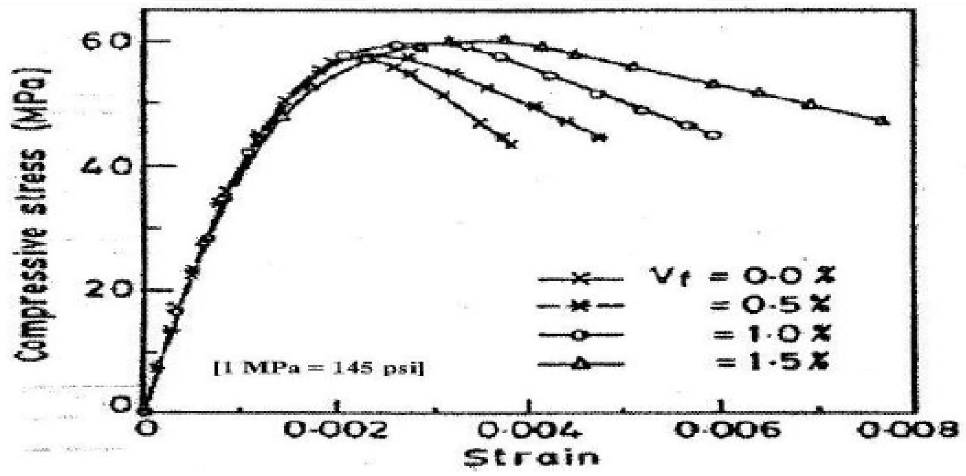


Figure 2.5 Influence of the steel fibres Content on the FRC's Compressive Stress-Strain Curve (Padmarajaiah & Ramaswamy, 2002)

Two type of steel fiber (Straight and hooked-end SF) were utilized by Sahmaran et al., (2005), who conducted testing in hardened states. The maximum compressive strength values were found in self-consolidating concrete reinforced with straight steel fibres.

Interestingly, Steel fibre reinforced self-consolidating concrete was found to have a faster rate of compressive strength gain over time than traditional vibrated Steel fibre reinforced concrete, although having a 28-day compressive strength which was similar (Dhonde et al., 2007).

In the study by Siddique et al., (2016), fibre doses up to 1.5 vol.% were examined, and the impact of steel fibres also on the compressive strength of self-consolidating concrete was found to be moderate shown in Figure 2.6. When comparing the highest and lowest fibre dosages, a relative loss in compressive strength was found, indicating the opposing effects of matrix reinforcement and ineffective fibre utilization and insufficient compaction.

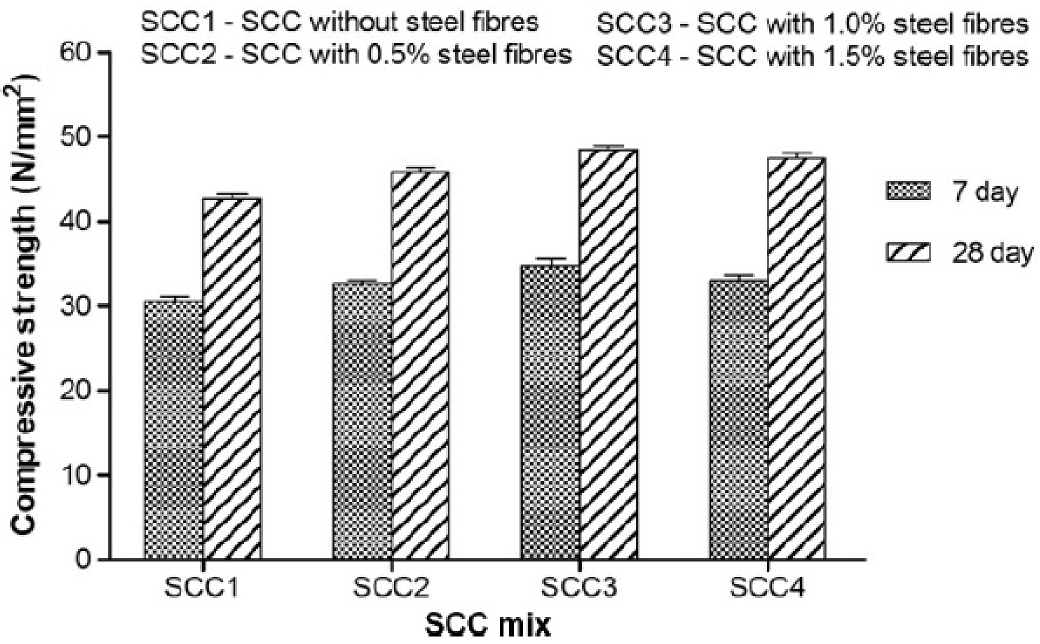


Figure 2.6 Role of concrete age and steel fiber content on the compressive strength of self-consolidating concrete and fibre reinforced self-consolidating concrete (Siddique et al., 2016).

2.2.1.3.2 Splitting Tensile Strength

Because the test sample, structure, or structural element may break at the weak point and deformations may concentrate in this point, which needs to be taken into account, the fibre contribution is crucial in tension. According to Siddique et al., (2016), the splitting tensile strengths as well as enhanced as steel fibre dose increased as compared to the control self-compacting concretes; the increases were up to 39% and 33%, respectively, in the time up to 28 days after casting.

In the study by Sahmaran et al., (2005), steel fibres were employed in both the fresh and hardened phases. Self-compacting concrete with an equal mix of straight and hooked-end steel fibres had the highest splitting tensile strength.

Using high-volume fly ash, Sahmaran & Yaman, (2007) studied the characteristics of fibre-reinforced self-consolidating concrete when it was both fresh and hardened. The self-consolidating concrete splitting tensile strength with high-volume fly ash was found to be more effectively increased by longer fibres with hooked ends as shown in Figure 2.7.

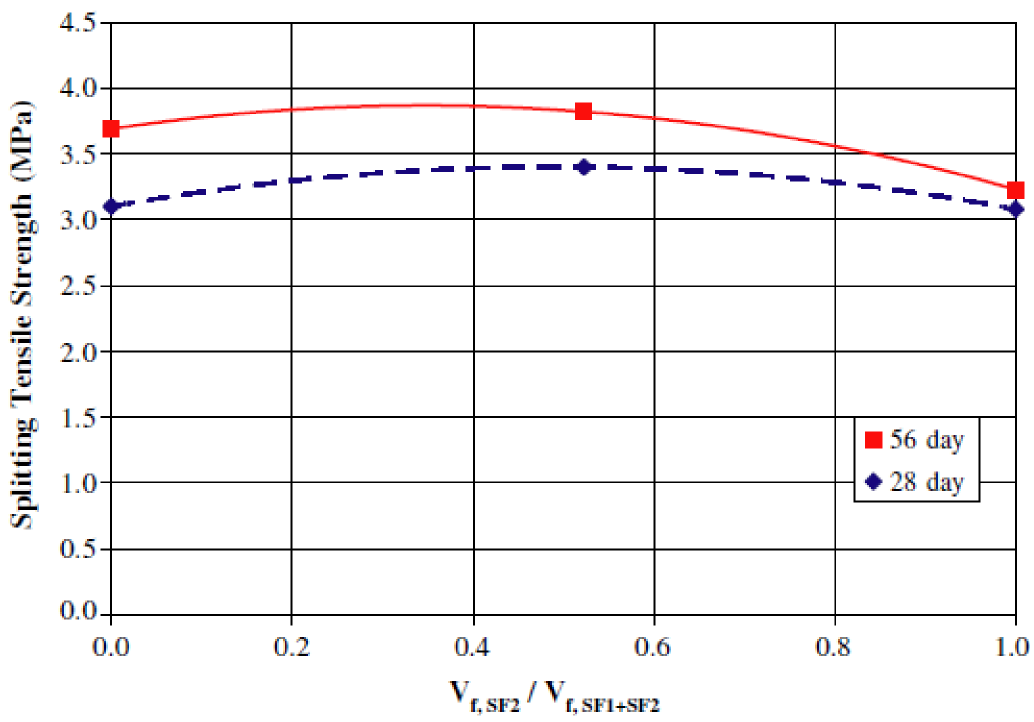


Figure 2.7 Steel fibers' impact on the splitting tensile strength (Sahmaran & Yaman, 2007).

High-strength lightweight consolidating concrete reinforced with a large number of steel fibres (ups to 125 kg/m3) was created by Iqbal et al., (2015). In comparison to the higher range (above 1%), they discovered that High strength lightweight consolidating concrete is less reactive to adding the same number of micro steel fibres to concrete in the smaller range (up to 0.75%). The concrete tensile and flexural strength was significantly increased by the addition of short SF, and strain-hardening material was created.

2.2.1.3.3 Shear Strength

According to earlier studies, adding steel fibres significantly boosts concrete's shear strength (Barr, 1987; Narayanan & Darwish, 1987; Noghabai, 2000; Oh et al., 1999). When compared to RC without SFs, the overall shear strength of SFRC with 1% volume fraction of SF rises by up to 170% (Narayanan & Darwish, 1987). The application of Steel fibres is a powerful substitute for conventional transverse shear reinforcement (Noghabai, 2000; Williamson, 1978). Combining Steel fibres with different aspect ratios seems to be more successful than utilizing just one kind of SF for enhancing the mechanical properties of SFRC (Noghabai, 2000).

Researchers looked at the behaviour of shear of both CVC as well as SFRC Boulekbache et al., (2012). Various matrices having 35 or 60-mm tall hooked end steel at 0.5 or 1% by volume ratio were taken into consideration (normal with high strength for vibrated concrete and moderate strength for self-consolidating concrete). The data obtained supported the significant expected correlation between the final shear stress and both compressive strength as well as, even though to a lesser extent, fibre factor as shown in Figure 2.8.

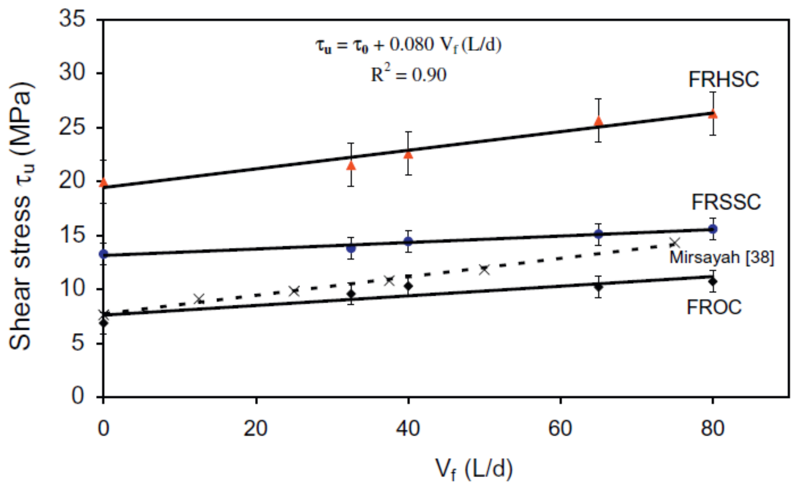


Figure 2.8 Test of the maximum shear stress vs Vf (L/d) in direct shear (Boulekbache et al., 2012).

2.2.1.4 Durability

When compared to conventional vibrated concrete, the durability can also be increased in addition to mechanical performance. The resistance of concrete to possible attack first one is a physical attack (such as salt crystallization in pores, wear, and extreme temperature variations). The second one is chemical attack is one of the durability features of concrete and concrete constructions (e.g., corrosion of reinforcement through acids, sulphate attack, alkali-silica reaction)(Siddique, 2019).

Compared to traditional reinforced concrete buildings, corrosion in concrete caused by cracks is less severe in steel fiber-reinforced concrete structures (Aufmuth et al., 1974; Halvorsen et al., 1976; Mangat & Gurusamy, 1987; Morse & Williamson, 1977).

2.2.1.4.1 Acid attack

Acid rain contamination has recently transformed into one of the significant environmental problems facing the world today due to a sharp rise in nitrogen oxide and sulfur dioxide emissions, and it exhibits a constant trend of the impacted area's size increasing (Yu et al., 2021). For instance, research findings show that acid rain issues cost China over one hundred billion yuan annually, with the corrosion of concrete and other building materials by acid rain accounting for the majority of economic losses (Y. Zhou et al., 2021). The life span of concrete structures in acid rain areas is much less than in non-acid rain areas, necessitating periodic maintenance to increase the service life (Yu et al., 2021). Acid rain of the sulfuric acid type can react to alkaline substances in concrete to change the composition of cementite, causing the concrete to enlarge in size and crack, ultimately resulting in the collapse of the concrete building. Therefore, an efficient way to prevent acid rain from corroding concrete materials is urgently needed (M.-C. Chen et al., 2013; Fan et al., 2010; C. Zhou et al., 2019).

Research has been done on the acid rain corrosion impact of concrete and the reduction in concrete performance after corrosion. Improvement techniques to lessen acid rain corrosion of concrete have also been offered (Yu et al., 2021). The two primary areas of improvement are as follows: on the one hand, adding mineral admixtures might increase the concrete's corrosion resistance against acid rain. On the other hand, fibre concrete has increasingly gained popularity in engineering and people's attention due to its resistance to acid corrosion while taking into account the impact of building materials on the engineering economy. The method of reinforcing concrete that has been the most thoroughly investigated and first created is the addition of steel fibres (Yu et al., 2021).

The impact of SFs on the strength and corrosion resistance of FRC for road pavements as well as industrial floors in an acidic environment was examined by Kos et al., (2022). The steel fibres utilized had a diameter of one mm as well as a length of 50 mm. SF content ranged between 15 to 25 kg/m3. They discovered that adding steel fibre in the quantity of 20 kg/m3 also improves concrete's resistance to corrosion in an acidic media see Figure 2.9.

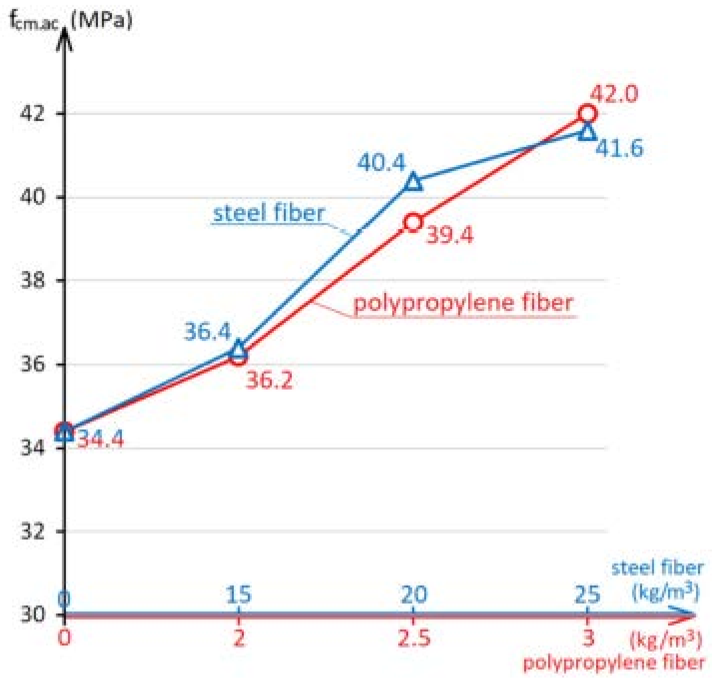


Figure 2.9 The strength of concrete reinforced with steel and polypropylene fibres after six months of exposure to an acidic environment with a pH of three (Kos et al., 2022).

The durability of SFRC against the combined impacts of acid rain and carbonization corrosion was examined by Niu & Wang, (2013). As assessment indices, splitting tensile strength rate of loss, mass loss rate, neutralization depth, and deteriorated thickness were used. According to test results, a proper steel fibre mixture can effectively prevent original concrete from eroding under the influence of acid rain and can even lessen the neutralization depth. The steel fibre reinforced concrete with the SF mixing ratios of 1.5% seems to have the best durability, according to the various mixing proportions tested.

2.2.1.4.2 Sulfate attack

AHMAD et al., (2021) conducted an experimental investigation on the high-performance fiber-reinforced concrete durability and mechanical characteristics following exposure to four distinct media. These media included control (air), water, sodium chloride (NaCl), and magnesium sulfate ($MgSO_4$), the concentration of chloride and sulfate media were 7%. Hooked-end galvanized steel fibres of 50 mm length were used in concrete having macro silica fume at volume ratio of 0.5%, 1.0%, as well as 1.5%, respectively. After subjecting high-performance fiber-reinforced concrete specimens to prior media for 28 and 180 days, they underwent compression, flexural and indirect splitting tensile testing. According to the test results, high-performance fibre-reinforced concrete with SF is more durable than plain concrete (concrete without fibre) as shown in Figure 2.10, particularly when subjected to NaCl and $MgSO_4$ media.

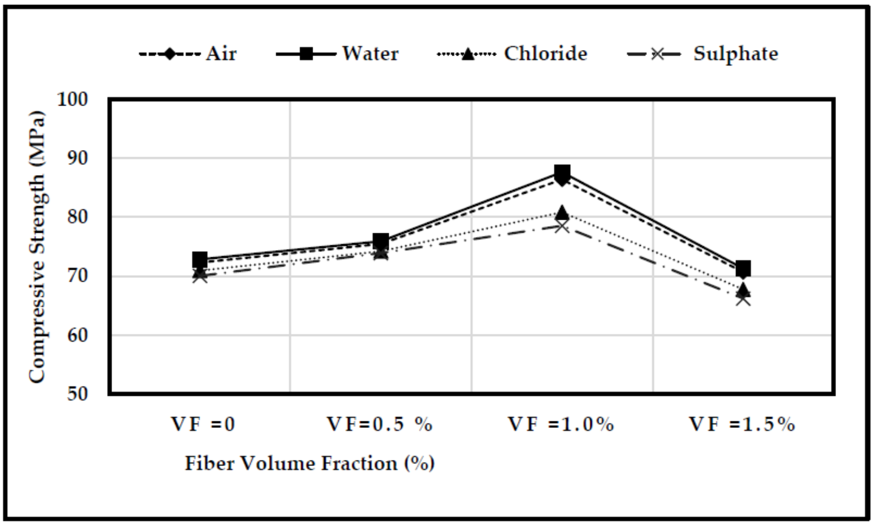


Figure 2.10 After 28 days, steel fibre concrete's compressive strength.

2.2.2 Polypropylene fiber

Propylene polymerization produces a type of synthetic fibre known as polypropylene fibre (PPF) see Figure 2.11. It offers some benefits, including as low weight, high tensile strength, high toughness, as well as resistance to corrosion. Polypropylene is widely utilized in the chemical industry, energy, apparel, environmental protection, and building construction (Ali et al., 2020; Bracho et al., 2012; Mahmoud & Elkatatny, 2020; Pérez-Rocha et al., 2015; Tapiero et al., 2019; Yamamoto & Ota, 2021). Concrete's shortcomings in the construction sector include its low tensile strength, poor deformation resistance, and inadequate crack resistance. The concrete becomes more permeable as a result of the fact that simply the microcracks can be produced from the exterior to the inside. Concrete is easily penetrated by water and other harmful ions, which speeds up the concrete's disintegration (Hussain et al., 2020). adding polypropylene to concrete allows for the formation of a randomly distribution network structure which is 3-dimensional, which effectively prevents the growth and development of microcracks (Çelik & Bingöl, 2020; Qin et al., 2019; Shen et al., 2020; Smarzewski, 2020). As a result, the PPF can stop water and other damaging ions from penetrating concrete (Y. Liu et al., 2021).

They are formerly known as Stealthe, 100percentage virgin homopolymer PP-graded monofilament fibres. Polypropylene fibres are micro-reinforcing fibres (Madhavi et al., 2014). They do not include any recycled Olifin components. The entirely hydrocarbon monomeric compound C_3H_6 serves as the basis for polypropylene. The suggested dosage ratio of PPF is 0.9 kg/m3, or 0.1% by volume, for effective performance for conventional vibrated concrete (Madhavi et al., 2014).

Fibres made of polypropylene should not be used to replace traditional reinforcement. Thicker sections and wider joints than those recommended for unreinforced masonry should not be made with these fibres (Madhavi et al., 2014)

Figure 2.11 Polypropylene fiber used in this research

2.2.2.1 Advantages

The fibres made of polypropylene are, not rusted, non-magnetic, alkali-resistant, secure, and easy to use. PP twine is cheap, widely accessible, as well as of consistently high quality. PP fibres may be handled easily and are compatible with all chemical admixtures used in concrete. Polypropylene has a lot of helpful qualities due to its large molecular weight (Madhavi et al., 2014).

Due to the chemical barrier properties of polypropylene, any substance that will not harm the components of concrete will not affect the fibre either. Concrete always deteriorates first (before PPF) when more corrosive chemicals are in contact, then fibres (Madhavi et al., 2014).

When polypropylene fibres are utilized in concrete, there is no need for a minimum quantity cover for concrete member because the hydrophobic surfaces of the fibres are not wetted by the cement paste, which helps to minimize the balling influence of chopped fibres. Fibres in concrete help to prevent settling and bleeding. Improved impact, abrasion, and freeze/thaw resistance (Madhavi et al., 2014).

2.2.2.2 Properties of polypropylene fiber reinforced SCC

According to ACI Committee 544, fibre FRC is a type of concrete comprised of hydraulic cement, fine and coarse aggregates, and discrete discontinuous fibres.

Numerous studies have examined how different types of fibres affect the mechanical characteristics of concrete. However, the available research on PPFRC could be more and do better.

2.2.2.2.1 Workability

The magnitude of trapped air voids grows when fibres are taken in, and the decreased workability is due to the difficulty to compact mixtures because of the high air content. s. The PPF could also obstruct and lead to issues with finishing (Madhavi et al., 2014).

Patel et al., (2012) discovered that as the volume fraction ratio of polypropylene fibre increased, the concrete workability decreased.

Thirumurugan & Sivakumar, (2013), reported that adding polypropylene fibres reduced the workability of concrete but that using HRWRA could remedy this.

In order to study the workability and mechanical characteristics of SCC with fly ash, Gencel et al., (2011) employed monofilament PPF. The workability of the materials employed in this study decreased along with increasing PPF volume fraction.

Widodo, (2012) assessed how the addition of PPF affected the properties of SCC mixtures in their fresh form. He used PPF with volume fractions of 0%, 0.05%, 0.10%, and 0.15%. According to the results of his evaluation of the fresh features of SCC's passing ability, flowability, segregation resistance, and viscosity, PPF tends to decrease SCC's flowability and passing ability while increasing its viscosity and segregation resistance. Additionally, he came to the conclusion that PPF lessens the fresh state deformability of SCC see Figure 2.12.

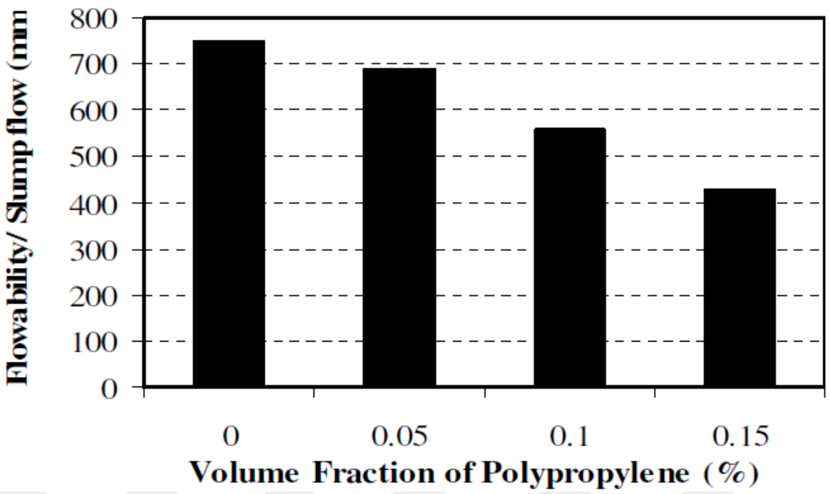


Figure 2.12 Effect of PPF usage on SCC Mixes' Flowability (Widodo, 2012).

2.2.2.2.2 Compression Strength

One of the RC's most important characteristics is its compressive strength. It serves as a qualitative measurement for concrete. Compression failure of concrete is a combination of shear failure as well as crushing. As a result of the cement paste and fibres, the compressive strength varies. Greater compressive strength is provided by a greater binder ratio (Madhavi et al., 2014).

Fibrillated PPF with a low-value density of 0.9 kN/m3, a diameter measure of 34 microns, and a length mesure of 12 mm, and was employed in high-strength concrete by Mehul J. Patel & S. M. Kulkarni, (2013) in proportions of 0.5%, 1%, and 1.5%. Conplast-Sp430, a powerful plasticizer, was used. They noticed compressive strength increased along with adding fibres.

The impact of PPF on Fay ash concrete was studied by K.Murahari & Rama mohan Rao p, (2013). Class C fly ash, derived from NLC, was employed in fly ash concrete at the fibre volume fractions of 0.15, 0.2, 0.25, as well as 0.3%. in addition, Fly ash content ranged from 30% to 50%. The coarse aggregates utilized had a specific gravity of 2.7 and were 12 mm (40percentage) and 20 mm (60percentage) in size. The cube samples underwent 28-day and 56-day strength tests. For all samples of fly ash and PPF concrete, the compressive strength reached its maximum strength earlier. Additionally, it was shown that the fibre content's compressive strength gradually elevated from 0.15 to 0.3%.

Widodo, (2012) looked into how PPF affected several of the hardened characteristics of SCC. This study used PPF with volume fractions of 0%, 0.05%, 0.10%, and 0.15%. A test of compressive strength was performed after 28 days of curing. According to the findings, adding PPF up to 0.10% of the volume tends to increase compressive strength, as depicted in the Figure 2.13.

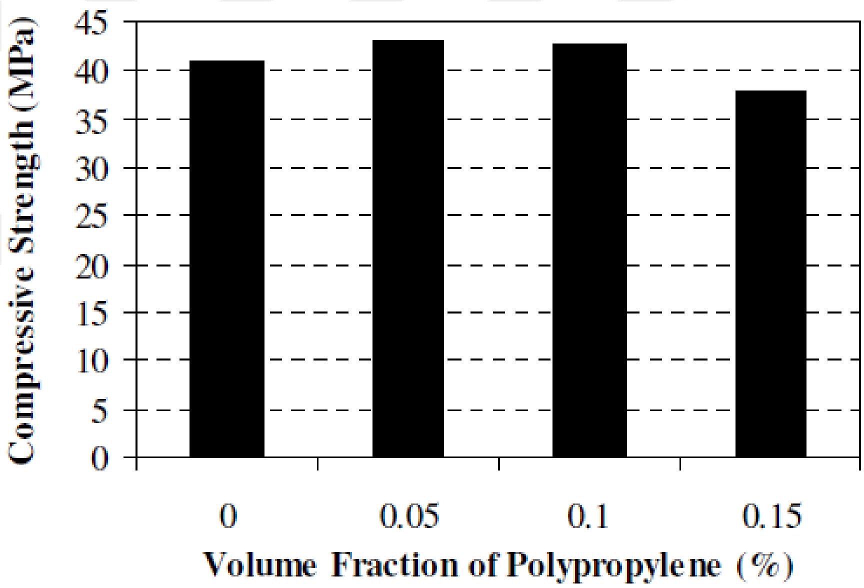


Figure 2.13 Effect of Adding PPF on SCC's Compressive Strength

2.2.2.2.3 Split Tensile Strength

Both direct and indirect approaches can be used to calculate split tensile strength. trying to apply a uniaxial tensile force to an eccentricity-free specimen and holding the specimen securely in the testing equipment without creating stress concentrations are two challenges with the direct approach. Concrete breaks at the apparent tensile stress instead of the tensile strength because it is weak under tension, which is caused by even a little eccentricity of load (Madhavi et al., 2014).

From their experimental studies, K.Murahari & Rama mohan Rao p, (2013) found little evidence of major fibre interference with split tensile strength. Compared to 56 days, the splitting tensile strength strengthened more quickly at 28 days of age.

Using fibres up to 9 kg/m3, Gencel et al., (2011) tested the split tensile strength. It was discovered that as the fibre content grew, the splitting tensile strength improved as well. Microcracks are typically bridged by fibres, which also prevent cracks from spreading. The microcracks are stopped when tensile stress is transmitted to the fibres, increasing the splitting tensile strength of the concrete.

Widodo, (2012) looked into how PPF affected some of the hardened characteristics of SCC. This study used polypropylene fibre with volume fractions of 0%, 0.05%, 0.10%, and 0.15%. A test of splitting tensile strength was performed after 28 days of curing. When the fibre addition is up to 0.10 per cent, the splitting tensile strength is seen to be better, and after that, it tends to decline. Figure 2.14 shows the splitting tensile test outcome.

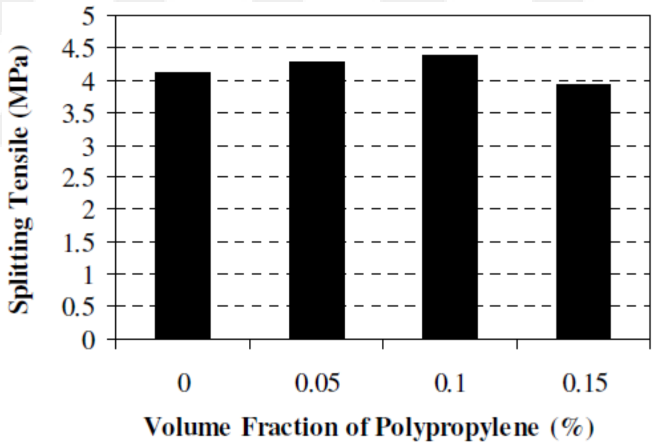


Figure 2.14 Effect of Adding PPF on the SCC's Splitting Tensile Strength

2.2.2.2.4 Shear Strength

Ahmed et al., (2006) They investigate how polypropylene affects plastic shrinkage cracking, compressive, tensile, flexural, and shear strength. Flexural, tensile, and shear strength all showed a noticeable improvement as shown in Figure 2.15. Compression strength did not vary, though. Adding fibers in the region of 0.35 to 0.50% also reduces shrinkage cracking by 83 to 85%.

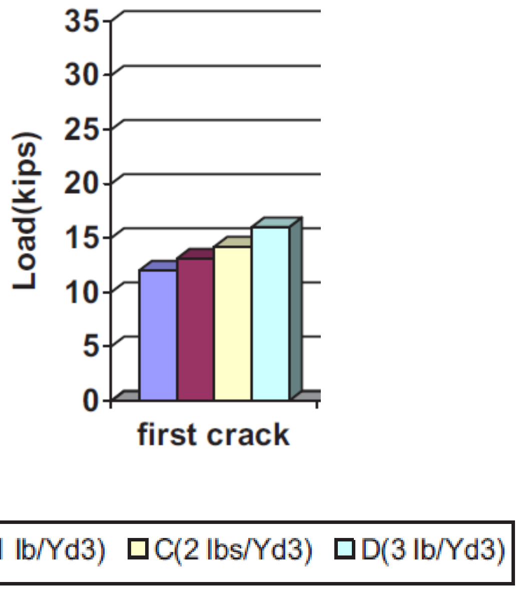


Figure 2.15 Effect of Fibers on RCC Beam Shear Strength (Ahmed et al., 2006)

2.2.2.2.5 Durability

PPF can be added to concrete to increase its tensile strength (D. Li & Liu, 2020; Mahmoud & Elkatatny, 2020; Rashid, 2020; J. Wang et al., 2019). PPF can be utilized in the pavement, architectural, and hydraulic engineering because of its impressive attributes (Hussain et al., 2020; D. Li & Liu, 2020; Rashid, 2020; J. Wang et al., 2019). For the building of high-rise structure foundations in architectural engineering, mass concrete must be poured just once. Early on, mass concrete is susceptible to developing thermal fissures (Jung et al., 2017; Z. Zhao et al., 2019). The polypropylene fiber can reduce the concrete's temperature fractures (Saeed et al., 2019). As a result of fewer through cracks in the concrete, introducing PPFs can also increase the concrete's resistance to permeability (Islam & Gupta, 2016; D. Li & Liu, 2020). Regarding pavement engineering, pavement frequently carries the impact force of moving vehicles, necessitating a high degree of toughness and crack resistance, particularly for pavements with high traffic volumes or heavy loads (Ma & Zhang, 2020; Mansourian et al., 2018). PPF-reinforced concrete is more durable than unreinforced concrete (H. Guo et al., 2021; Smarzewski, 2019). The toughness of pavements can be significantly increased when polypropylene fibre is utilized in concrete (Hussain et al., 2020). Meanwhile, fewer creaks are heard when vehicles contact the pavement, demonstrating that incorporating PPFs in concrete increases the pavement's durability (Y. Chen et al., 2018b, 2018a). Bridges, culverts, docks, and dams are examples of hydraulic engineering that frequently come into touch with water. For this, concrete needs to be impermeable to hazardous ions and running water. The PPF may efficiently boost concrete's resist-permeability and stop water and hazardous ions from entering through cracks, indicating that employing PPFs can improve concrete performance. (Y. Li & Zhang, 2021; Rashid, 2020; Smarzewski & Barnat-Hunek, 2017)

2.2.2.2.5.1 Sulfate Resistance

Chemical corrosion of concrete most frequently and severely presents itself as sulfate corrosion. Sulfate corrosion is a complicated physical as well as a chemical process that occurs in concrete at the same time (Y. Liu et al., 2021). The sulfate ion penetrates the concrete and interacts with hydration products to form expansive products that damage and break the concrete. PPF addition can lessen concrete's permeability and increase concrete's crack resistance (Y. Liu et al., 2021). Concrete's PPF effectively blocks the transfer of sulfate ions from the surface to the inside. Consequently, adding PPF to concrete can increase its resistance to sulfates (Y. Liu et al., 2021).

Behfarnia & Farshadfar, (2013) explored the sulfate resistance of PPFRSCC that was subjected to attacks from 5per cent and 10per cent mass concentrations of magnesium sulfate. According to the findings, adding polypropylene fibres can significantly lessen the mass loss as well as compressive strength loss of concrete submerged in a Magnesium sulfate solution.

The expansion rate of concrete was utilized by Mardani-Aghabaglou et al., (2018) to describe the eroding effect of Sulfate solution on concrete. In their investigation, the polypropylene percentage by volume fraction was 0.4%, 0.8%, and 1%. According to the findings, the concrete with 1% polypropylene concentration had the maximum expansion rate. The expansion rate of 0.8% PPF concrete, which was just 76% of regular concrete, was the least.

In order to investigate the impact of soaking age on the sulfate attack resistance of concrete by Ranjith et al., (2017) 5% sodium sulfate solution was applied to the concrete specimens for 30, 60, and 90 days, respectively. Within the range of 0-2% volume content, the compressive strength loss rate initially dropped and then increased. The smallest compressive strength loss occurs in concrete with 1.5% PPF. Currently, the most of study findings suggest that adding polypropylene fiber can successfully lessen sulfate ion penetration in concrete. Sulfate ion penetration resistance initially increased and then decreased as fibre content increased. The amount of concrete porosity can be reduced, and the transport of sulfate ions can be decreased with the proper use of fibre. However, excessive material may make concrete more porous and make it harder to resist sulfate ion penetration (L. Guo et al., 2020).

2.2.2.2.5.2 Acid resistance

Kos et al., (2022b) investigated how PPF affected the strength and corrosion resistance of FRC for road pavements as well as industrial floors in an acidic environment. The polypropylene fibers utilized had a diameter of 0.68 mm and a length of 36 mm. Between 2 and 3 kg/m3 of polypropylene fiber were present. They found that adding polypropylene fiber in the amount of 2.5 kg/m3 also improves concrete's resistance to corrosion in an acidic environment.

The durability of designed cementitious composites with reinforcment of both PPFs as well as glass fibers was studied by Ranjith et al., (2017). Both polypropylene and glass fiber volume fractions ratio (0.5%, 1%, 1.5%, as well as 2%). chloride penetration, Water absorption, acid attack resistance, sulfate attack resistance are their durability indices. They revealed that elevating the fiber content of ECC by increased to 1.5% improved its durability. According to the test reports, Engineered Cementitious Composites reinforced with glass fiber exhibit superior durability properties than those of ECC reinforced with polypropylene fiber.

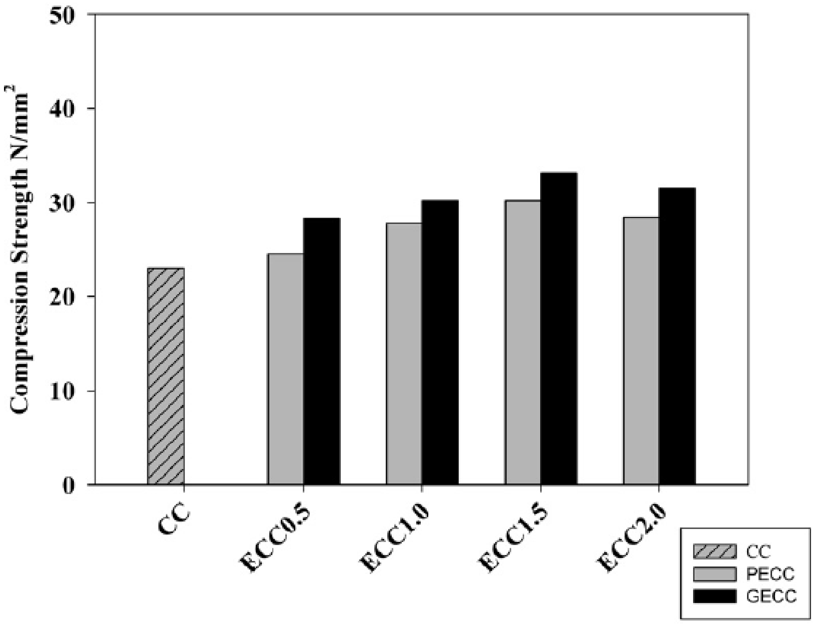


Figure 2.16 Compressive strength after 90 days of acid cure.

CHAPTER III

MATERIALS AND EXPERIMENTALWORK

3.1 Introduction

In this project, our experimental work was performed in Halabja Group Concrete Laboratory in Sulaimani-Iraq. Self-Compacting Concrete material composition is very important and sensitive because any change in material can affect its ability of flowing or passing or can cause segregation. so, we chose its composition very carefully and after each trail mix design we check mix ability to conform EFNARC, (2005) and ACI Committee 237, (2007) precision of Self Compacting Concrete. Since the powder in SCC occupy a large volume, we used Fly ash with Cement. In addition, we used PPF fiber in different fraction.

This chapter shows all materials properties, compositions, how we mix and cast them and how these proportions affect filling, passing, and segregation of self-compacting concrete. Finally, how can PPF fiber affect compressive, tensile and direct shear strength of self-compacting concrete.

3.2 Materials

Cement, water, sand, gravel, flay ash and high range water reducer admixture were used in this investigation. Properties of materials used are described in the following sections.

3.3 Cement

We used Ordinary Portland cement (Delta Cement) in this study, which is Type I. Produced by Bestun group in Sulaimani in Iraq. The quality of cement is conforming to Iraqi (I.O.S 5/2019) standard. chemical composition and the physical properties of the cement used are shown in Table 3.1 and Table 3.2 respectively.

Table 3.1 Chemical composition of cement.

CHEMICAL COMPOSITION			
Constituents	Unit	Result Obtained	I.O.S 5/2019 Confines
SiO_2	%	19.38	-
AL_2O_3	%	4.89	-
Fe_2O_3	%	3.11	-
CaO	%	61.82	-
MgO	%	4.15	Max 5%
SO_3	%	2.25	Max. 2.8%
LOI	%	3.46	Max. 4%
In.R	%	0.21	Max 1.5%
LSF	%	0.97	0.66-Max 1.02
C3S	%	60.62	-
C2S	%	10.66	-
C3A	%	7.69	-
C4AF	%	9.46	-
Alkalies (0.658*K_2O+Na_2O)	….	0.6	-

Table 3.2 Physical properties of cement.

PHYSICAL COMPOSITION			
Description	Unit	Result Obtained	O.P.C/acc to I.O.S 5/2019
Initial setting time (Vicat)	Minutes	138	≥ 45 Mins
Final setting time (Vicat)	Hours	2:48	≤ 10 Hours
Fineness (Blaine)	cm^2/gm	3338	Min. 2800 cm^2/gm
Soundness (Le-Chatlier)	MM	1	Min. ≤ 10 mm
02 Days strength	MPa	24	Minimum 20 MPa
28 Days strength	MPa	44	Min. 42.5 MPa

3.4 Fine Aggregate

The fine aggregate that used in this study was natural river sand, having a coarse grading obtained from Kaneby quarry shown in Figure 3.1. Properties of sand are given in Table 3.3. Table 3.4 shows present result of sieve analysis of fine aggregate. The gradation of sand is confirming the limits of ASTM C33 specification (ASTM C33). The grading curves are also shown in Figure 3.2.

Table 3.3 Properties of fine aggregate

Properties	Value	Test method
Fineness modulus	3.8	ASTM C136/C136M
Specific gravity	2.6	ASTM C128
Water absorption, %	2.25	ASTM C128
Loose bulk density, kg/m^3	1592.15	ASTM C29/C29M
Compacted bulk density, kg/m^3	1721	ASTM C29/C29M

Table 3.4 Sieve analysis of fine aggregate

Sieve No.(mm)	% Passing	Specification limits from ASTM C33
9.5	100	100
4.75	100	95-100
2.36	98	80-100
1.18	84	50-85
0.6	44	25-60
0.3	25	5-30
0.15	1	0-10
0.075	0	0-3

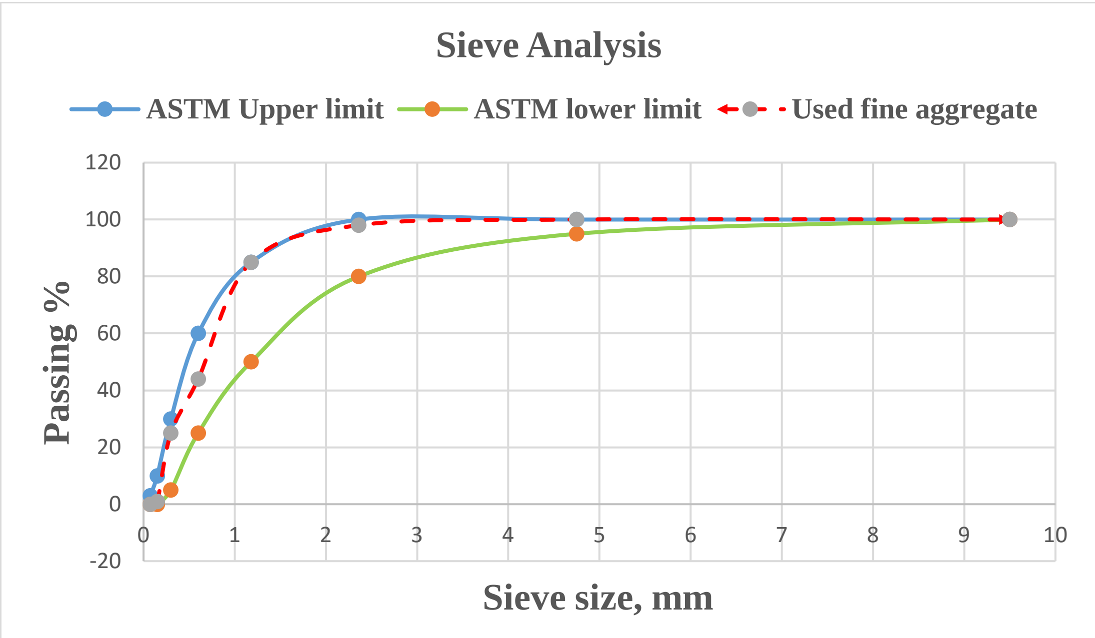


Figure 3.1 Fine aggregate Sieve analysis.

Figure 3.2 Used fine aggregate

3.5 Coarse Aggregate

Crushed stone with maximum size of 10 mm achieved from Tanjaro quarry was utilized as coarse aggregate shown in Figure 3.3. Properties of gravel used are given in Table 3.5. Table 3.6 shows grading results of sieve analysis and ASTM C33 specification limits. The grading curves are shown is shown in Figure 3.4. the utilized coarse aggregate conforms to the specification limits.

Table 3.5 Properties of coarse aggregate

Properties	**Value**	**Test method**
SSD Specific gravity	2.57	ASTM C127
Water absorption, %	1.59	ASTM C127
Loose bulk density, kg/m^3	1386.52	ASTM C29
Compacted bulk density, kg/m^3	1534.13	ASTM C29

Table 3.6 Actual grading of coarse aggregate and specification limits

Sieve No.(mm)	% Passing	Specification limits from ASTM C33
12	100	100
9.5	93	90-100
4.75	27	20-55
2.36	11	5-30
1.18	0	0-10
0.03	0	0-5

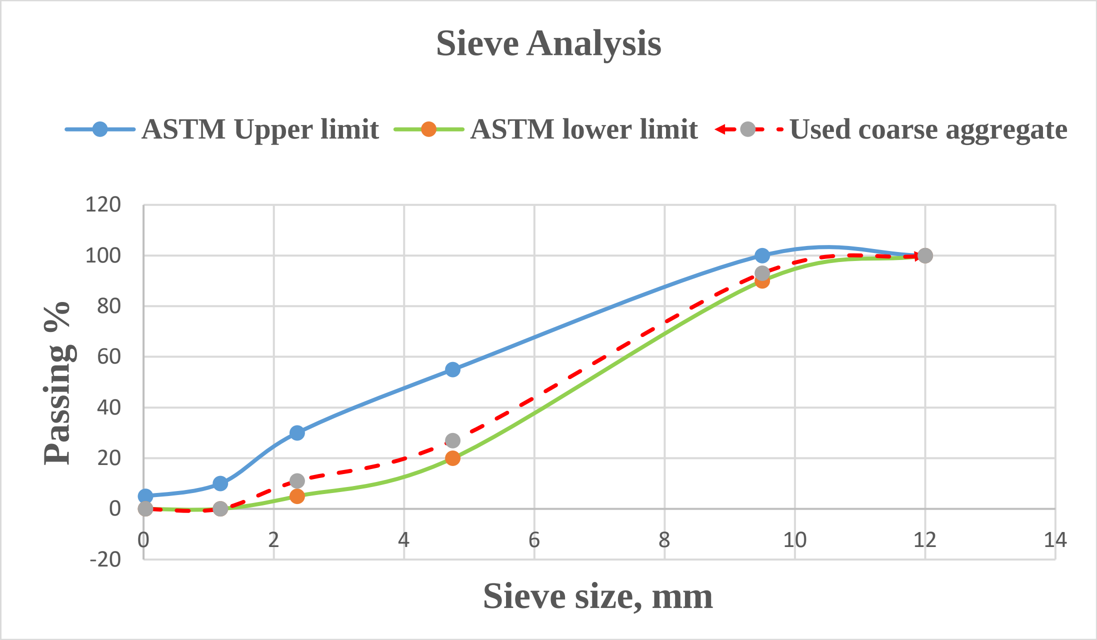


Figure 3.3 Grading curves of coarse aggregate and ASTM C33 limits.

Figure 3.4 Used coarse aggregate.

3.6 Water

Concrete mixing and specimen curing were done with tap water throughout this experiment.

3.7 Fly ash

This study utilized Class F of FA shown in Figure 3.5, whose chemical composition is shown in Table 3.7. The Blaine fineness, which is a measurement of the cement and additional cementitious materials' particle size or fineness, was 5230 kg/m3. The specific gravity was 2.02 g.cm^{-3}. Since it acts as a carrier for the aggregates, the cement paste in SCC is essential. As a result, more cement paste has been added using the FA (Topçu & Bilir, 2009).

Figure 3.5 Used Fly ash

Table 3.7 Chemical composition of fly sh.

CHEMICAL COMPOSITION		
Constituents	Unit	Result Obtained
SiO_2	%	48.43
AL_2O_3	%	17.15
Fe_2O_3	%	11.96
CaO	%	15.48
MgO	%	1.35
SO_3	%	0.82
LOI	%	1.47
TiO_2	%	2.68
K_2O	%	0.41
P_2O_3	%	0.4
Mn_2O_3	%	0.17
Na_2O	%	0.0019
SrO	%	0.2

3.8 High range water reducer admixture (HRWRA)

An additive called HRWRA lowers the amount of water needed to mix concrete to a specific consistency by at least 12% (ASTM Standard C 494, 1999). At greater dosages, such as 0.8 per cent of cementitious materials, HRWRA could save water by up to 40% (ACI Committee 212.3R, 2016). High-range water reducers, chemical substances commercially known as super-plasticizers, can be used in the concrete mix to increase the workability of fresh concrete because fibre-reinforced self-compacting concrete requires making concrete with a lower w/b ratio than normal concrete, which concrete may have low workability.

Polycarboxylate based super-plasticizer (Flocrete SP90S) provided by DCP company-Sulaimani was used in the experimental program to improve workability of fresh concrete. Flocrete SP90S used is shown in Figure 3.6. Properties of the super-plasticizer used are shown in Table 3.8.

Figure 3.6 Flocrete SP90S

Table 3.8 Properties of super-plasticizer

Technical Properties @ 25°C	
Colour	Brown liquid
Freezing point	≈ -2°C
Specific gravity	1.16 ± 0.02
Chloride content: BS 5075	Nil
Air entrainment	Typically, less than 2% additional air is entrained above control mix at normal dosages
Complies with	ASTM C494, Type B, D and G

3.9 Polypropylene Fibres

The monofilament PP fibres (SikaFiber PPM-12) with a fraction of 0.1% and 0.2% by volume used in this work are shown in Figure 3.7. Bunsell et al., (2021) describe in depth the function of fibres in composites. Properties of the fiber used are shown in Table 3.9.

PP monofilament fibers, unlike steel, are unaffected by the weather, the alkaline environment found in concrete, or the presence of moisture. The concretes produced here should be long-lasting and strong because there is no corrosion or rusting (Gencel et al., 2011).

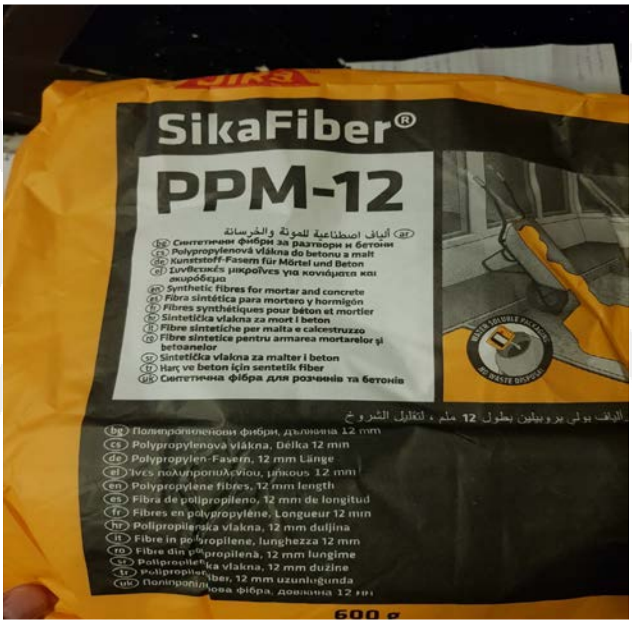


Figure 3.7 SikaFiber PPM-12

Table 3.9 Properties of SikaFiber PPM-12

Properties of used Polypropylene fiber	
Composition	100 % polypropylene
Appearance / Colour	Transparent fibres
Density	~0,91 g/cm^3
Dimensions	Diameter: 32 µm
	Length: 12 mm
Product declaration	Class 1a: Mono-filamented (EN 14889-2)
Melting point	~160 °C

3.10 Steel Fibres

The straight high strength micro steel fibers (SDS-2213) were used with a fraction of 0.1% and 0.2% by volume. Figure 3.8 shows steel fibers used in this research. Properties of the fiber used are shown in Table 3.10.

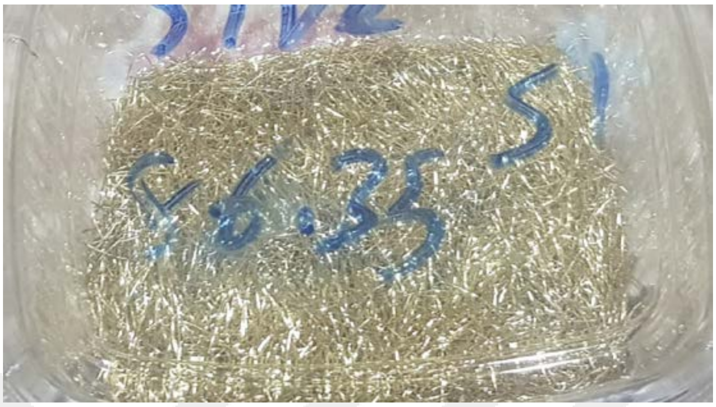


Figure 3.8 Steel fibers (SDS-2213)

Table 3.10 Properties of steel fiber

Properties of SDS-2213	
Appearance	Copper coated
Diameter	0.22mm
Length	13mm
L/D(length/diameter)	59
Tensile strength	>2850Mpa

3.11 Mix proportion design

3.11.1 Mix proportions

Mix design is the procedure of selecting suitable components for concrete and calculating the correct ratios of its elements to obtain a target workability. The advice (EFNARC, 2005) for designing a concrete mix of FRSCC was applied. The European Federation (EF) for Specialized Construction Chemicals, as well as Concrete Systems, is known as EFNARC. The EF of National Trade Associations, which represents manufacturers and users of specialized building materials, was established in March 1989. In this investigation, more than tril thirty mixes were tested with various water/binder ratios, flay ash, cement content, fine aggregates, coarse aggregates, and HRWRA in order to attain the desired acceptable workability for the FRSCC, which can be confirmed by EFNARC specification of self-compacting concrete properties. It should be noted that more superplasticizer was utilized in PPM FRSCC mixes to attain the desired workability. The selected mix proportions are shown in Table 3.11.

Table 3.11 Mix proportions of FRSCC mixes

Name	Cement	FLY	F.A	C.A	Water	Water after correction	SP	W/P	PF %	SF %
N	465.3	51.7	799.45	751.72	196.46	226.4	2.3	0.38	0	0
S1	465.3	51.7	799.45	751.72	196.46	226.4	2.3	0.38	0	0.1
S2	465.3	51.7	799.45	751.72	196.46	226.4	2.3	0.38	0	0.2
F1	465.3	51.7	799.45	751.72	196.46	226.4	3	0.38	0.1	0
F2	465.3	51.7	799.45	751.72	196.46	226.4	3.8	0.38	0.2	0

Note: All values are in Kg/m^3 except for fiber content, which is a volume fraction.

3.11.2 Mixing, Casting and Curing

The laboratory mixer with a 120-litre capacity shown in Figure 3.9 was used to prepare the concrete mixtures. Typically, the materials were added to the mixer in the order listed below: Initially, dry material, excluding the fibre, was mixed for one minute with coarse aggregates, fine aggregates, flay ash, and cement before adding 75% water (after adding 75% of the water the mixer frequently stopped for 2 min to avoid the formation of lumped concrete in the mixer.). The remaining water and SP were added after three minutes of mixing. Along with this the fibre was gently spread inside the mixer and the mixer was continuously rotated about 5 minutes. Finally, Concrete was poured directly into moulds without being compacted to prepare the specimens for testing the characteristics of hardened concrete.

For each concrete mixture, eighteen specimens were cast in 100 mm diameter and 200 mm height cylindrical moulds. Moreover, nine L-shape moulds were cast. The cylindrical was used for compressive strength and splitting tensile strength, while the L-shape was used for direct shear strength tests. All details are presented in Figure 3.9. After casting, the concrete specimens were covered with nylon sheets and kept in the laboratory at room temperature for 24 h for most of the samples. However, the samples containing polypropylene fibre were kept in the mould for 72 h for a 0.1% ratio and 120 h for 0.2 % before demolding to finish its setting time and become solid. The researcher noticed that if directly after 24 h they have been demolded, the sample directly breaks or comes apart, or it will lost most of the surface motors, as in Figure 3.10. this may be because of a high percentage of superplasticizer ratio.

Figure 3.9 View of mixer, moulds and specimens in the mold after casting.

Figure 3.10 demolding of PPM sample directly after 24 h

It is well known that proper concrete curing is necessary to give concrete the necessary compressive strength and create lasting concrete. Specimens during and after curing period are shown in Figure 3.11 and Figure 3.12 respectively.

Figure 3.11 Curing of specimens

Figure 3.12 specimens after curing

3.12 Exposure to Sulfate attack

No standard test method estimates how long concrete will last (durability) when exposed to chemicals. Nevertheless, specimens were exposed to a 5% magnesium sulfate solution (50,000 mg/L) for 30 days at room temperature, as done by (Amin et al., 2008). In addition, Control samples for each mix were kept in an ambient condition simultaneously in the laboratory for 30 days for comparison. After the exposure period, the specimens were taken out for compressive strength, Splitting tensile strength and shear strength. All details are presented in Figure 3.13, Figure 3.14 and Figure 3.15.

Figure 3.13 details of specimen's exposure to $MgSO_4$

Figure 3.14 specimens after 1 month of exposure to $MgSO_4$

Figure 3.15 each specimen after 1 month of exposure to $MgSO_4$

3.13 Exposure to Acid attack

No standard test method estimates how long concrete will last (durability) when exposed to chemical attacks. Nevertheless, specimens were exposed to a 5% sulfuric acid (H_2SO_4) solution 30 days at room temperature. In addition, Control samples for each mix were kept in an ambient condition simultaneously in the laboratory for 30 days for comparison. After the exposure period, the specimens were taken out for compressive strength, Splitting tensile strength and shear strength. All details are presented in Figure 3.16, Figure 3.17 and Figure 3.18.

Figure 3.16 details of specimen's exposure to H_2SO_4.

Figure 3.17 all specimens after 1 month exposure to H_2SO_4

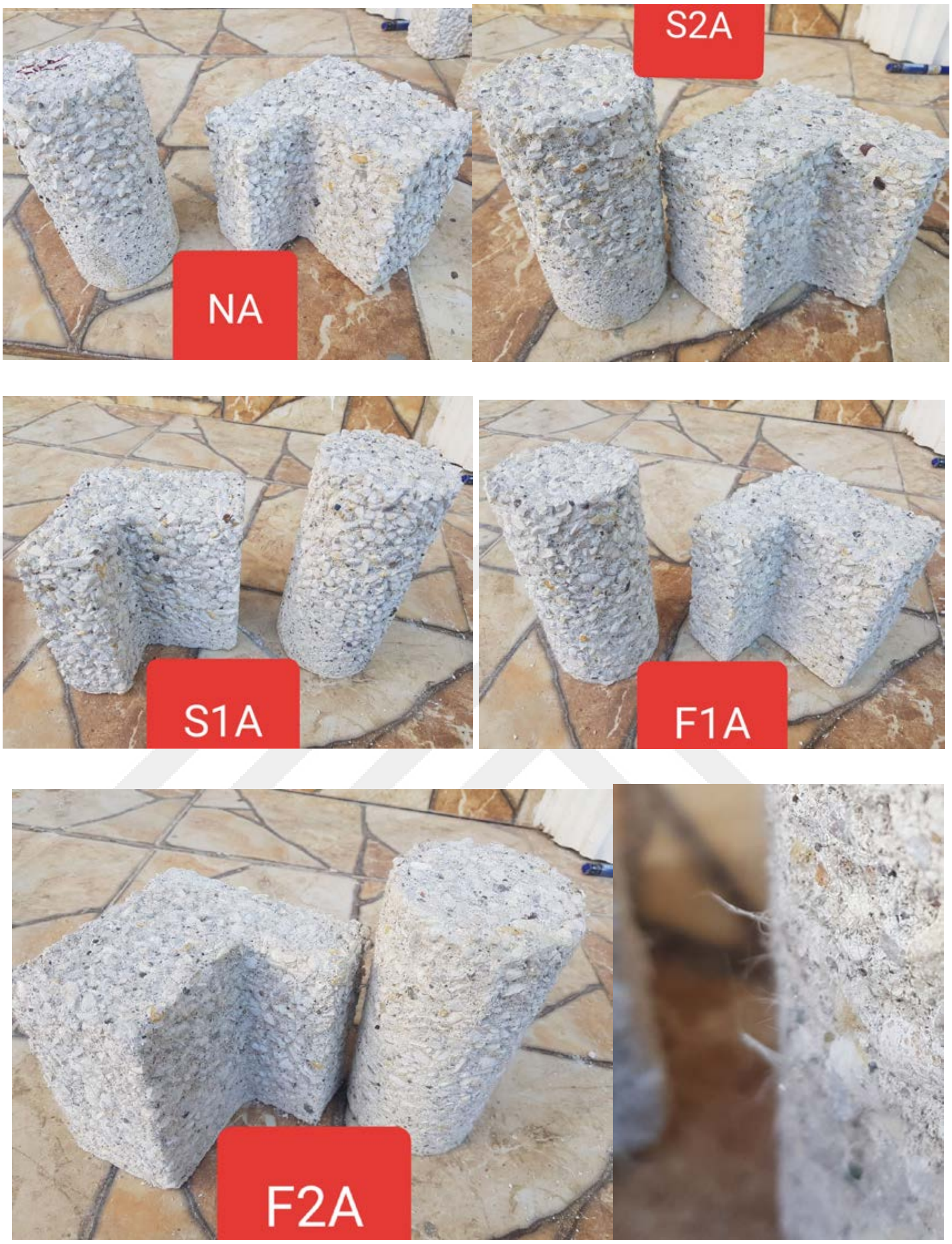


Figure 3.18 each specimen after 1 month exposure to H_2SO_4.

3.14 Experimental Tests

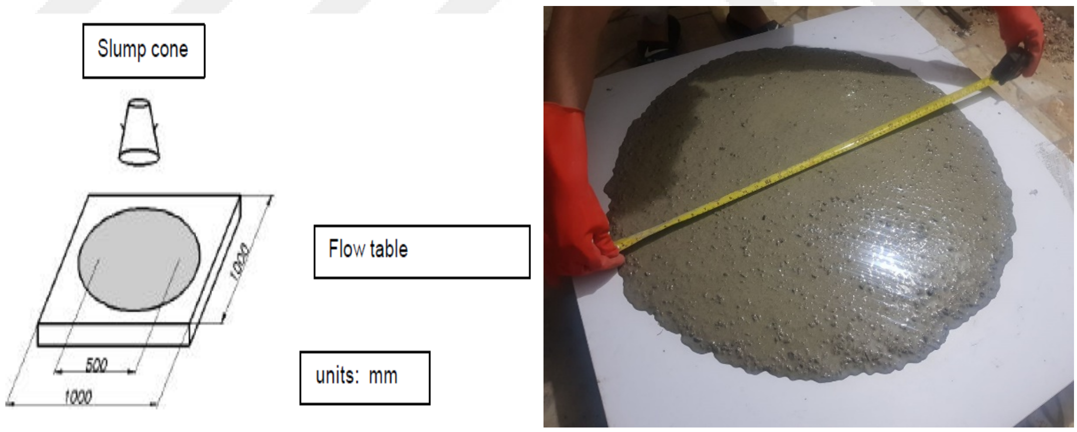
3.14.1 Fresh properties

There are numerous test procedures, including those employed by some authors, for assessing the workability and rheological behavior of concrete containing or without fiber reinforcement. EFNARC's SCC Committee standards were used to evaluate the mixtures' ability to self-compact.

Three types of workability tests, including slump flow tests, L box tests, and Visual stability index tests were performed on freshly mixed concrete. to assess the material's workability. The descriptions of these tests can be found in the following documents (EFNARC, 2005; ACI Committee 237, 2007).

3.14.1.1 Slump flow test and T50cm test

Slump flow without barriers is used to assess self-compacting concrete's horizontal free flow. It was produced for use in evaluating underwater concrete for the first time in Japan (Japan Society of Civil Engineers, 1992). The concrete circle's diameter serves as an indicator for its capacity to fill spaces (EFNARC, 2005).



(a) (b)

Figure 3.19 (a) Slump test apparatuses (EFNARC, 2005), (b) Slump experimental work.

This test is quick and easy to do. However, two persons are required to measure the T50 time. Although the size of the base plate makes it difficult to handle and level ground is necessary, it can be used on work sites. It is the most widely used test and provides a reliable evaluation of filling capacity. The concrete cannot move between the reinforcement without being blocked, although it may provide some insight into the concrete's resistance to segregation. Although it could be claimed that the entirely unrestricted flow does not reflect what occurs in concrete construction, the test can estimate how reliably ready-mixed concrete is supplied to a site (EFNARC, 2005). The test protocol used in this study was carried out in the order described below:

• A typical sample of 6 litres of concrete is required for the test.

• Moist the drooping cone's interior and base plate. Place the baseplate on a solid, level surface. Center the slump cone on the baseplate and firmly press it down.

• Scoop the contents into the cone. Do not tamp. However, in the place of it, use the trowel to strike off the concrete at the level of the top of the used cone. erase any extra concrete that may have accumulated near the cone's base.

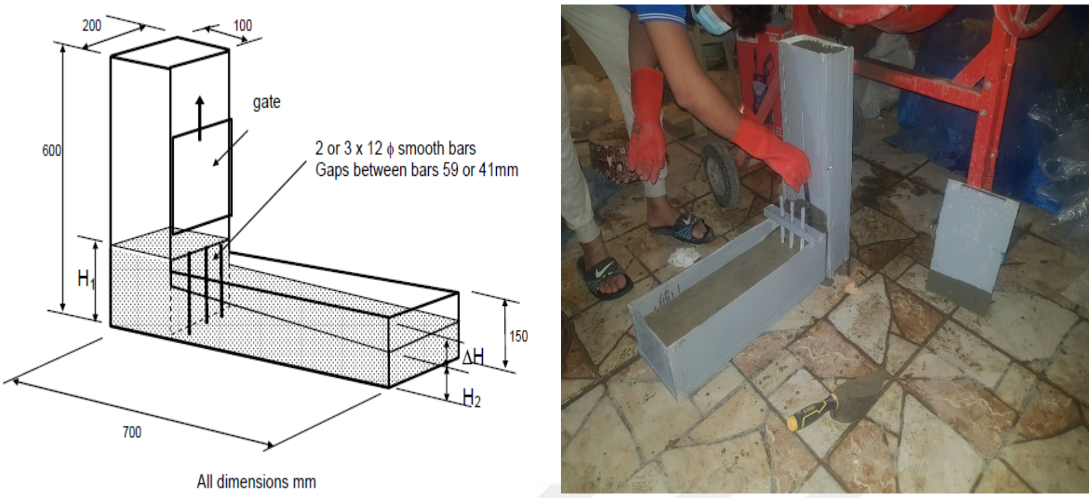
• Lift the cone up and let the concrete to pour out naturally. simultaneously begin the stopwatch, as well as record how time it takes for the concrete getting to the 500mm-wide circle. The T50 time is now.

Two perpendicular sides should be used to gauge final diameter of the concretes. Determine the average diameter between the two measurements. (This is slump flow in millimeters.)

3.14.1.2 L box test method

Petersson described this test based on a Japanese concept for underwater concrete (Petersson et al., 2004). The test evaluates the concrete's flow as well as its susceptibility to obstruction by reinforcing (EFNARC, 2005). The equipment is displayed in Figure 3.20.

The equipment consists of a rectangular box with an "L"-shaped cross-section, a vertical and horizontal section, and a moveable gate and vertical lengths of steel reinforcement bar installed in front of it. The gate is opened to permit concrete to go into the flat section when the vertical part has been filled with concrete (EFNARC, 2005). When the flow has ceased, the height of the residual concrete in the vertical part is exhibited as a percentage of the height of the concrete at the end border of the horizontal part. It displays the concrete's incline at rest (EFNARC, 2005). This is a sign of passing ability, or how tightly the bars can let concrete pass through them.



(a) (b)

Figure 3.20 (a) L-box test apparatuses (EFNARC, 2005), (b) experimental work.

The following sequential phases made up the test protocol used in this study:

• A typical sample of 14 litres of concrete is required for the test.

• Position the equipment level and on a solid surface. After making sure the sliding gate can move freely, close it. Mist the equipment's internal surfaces with water, then drain any extra.

• Place the concrete sample in the apparatus's vertical part. For one minute, let it stand.

After raising the sliding door and allowing the concrete to go out into the horizontal part, measure the lengths "H1" and "H2" once the concrete has stopped flowing.

3.14.1.3 Visual stability index

The slump cone test's resultant SCC slump cone flow spread is visually examined as part of the visual stability index (VSI) test (ACI Committee 237, 2007). The aim of this test procedure is to show the user a path to assess the stability of self-compacting concrete combinations (Daczko & Kurtz, 2001). The comparatively stable batches of same or identical self-compacting concrete combinations are assessed using this method.

Slump flow test following. The stability of the mixture is determined by visually seeing how the concrete spreads. In accordance with Table 3.12, a VSI score of 0, 1, 2, or 3 is assigned to the dispersion to describe mixture stability.

If the SCC combination has a VSI classification of 0 or 1, it is stable and should be appropriate for the intended purpose. A designer should make a change by adjusting the mixture to achieve stability if the VSI classification is 2 or 3, which denotes a potential for segregation (ACI Committee 237, 2007). The VSI rating can be subjective for the reason that it is specified visually. VSI rating is a great quality control tool for Self-compacting concrete production as a result.

Table 3.12 SCC mixes' visual stability index (VSI) rating (ACI Committee 237, 2007; Daczko & Kurtz, 2001)

Visual stability index value	Point of reference
0 = very stable	In slump flow spread, there is no evidence of segregation.
1= stable	No aggregate pile or mortar halo was present inside the slump flow spread.
2 = unstable	A little aggregate pile or mortar halo (less than 10 mm) inside the slump flow dispersion
3 = very unstable	A huge aggregate pile in the middle of the concrete spread, a significant mortar halo (>10 mm) around it, or both are indications that the material is clearly separating.

Using the standards indicated in Figure 3.21, the VSI values were assigned to the concrete spread (ASTM standard C1611, 2005).

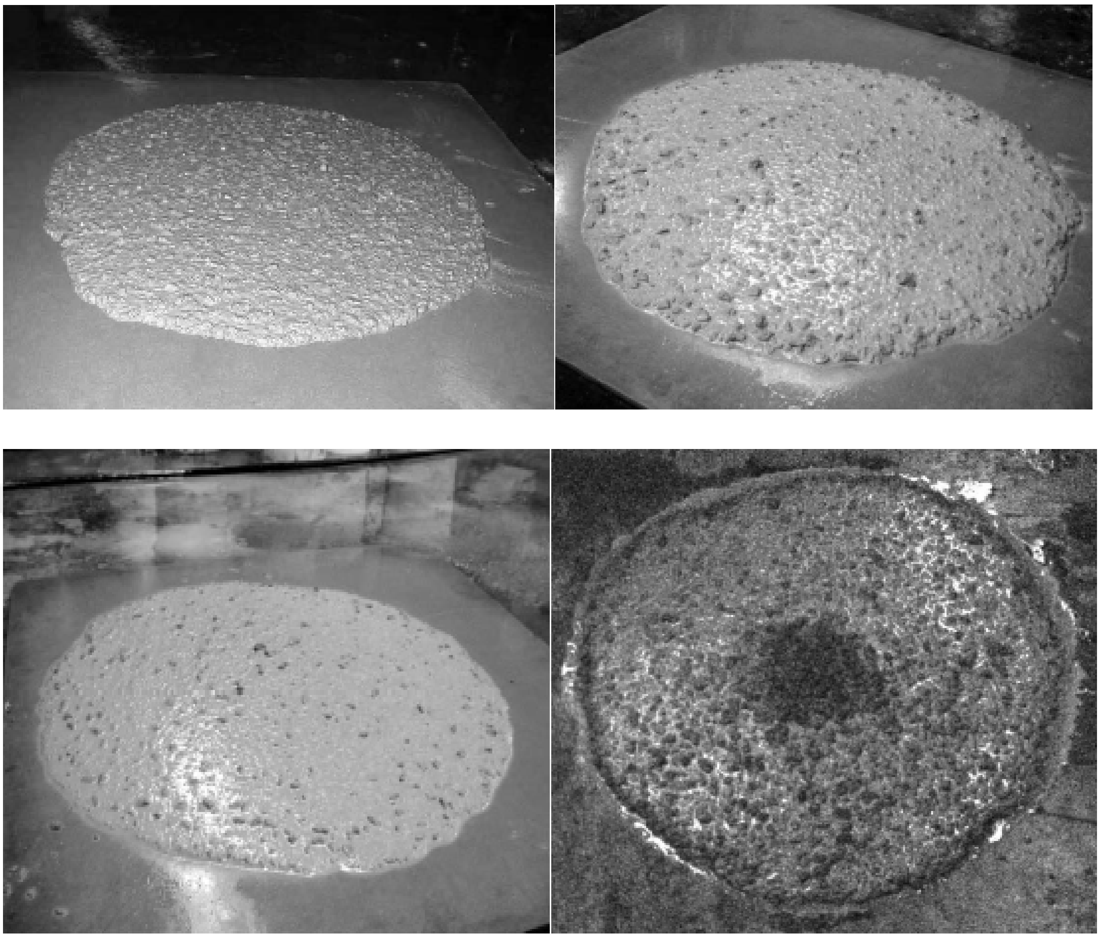


Figure 3.21 Visual Stability Index, (a) VSI = 0, (b) VSI = 1, (c) VSI = 2, (d) VSI = 3 (ASTM standard C1611, 2005).

3.14.2 Mechanical properties

3.14.2.1 Compressive strength (ASTM C39)

The measurement of concrete compressive strength was performed on the standard 100*200 mm cylinders using a digital compression machine of 3000 kN capacity showen in Figure 3.22.a of ALFA model-Turkey, according to ASTM C39 (2012). 3 days before testing, the loading rate was (0.15 MPa/sec) as per the ASTM C39 specification limit [0.15-0.35] MPa/sec. Figure 3.22.b shows one cylinder ready for testing. The average result of three tested cylinders was determined at the end period of exposure.

(a) (b)

Figure 3.22 (a) testing machine, (b) test cylinder specimen for compressive strength.

3.14.2.2 Splitting tensile strength (ASTM C496)

The measurement of concrete splitting tensile strength was performed on the 100*200 mm cylinders using the same machine utilized for compression test using loading rate of 60 kN/min as proposed (50 to 100 kN)/min, according to ASTM C496 (2011). Figure 3.23 shows one cylinder before and after for testing. The average result of three tested cylinders was determined at the end period of exposure. According to ASTM C496 splitting tensile strength is calculated based on the following equation:

$$T = \frac{2P}{\pi d l} \tag{3.1}$$

Where:

P : testing machine’s maximum applied load (N)

T : splitting tensile strength (MPa)

d : diameter (mm).

l : length (mm)

Figure 3.23 Splitting tensile strength test.

3.14.2.3 Direct shear strength

The shear tests were carried out using the method proposed by (Bairagi & Modhera, 2001), as the model was subjected to pure shear force. Several procedures are available to explore concrete's shear strength. However, they appear to be not practical due to their deficiencies and divergence as samples have two shear planes as well as practically; it is not possible that two plane collapses at the exact moment for a sample never occurred (Kurup & Senthil Kumar, 2017). A similar approach has been used by numerous researchers to examine the shear characteristics of concrete (Badagha & Modhera, 2015; Baruah & Talukdar, 2007; Daczko & Kurtz, 2001; Kurup & Senthil Kumar, 2017; Maroliya, 2012; Senthil Kumar & Baskar, 2015; Sivaraja & Kandasamy, 2011; Vijapur & Tontanal, 2013). Two plates (150 mm by 85 mm by 10 mm) as well as (150 mm by 110 mm by 10 mm) and two steel bars are needed to execute the test on a compression machine (diameter 12 mm with 22 mm). A hardwood block of 150 mm in height, 90 mm in width, and 60 mm in depth can be placed inside a 150 mm cube to make the L-shaped specimen utilized in this project. The plates are set up on the L-shaped specimen's top so that the plate measuring 150 x 85 x 10 mm sits on the side with the solid portion measuring 150 x 150 x 90 mm. The plate was positioned adjacent to the 22 mm size bar. As illustrated in Figure 3.24 and Figure 3.25, a second bar with a diameter of 12 mm was positioned on the bottom plate, and a second plate measuring 150 x 110 x 10 was positioned on the two bars. The model was tested using compression testing equipment with a 3000 kN capacity and the loading rate of the machine is kept below 140 $kg/cm^2/min$ (exactly 1 kN/s used) to obtain the shear failure precisely and shear strength value more accurately (Kurup & Senthil Kumar, 2017).

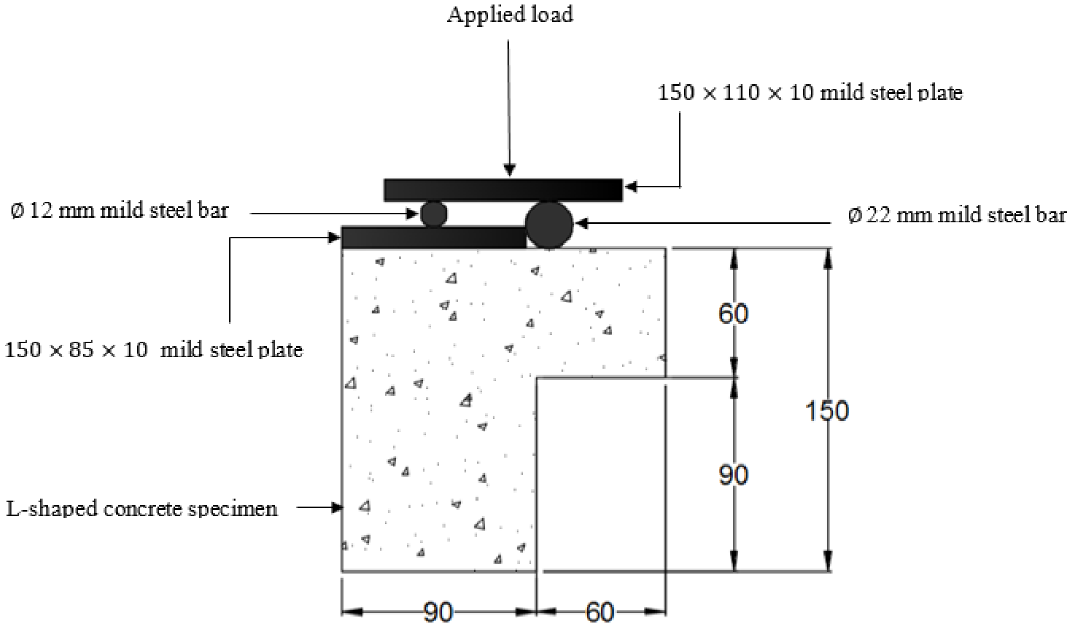


Figure 3.24 Schematic diagram of testing arrangement.

Figure 3.25 Testing arrangement and tested samples.

The shear strength has been examined in this investigation at room temperature. At the end of the exposure time, the result obtained from three L-shape samples was computed. Moreover, using the formula, the shear stress just at the segment was determined.

$$\tau = \frac{Pu}{b \times d} \qquad (3.2)$$

Where:

Pu: is the maximum applied load at failure of the specimen

τ : is shear stress

d with b are the size dimensions of the shear plane.

CHAPTER IV

TEST RESULTS AND DISCUSSION

4.1 Introduction

This section covers the findings about the influence of the two types of fibers under discussion on the fresh and hardened properties of SCC. The properties studied are Slump cone & T50, L-box, visual stability index, compressive strength, split tensile strength as well as shear strength.

4.2 Test results and discussions

The findings of this study are interesting and may inspire additional research on the nature of SCC including steel and polypropylene fiber. The sections that follow provide test results for each property considered in this study as well as a detailed discussion of the findings.

4.2.1 Slump and T50 test results

Slump flow test results for different mixes of FRSCC are presented in Table 4.1. Figure 4.1 shows the fresh SCC slump flow value variation with Steel and polypropylene fibre fraction volume. According to the findings, the polypropylene fibre content has a significant impact on the workability of FRSCC. Slump flow for control samples was 800 mm and decreased proportionally with increasing polypropylene fibre content down to 710 and 620 mm. This decrease in workability is expected since adding fibres to a concrete matrix influence the fresh state characteristic of the FRSCC due to both fibres surface area which is large, which needs a higher volume of fluid phase to be appropriately covered and lubricated, and the great interlocking among the fibres as well as between the fibres and aggregates and inter-particle friction. The enormous impact of polypropylene fibre on slump flow is very well known in the literature, like the work done by Widodo, (2012). For Steel fibre samples, slump flow was equal to the control sample, which is 800 mm. This stability in workability in steel fibre cases is expected since our steel fibre ratio is minimal as well as they are the straight and smooth type which will not restrict the flow of concrete. However, based on literature like the one done by Abbas, (2013), in general, steel fibres in large volumes and different shapes will cause a drop in slump but never drop slump as polypropylene fibres do.

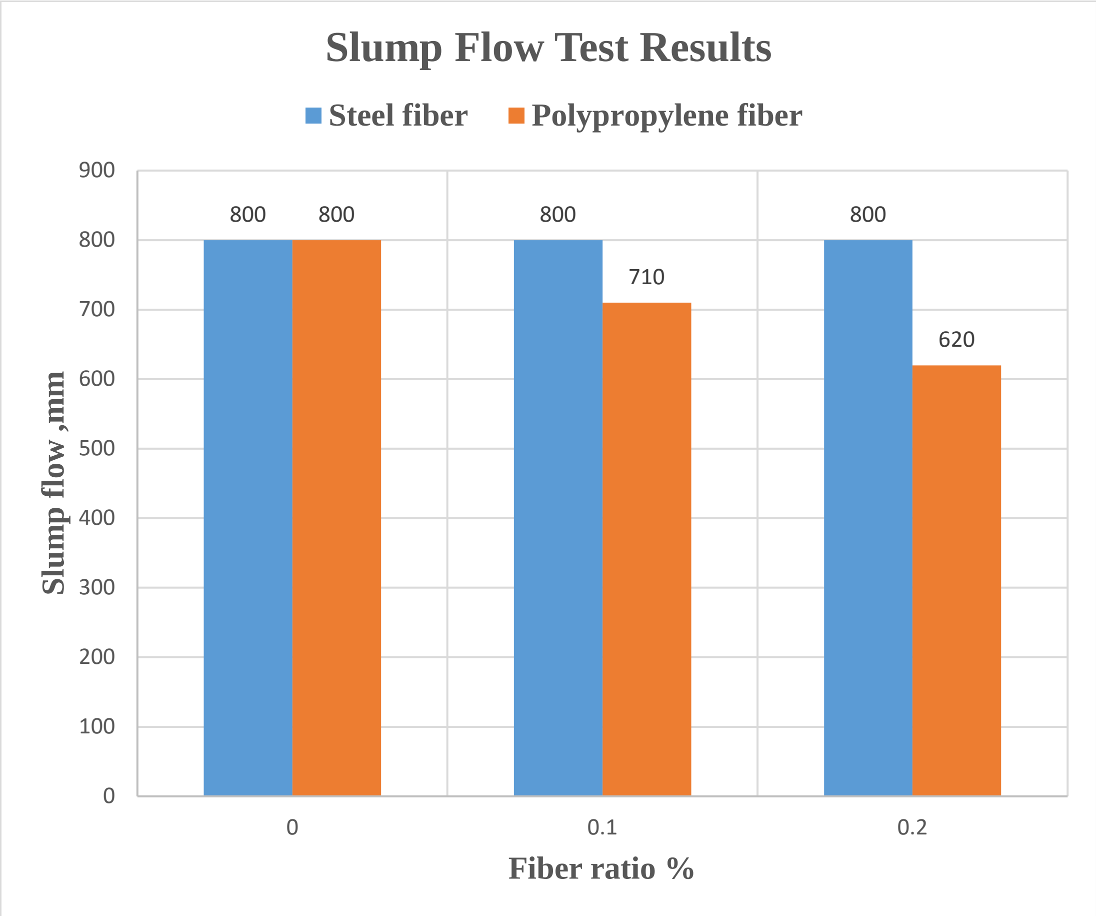


Figure 4.1 Slump flow change versus fiber content

T50 flow test results for different mixes of FRSCC are presented in Table 4.1. Figure 4.2 shows the fresh SCC T50 time values for Steel and polypropylene fibre volume fractions. T50 flow time for control samples was 2.02 sect and decreased proportionally with increasing polypropylene fibre content down to 1.71 and 1.33 sec. This drop in T50 flow time is due to increased superplasticizer dosage to improve workability because polypropylene fibre generally increases viscosity and decreases workability (Widodo, 2012), as known in literature. So, for SCC superplasticizer dosage is essential to get workable concrete. However, steel fibre samples did not significantly affect T50 flow time (which increased to 2.11 and 2.16 sec) because the utilized fibre volume fraction is very small. More extensive volume and different shapes must be used to see the notable effect of steel fibre.

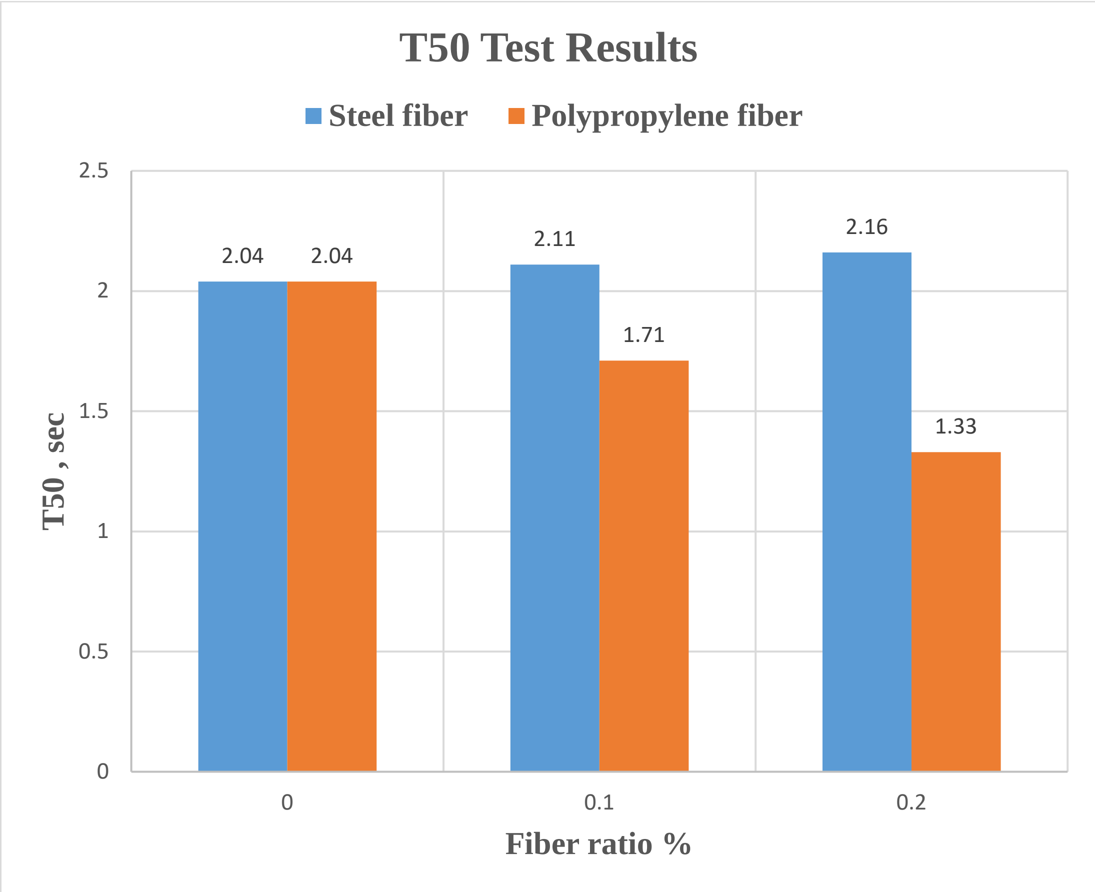


Figure 4.2 T50 time change versus fiber content

4.2.2 L-box test results

Table 4.1 shows the test results of different concrete mixes' L-box (H2/H1 ratio). Figure 4.3 shows the H2/H1 ratio of L-box (mix without fibre, with polypropylene and steel fibres) variation with fibre volume. For the control mix, H2/H1 is 0.9. A small (ineffective) reduction in the H2/H1 ratio is observed with increasing steel fibre to 0.2%, and this ineffectiveness is due to what we mentioned in the previous part.

For polypropylene fibre, H2/H1 ratio increased with adding it. This opposite behaviour (opposite because normally PPF restrict the flow) is due to the increasing superplasticizer ratio to overcome workability problems caused by polypropylene fibre.

Figure 4.3 L-box ratio change versus fiber content.

4.2.3 Visual stability index results

The appearance of SCC mixture slumps and VSI results for different mixes of FRSCC are presented in Figure 4.4 and Table 4.1 respectively. The Self-compacting concrete mixture with (0.1% F1) polypropylene was greatly stable with a visual stability index value of ‘0’ for no trace of segregation and bleeding. However, the control and steel fibre (0.1% S1 and 0.2% S2) mixtures of self-compacting concrete were stable, achieving a visual stability index value of ‘1’ for no trace of segregation but they have slight bleeding. The visual stability index values of these two concrete mixtures show excellent segregation resistance. However, the self-compacting concrete mix with 0.2% polypropylene presented slight bleeding and a mortar halo (>10 mm). This may be because of an excess amount of superplasticizer. This concrete was classified as ‘unstable’ with a VSI value of ‘2’, suggesting that it had poor segregation resistance.

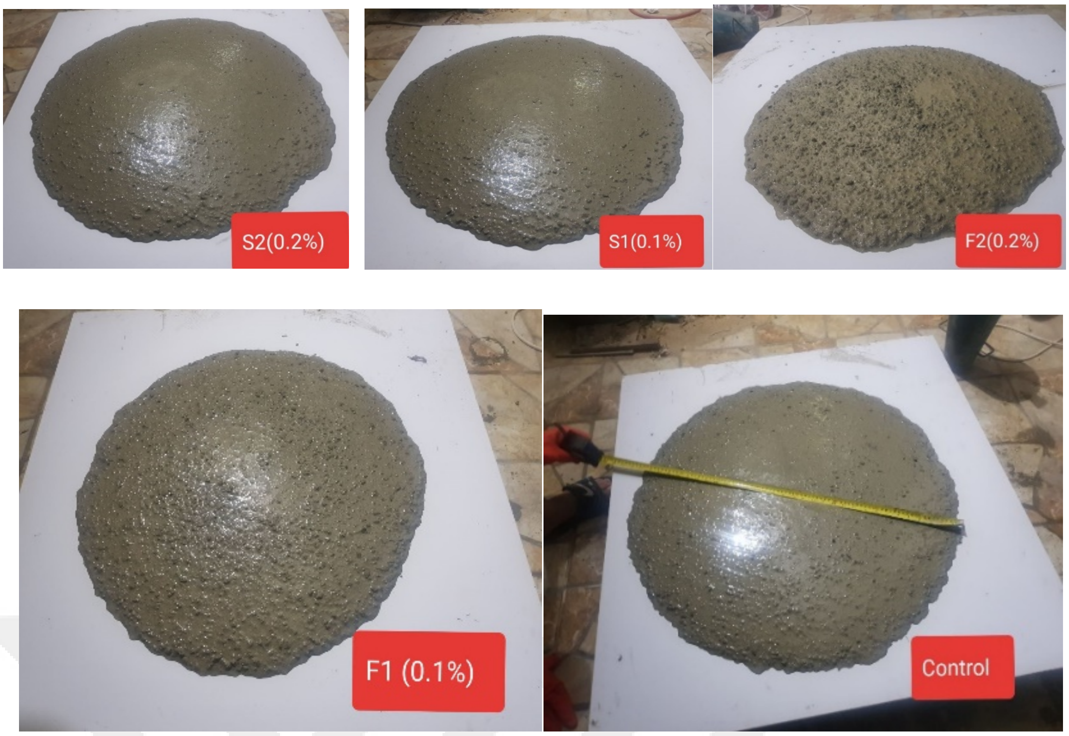


Figure 4.4 Slump flow expermint

Table 4.1 Results of concrete workability test

Sample	Slump flow (mm)	T50 time (sec)	L-box (ratio)	Visual Stability Index
N	800	2.04	0.95	1
S1	800	2.11	0.93	1
S2	800	2.16	0.9	1
F1	710	1.71	0.96	0
F2	620	1.33	0.98	2

These observations may be important for practical applications of using polypropylene fiber and steel fiber in concrete. According to the European federations: **(BIBM, CEMBUREAU, ERMCO, EFCA, EFNARC 2005**), firstly, for the slump flow class SF1, slump flow is between 550 to 650 mm, for the slump flow class SF2, slump flow is between than 660 to 750 mm, and for the slump flow class SF3, slump flow is between than 760 to 850 mm. Secondly, for the viscosity class VS1/VF1, T_{50} time is smaller than 2 sec, and for the viscosity class VS2/VF2, T_{50} time is larger than 2 sec. Thirdly, for Passing ability class PA2, H2/H1 ratio should be larger than 0.8 with three bar. Finally, If the results obtained in this study are compared with these limits of workability of self-compacting concrete, control and steel fiber mixes are within the limits of viscosity class VS1/VF1, slump flow class of SF3, and passing ability of PA2. For both polypropylene fiber mixes passing ability class is PA2, and viscosity class is VS2/VF2. however, for PPF ratio of (0.1%) slump flow class is SF2, but for volume fraction of (0.2%) slump flow class is SF1.

4.2.4 Compressive strength

Compressive strength test results are shown in Table 4.2 for each mix. Figure 4.5 and Figure 4.6 shows the behaviour of FRSCC compression with various environment condition and difference fraction volume.

According to the results, it can be deduced that inserting steel fibre into SCC increases compressive strength for all mixes along with increasing the fibre volume fractions. However, it is normal in the case of air environment that the first steel ratio (0.1%) decreased compressive strength slightly that is because of that fact steel fibre ratios lower than 0.3% volume ratio, the compressive strength improvement may or may not appear clearly. For structural purposes normally more than (0.3%) SF volume fraction used (Siddique, 2019). However, the steel ratio of 0.2% increased compressive strength by approximately 3%, as shown in Figure 4.5.

In the sulfated environment case, $MgSO_4$ decreased the compressive strength of samples by 11.66, 10.06 and 11.84% for the fibre volume fraction of 0, 0.1 and 0.2%, respectively, shown in Figure 4.5. However, in the sulfate case also, steel fibre helped to enhance compressive strength with respect to the control sample by 1% and 2.66% for fibre volume of 0.1 and 0.2%, respectively—this improvement in sulfate media by steel fibre was also reported by AHMAD et al., (2021).

In the Acid environment case, H_2SO_4 decreased the compressive strength of samples by 43.67, 31.5 and 34.6% for the fibre volume fraction of 0, 0.1 and 0.2%, respectively. However, in the acid case also, steel fibre helped to enhance compressive strength with respect to the control sample by 20.59 and 19.44% for fibre volume of 0.1 and 0.2%, respectively, shown in Figure 4.5. This improvement in acid media by steel fibre also reported by Kos et al., (2022) and Yu et al., (2021).

The confinement influence of fibres that increases the stiffness of concrete, the capabilities of steel fibres to increase cohesion between the components of the concrete mixture as well as providing extra strength with resistance to concrete under the influence of applied loads can all be attributed to the improvement in compressive strength with the addition of steel fibre in these media.

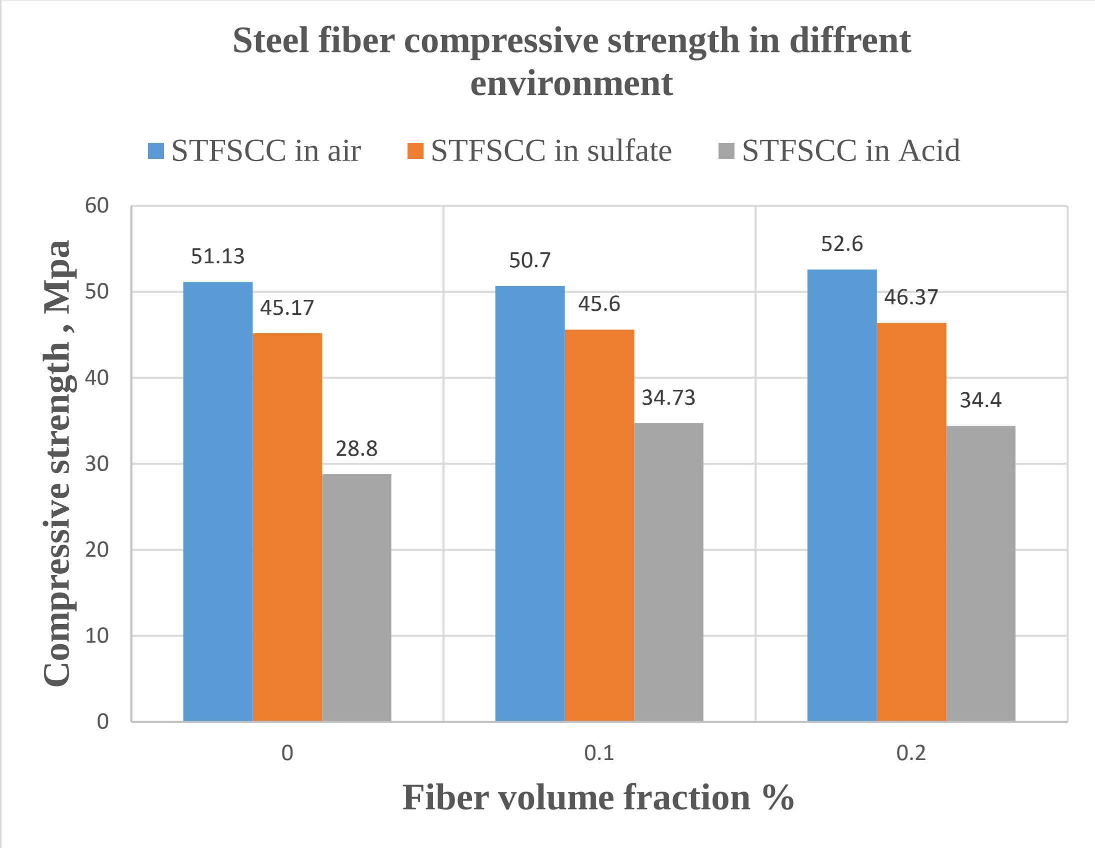


Figure 4.5 Variation in compressive strength steel reinforced self-compacting concrete with different environment and fiber fraction volume.

For polypropylene FSCC Figure 4.6 shows that using polypropylene fibre with a volume fraction of 0.1 and 0.2% did not improve compressive strength. Generally, polypropylene fibres did not have a significant enhancement for compressive strength compared to steel fibres, as mentioned in literature as the one reported by AHMAD et al. (2021).however, it has been reported is a slight (small) increase in compressive strength for lower ratios of polypropylene fibre as reported by AHMAD et al., (2021); Gencel et al., (2011); Widodo, (2012).in this research case, we can conclude that our primary reason for decreasing compressive strength in air and sulfate case is due to excessive superplasticizer content which can lead to dropping in compressive strength as reported by Benaicha et al., (2019). But is important to mention that even with excess superplasticizer we cannot judge on long term effect of PPF under sulfate attack. because concrete large degradation appears in long term exposure to sulfate generally, so further studies needed to investigated the PPF effect on concrete in long term exposure to sulfate attack.

In the Acid environment case, H_2SO_4 decreased the compressive strength of samples by 43.67, 30.29 and 32.59% for the fibre volume fraction of 0, 0.1 and 0.2%, respectively. However, the exciting part of polypropylene fibre is its effect on the acid environment. Which is shown in Figure 4.6. the compressive strength was enhanced by 17.47 and 10.17% for a fibre ratio of 0.1 and 0.2%, respectively, compared to the control sample, which does not contain fibre. Also, in the acid case, the enhancement of polypropylene fibre can be near or equal to steel fibre in terms of resistance to acid attack. This conclusion was also reported by Kos et al., (2022).

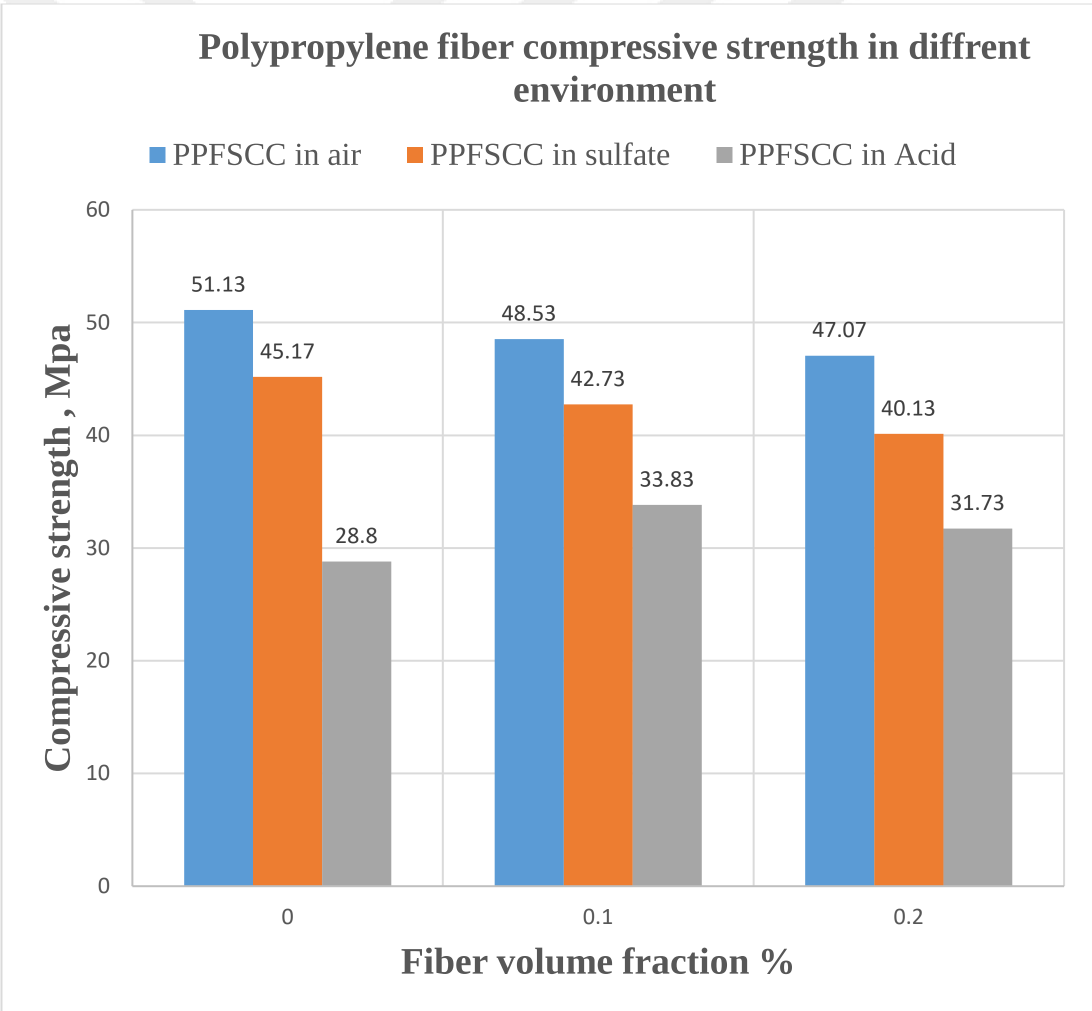


Figure 4.6 Variation in compressive strength polypropylene reinforced self-compacting concrete with different environment and fiber fraction volume.

Table 4.2 Compressive strength results of mixes (MPa).

Control	Compressive	Sulfate	Compressive	Acid	Compressive
N	51.13	NS	45.17	NA	28.8
S1	50.7	S1S	45.6	S1A	34.73
S2	52.6	S2S	46.37	S2A	34.4
F1	48.53	F1S	42.73	F1A	33.83
F2	47.07	F2S	40.13	F2A	31.73

Figure 4.7 Failure modes of FRSCC cylinder samples after compressive test.

4.2.5 **Split tensile strength**

Table 4.3 displays the differences in tensile strength for various concrete mixtures, and Figure 4.8 and Figure 4.9 illustrates the split tensile behaviour of SCC under various environmental conditions, fibre types, and fraction volumes. When the concrete fractured, the fiberless concrete suddenly split out. Due to the fibres' high dispersions, which led to a superior bridging activity in the concrete matrix. As illustrated in Figure 4.10, the FRSCC fiber concrete started to break but did not completely split apart.

Generally, Steel fibres showed improvement in tensile strength. In the air environment case, steel fibre helped increase the splitting tensile strength of samples increased by approximately 4 and 8% for the fibre volume fraction of 0.1 and 0.2%, respectively, shown in Figure 4.8. This improvement of splitting tensile strength in the air (control) media by steel fibre was also reported by AHMAD et al., (2021).

In the sulfate environment case, $MgSO_4$ decreased the splitting tensile strength of samples by 22.38, 19.15 and 8.18% for the fibre volume fraction of 0, 0.1 and 0.2%, respectively shown in Figure 4.8. Haufe & Vollpracht, (2019) reported that concrete tensile strength decreased when exposed to sulfate attack. They clarified that this drop in tensile strength was helped to the production of gypsum and ettringite. However, in the sulfate case also, steel fibre helped to enhance splitting tensile strength with respect to the control sample by 8.19% and 27.76% for fibre volume of 0.1 and 0.2%, respectively. This improvement in splitting tensile strength in sulfate media by steel fibre was also reported by AHMAD et al., (2021).

In the Acid environment case, H_2SO_4 decreased the splitting tensile strength of samples by 12.16, 9.84 and 11.51% for the fibre volume fraction of 0, 0.1 and 0.2%, respectively. However, in the acid case also, steel fibre helped to enhance splitting tensile strength with respect to the control sample by 6.6 and 8.81% for fibre volume of 0.1 and 0.2%, respectively, shown in Figure 4.8. This improvement of splitting tensile strength in acid media by steel fibre was also reported by Niu & Wang, (2013), which concluded that, generally, suitable SF mixing could reduce the dropping of splitting tensile strength.

The enhancement in splitting tensile strength with the addition of steel fibre in these media is due to these factors: 1-the connection between the components of the mixture is strengthened, 2-delaying the occurrence of cracks and narrowing their width. As linking bridges in the crack area, 3-the fibres also play a vital part in the section's ability to increase bearing and produce additional resistance.

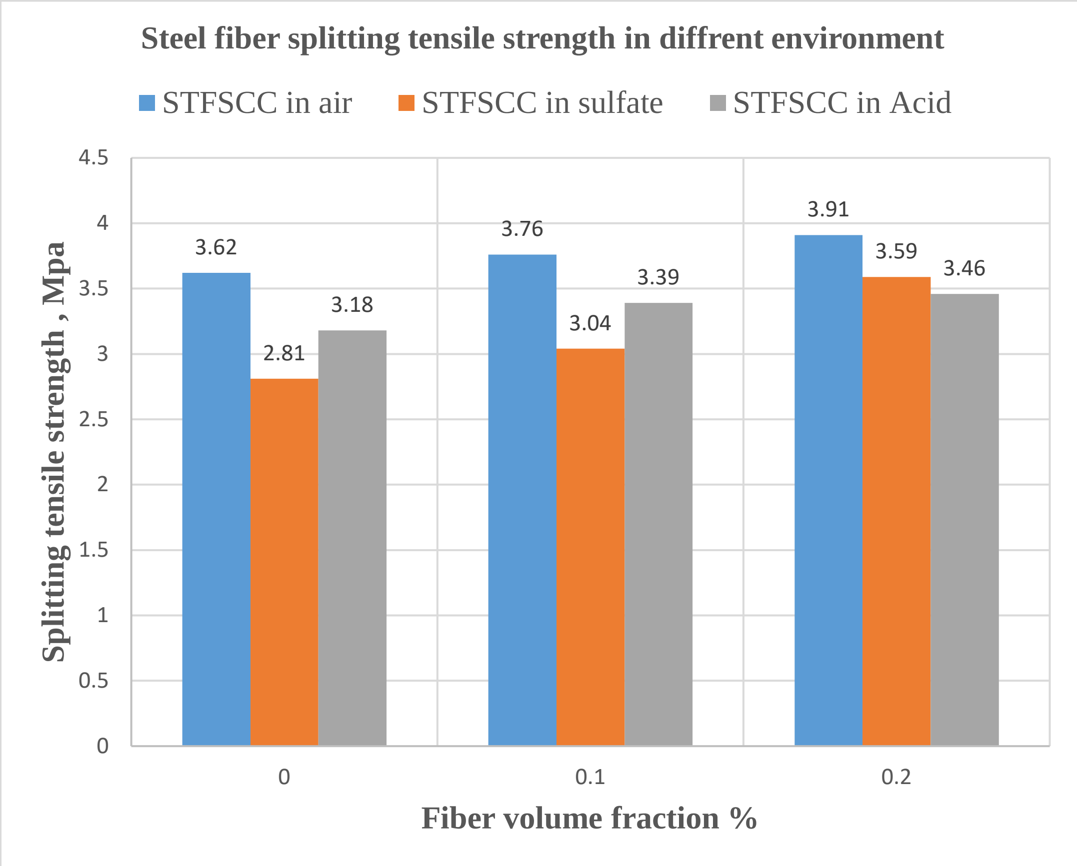


Figure 4.8 Variation in split tensile strength steel reinforced self-compacting concrete with different environment and fiber fraction volume.

For polypropylene FSCC Figure 4.9 shows that using polypropylene fibre has a slight improvement splitting tensile strength. Generally, polypropylene fibres did not have a high enhancement for splitting tensile strength compared to steel fibres, as mentioned in literature like the one reported by AHMAD et al., (2021). however, a increase in splitting tensile strength for of polypropylene fibre has been reported, as concluded by Widodo, (2012). in our case, we can conclude that our primary reason for decreasing splitting tensile strength in all environment cases when fibre volume is equal to 0.1% is due to excessive superplasticizer content, which can lead to a drop in compressive strength, as reported by Benaicha et al., (2019). However, besides the negative effect of excessive superplasticizer, we can see notable enhancement happen in splitting tensile strength when the polypropylene fibre volume ratio increased to 0.2%. This returns to the fact that, in most cases except in acid case, fibres act as a bridge between microcracks and prevent them from spreading. Transferring the tensile stress to the fibres can stop the microcracks from growing and greatly increase the concrete's splitting tensile strength. (Gencel et al., 2011).

In the air environment case, PPF helped increase the splitting tensile strength of samples increased with respect to control sample by approximately 3.59% for the fibre volume fraction of 0.2%, shown in Figure 4.9. In the sulfate environment case, $MgSO_4$ decreased the splitting tensile strength of samples by 22.38, 10.83 and 19.2% for the fibre volume fraction of 0, 0.1 and 0.2%, respectively shown in Figure 4.5. However, in the sulfate case also, PPF helped to enhance splitting tensile strength with respect to the control sample by 7.83% for fibre volume of 0.2%, respectively. In the Acid environment case, H_2SO_4 decreased the splitting tensile strength of samples by 12.16, 7.64 and 17.6% for the fibre volume fraction of 0, 0.1 and 0.2%, respectively. However, in the acid case PPF did not help to enhance splitting tensile strength with respect to the control sample, shown in Figure 4.9.

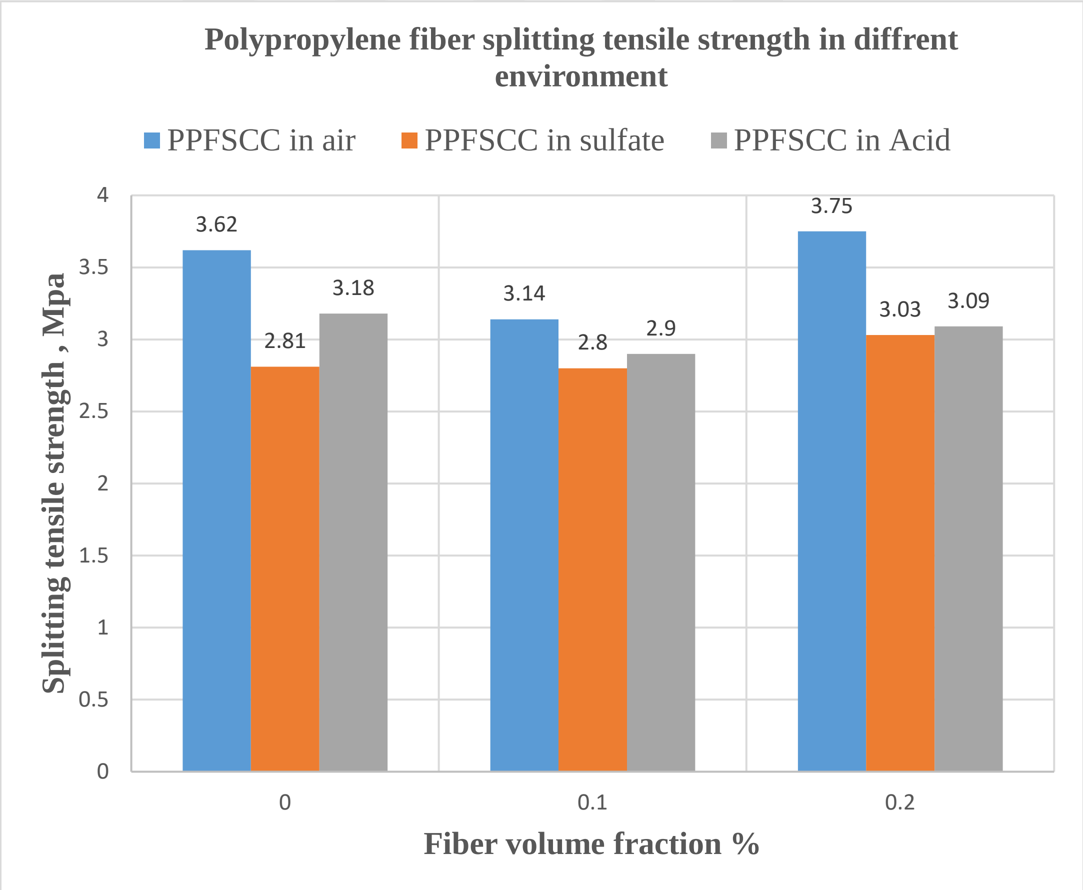


Figure 4.9 Variation in split tensile strength polypropylene reinforced self-compacting concrete with different environment and fiber fraction volume.

Table 4.3 splitting strength results of mixes (MPa).

Control	Splitting TS	Sulfate	Splitting TS	Acid	Splitting TS
N	3.62	NS	2.81	NA	3.18
S1	3.76	S1S	3.04	S1A	3.39
S2	3.91	S2S	3.59	S2A	3.46
F1	3.14	F1S	2.8	F1A	2.9
F2	3.75	F2S	3.03	F2A	3.09

Figure 4.10 Failure modes of FRSCC cylinder samples after splitting tensile test.

4.2.6 Shear strength

Table 4.4 displays the differences in shear strength for various concrete mixtures, and Figure 4.11 and Figure 4.12 illustrates the shear strength behaviour of SCC under various environmental conditions, fibre types, and fraction volumes. When the concrete fractured, the fiberless concrete suddenly split out due to the fibres' high dispersions, which led to a superior bridging activity in the concrete matrix. As illustrated in Figure 4.13, most of FRSCC fibre concrete started to break but did not completely split apart.

Generally, Steel fibres showed improvement in shear strength. In the air environment case, steel fibre helped enhance the shear strength of samples by approximately 24.61 and 43.85% for the fibre volume fraction of 0.1 and 0.2%, respectively, shown in Figure 4.11. This improvement of shear strength in normal environment media by steel fibre was also reported by Barr, (1987), Narayanan & Darwish, (1987), Noghabai, (2000) and Oh et al., (1999).

In the sulfate environment case, $MgSO_4$ increased the shear strength of samples, as shown in Figure 4.11. This may be happened in early sulfate exposing age due to the fact that since shear friction should be increased if normal tension and roughness increase, concrete's response to shear is definitely different from that to tensile stress (Zhang et al., 2020). Brueckner et al., (2012) evaluated the impact of thaumasite sulfate attack on the skin friction at the concrete interface. They discovered that the form of thaumasite at the contact close to concrete was the primary cause of the increased skin friction. According to their investigation, the local expanding pressure brought on by the sulfate product thaumasite was the reason for this improvement. This pressure has the fantastic ability to mobilize the friction at these locations by acting as a normal stress perpendicular to the shear plane (interface).

Additionally, this chemical process increased the interface's roughness, which increased the friction force along such failure spots (Zhang et al., 2020). Recently, Pastor et al., (2018) reported similar findings in their research on skin friction modification owing to sulfate attack (Brueckner et al., 2012). Rarely published are the shear failure mode and failure criteria of sulfate-attacked concrete under direct shearing (Zhang et al., 2020).

However, in the sulfate case also, steel fibre helped to enhance shear strength with respect to the control sample by 8.72% and 2.03% for fibre volume of 0.1 and 0.2%, respectively. This improvement of shear strength in sulfate media by steel fibre was also reported by Taqi et al., (2021), who concluded that steel fibres could enhance the performance of the beams for shear even in a harsh environment.

In the Acid environment case, H_2SO_4 decreased the shear strength of samples by 21.7, 7.9 and 14.46% for the fibre volume fraction of 0, 0.1 and 0.2% respectively. However, in the acid case also, steel fibre helped increase shear strength with respect to the control sample by 46.57 and 57.14% for fibre volume of 0.1 and 0.2%, respectively, shown in Figure 4.11. This improvement of shear strength in acid media by steel fibre was also reported by Badagha & Modhera, (2015).

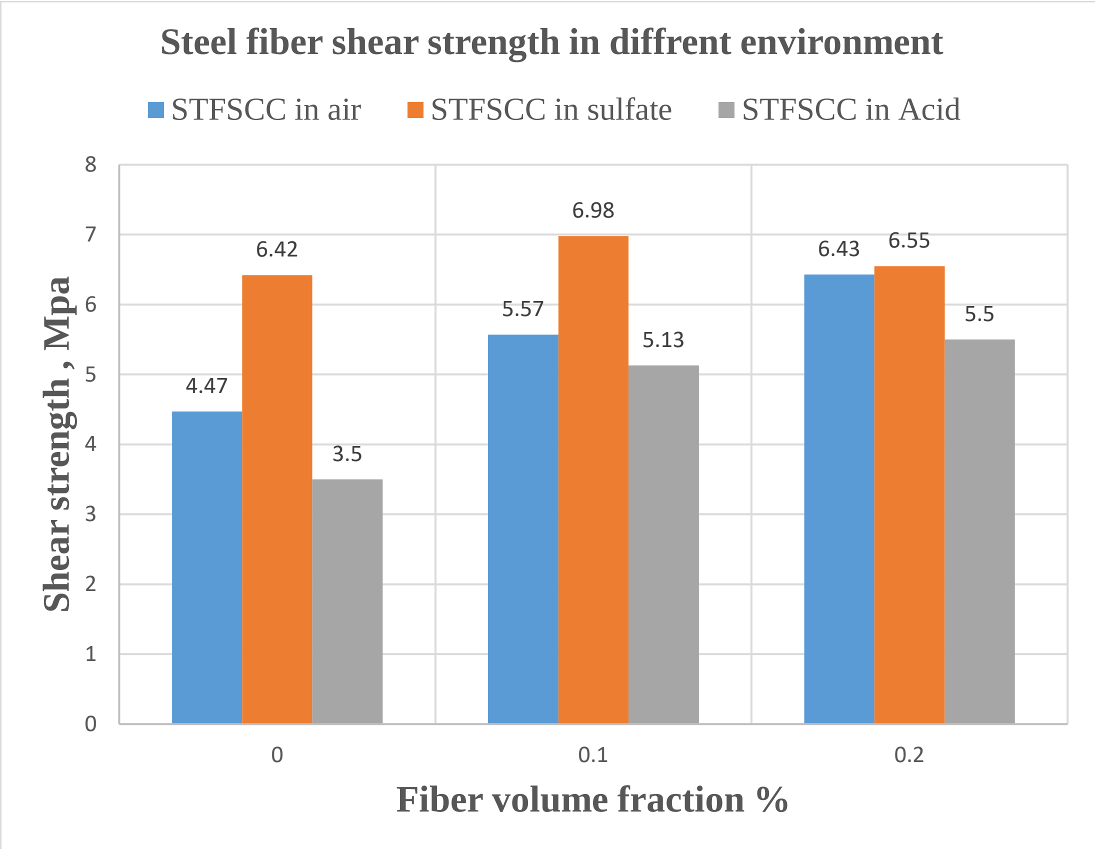


Figure 4.11 Variation in shear strength steel reinforced self-compacting concrete with different environment and fiber fraction volume.

Generally, polypropylene fibres showed improvement in shear strength. In the air environment case, polypropylene fibre helped enhance the shear strength of samples by approximately 27.96% for a fibre volume fraction of 0.1, shown in Figure 4.12. However, for a fibre volume fraction of 0.2% in the air case, the shear strength decreased by 4.03% with respect to the control sample. This slight drop in shear strength may be because of the instability of the mix or excess superplasticizer. This improvement of shear strength in normal environment media by polypropylene fibre was also reported by Ahmed et al., (2006).

In the sulfate environment case, $MgSO_4$ increased the shear strength of samples, as shown in Figure 4.12. This may be happened in early sulfate exposing age due to factors we discussed in the previous page for the case of steel fibre. However, in the sulfate case, the mixtures which contain polypropylene fibre their shear strength decreased with respect to the control sample by 13.86 and 4.83% for fibre volume of 0.1 and 0.2%, respectively. This drop may cause by excess superplasticizer, or based on literature; the actual sulphate attacks appear after 90 days or more, so further research is needed in this field to see the effect of fibre in the long-term attack. In addition, we can see a notable increase in shear strength by 10.49% when the fibre volume ratio increased from 0.1% to 0.2%, which may leave us concluding that polypropylene fibre in a sulfate environment also can enhance shear strength. This improvement of shear strength in sulfate media by steel fibre was also reported by Hegde et al., (2008).

In the Acid environment case, H_2SO_4 decreased the shear strength of samples by 21.7 and 7.9% for the fibre volume fraction of 0 and 0.1%, respectively. In addition, we think an error happened for the 0.2% fibre volume fraction, so we did not mention the decreased percentage because this drop may be due to the instability of the mix. However, in the acid case also, polypropylene fibre helped to enhance shear strength with respect to the control sample by 51.43 and 69.43% for fibre volume of 0.1 and 0.2%, respectively, shown in Figure 4.12.

Table 4.4 shear strength results of mixes (MPa).

Control	Shear strength	Sulfate	Shear strength	Acid	Shear strength
N	4.47	NS	6.42	NA	3.5
S1	5.57	S1S	6.98	S1A	5.13
S2	6.43	S2S	6.55	S2A	5.5
F1	5.72	F1S	5.53	F1A	5.3
F2	4.29	F2S	6.11	F2A	5.93

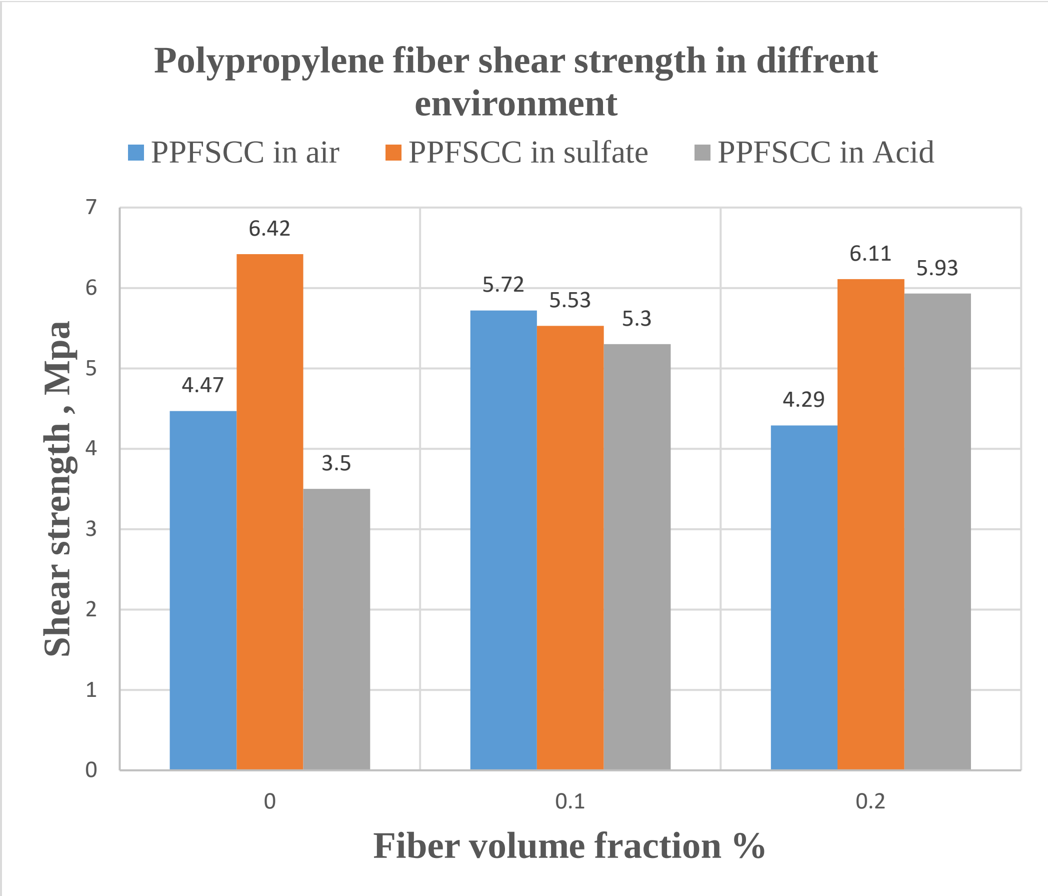


Figure 4.12 Variation in shear strength polypropylene reinforced self-compacting concrete with different environment and fiber fraction volume.

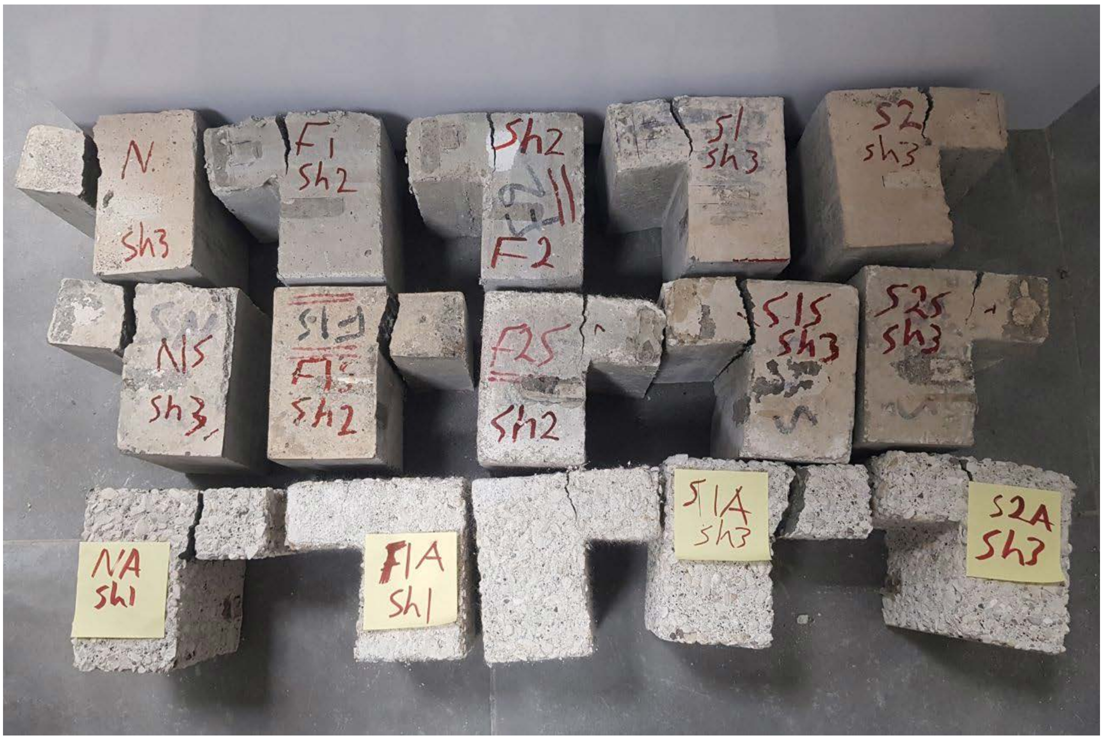


Figure 4.13 Failure modes of FRSCC cylinder samples after shear strength test.

CHAPTER V

CONCLUSION AND RECOMMENDATIONS

5.1 General

FRSCC generally improved mechanical properties and durability. Traditional transverse shear reinforcement can be wholly or partially replaced by adding SFs. Polypropylene fibres should not be used for structural reinforcement, producing thinner sections and increasing joint span. However, it gives SCC good durability and slight mechanical properties improvement.

The current work covers some properties of SCC with steel and polypropylene fibres, three different environment cases with two volume fractions (0.1 and 0.2%). Fresh and hardened properties of all mixes were studied compared to the control mix, results were discussed, and conclusions with recommendations are presented in this chapter.

5.2 Conclusions

The following conclusions can be drawn from the test results of this investigation.

1. Steel fibre with lower volume fraction with straight shapes has no adverse effect on workability properties like filling ability, passing ability and segregation except slight decreases. However, if polypropylene fibre is used, special care of workability tests is needed. Polypropylene fibre with 0.1 and 0.2% volume fractions decreased slump value from 800 mm to 710 and 620mm, respectively. We must be careful that we achieve these results by using the excess ratio of superplasticizers which may negatively affect mechanical properties, as reported in this study. However, it will be challenging to pass the workability criteria of SCC without increasing the superplasticizer ratio especially for a volume fraction above 0.1% of this small-size polypropylene fibre.

2. Presenting steel fibre in SCC generally increases compressive strength in all exposure cases, mainly when a more significant volume fraction is used. In our case for 0.1% volume fraction, we did not notice any improvement, but when the steel fibre volume fraction increased to 0.2%, we saw a notable increase of 3% for this small amount of steel fibre. This is due to the confinement effect of fibres that increases the stiffness of concrete, the resistance of cracking to the propagation of micro and macro-cracks and the ability of steel fibres to add cohesion between the components of the concrete.

3. For polypropylene fibre, compressive strength was reduced for all mixes showing continuous dissenting compressive results. Based on the literature, when this small type of polypropylene fibre is used up to 0.1%, it should slightly increase or not affect compressive strength. We conclude that the primary reason for our decreases in compressive strength, especially for a volume fraction of 0.1%, is the excess superplasticizer ratio added to the mixture to overcome workability problems caused by adding polypropylene fibre. It is good to mention that in the acid attack comparison, strength was enhanced by 17.47 and 10.17% for a fibre ratio of 0.1 and 0.2%, respectively, compared to the control sample, which does not contain fibre. This may be answering why the primary reason for adding polypropylene fibres is always for durability and not for structural purposes.

4. Due to the excellent distribution of fibres, which resulted in a better-bridging action in the concrete matrix, the concrete containing no fibres directly failed once the concrete cracked in tension. Meanwhile, the fibres concrete exhibited cracking but did not entirely separate. All steel fibres showed proportionally improved tensile strength with increasing volume fraction of steel fibre in all exposure. However, for polypropylene, fibre splitting strength reduced for all mixes for the volume fraction of 0.1%; these drops are not due to the effect of the fibre but are, as discussed before is, due to an excess amount of superplasticizer. However, the positive effect of fibre on tensile strength can be concluded from the fact that increasing polypropylene fibre from 0 to 0.2% increased splitting tensile strength by 3.59, 7.83% for exposure cases of air, sulfate.but didn’t improve splitting tensile strength in under acid attack.

5. All self-compacting concrete which contains steel fibres showed improvement in the shear strength proportionally with increasing volume fraction of steel fibre in all exposure cases. Steel fibre in the control case helped enhance the shear strength of samples by approximately 24.61 and 43.85% for the fibre volume fraction of 0.1 and 0.2%, respectively. In addition, in the sulfate case, steel fibre helped enhance shear strength with respect to the control sample by 8.72% and 2.03% for fibre volumes of 0.1 and 0.2%, respectively. In the acid case also, steel fibre helped increase shear strength with respect to the control sample by 46.57 and 57.14% for fibre volume of 0.1 and 0.2%, respectively. This may explain why much literature concluded that traditional transverse shear reinforcement could be replaced wholly or partially by adding SFs.

6. Generally, polypropylene fibres showed improvement in shear strength. In the air environment case, polypropylene fibre helped increase the samples' shear strength by approximately 27.96% for a fibre volume fraction of 0.1%. However, for a fibre volume fraction of 0.2% in the air case, the shear strength decreased by 4.03% with respect to the control sample. In sulfate case mixes which contain polypropylene, their shear strength reduced, but we can conclude these drops are not due to the effect of the fibre but, as discussed before is, due to the excess amount of superplasticizer. However, the positive effect of fibre on shear strength in lower volume fraction can be concluded from the fact that increasing polypropylene fibre from 0.1% to 0.2% increased shear strength by 10.49%. in the acid case also, polypropylene fibre helped enhance shear strength with respect of control sample by 51.43 and 69.43% for fibre volume of 0.1 and 0.2% respectively. Adding steel and propylene resulted in a better-bridging action in the concrete matrix; under direct shear stress, the concrete containing no fibres suddenly failed once the concrete cracked. Meanwhile, the FRSCC fibre concrete exhibited cracking but did not entirely separate.

7. We did not have a lot of volume fraction of steel fibre to select the optimum fraction, which gives us the highest workability, mechanical properties and durability at the same time. However, we will get better properties if the steel fibre volume fraction increases. Nevertheless, polypropylene fibre can make a proper self-compacting concrete mix without an excess superplasticizer, using

a volume fraction of **0.1%**, which will give us the best workability, mechanical properties, and durability at the same time.

8. We found that, generally, steel fibre has improved self-compacting concrete properties more than polypropylene fibre. However, it is noteworthy that when durability is a priority in an aggressive acid environment, we can get the advantage of the lower price of propylene fibre which gives us surprising resistance to an acid environment. Also, we observed that acid could not dissolve polypropylene fibre after the attack, which may be one of the reasons for their excellent resistance. However, we observed no trace of steel fibres on the surface of the concrete after the acid attack, meaning they were dissolved.

5.3 Recommendations for future works

1- Investigation of shear strength of both steel and polypropylene fibre RSCC under long-term acid and sulfate attack

2- More studies on the effect of polypropylene fibres on direct shear strength by using different sizes and volume fraction

3-Not using equal volume fractions for different fibres type because this will not make injustice comparison since they are totally different materials. Also, using the same amount of superplasticizer for all fibres types and volume fractions to obtain more insight view to effects.

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