INTERFACIAL BOND STRENGTH BEHAVIOUR OF STEEL FIBRE REINFORCED CONCRETE AND PLAIN CONCRETE SUBSTRATE

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MTech/SET/2017/7574

A THESIS SUBMITTED TO POSTGRADUATE SCHOOL, FEDERAL UNIVERSITY OF TECHNOLOGY, MINNA, NIGERIA, IN PARTIAL FUFILLMENT OF THE REQUIRMENTS FOR THE AWARD OF THE DEGREE OF MASTER OF TECHNOLOGY (MTECH) IN CONSTRUCTION TECHNOLOGY

SEPTEMBER, 2021

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ABSTRACT

The quality of the bonded concrete overlay depends on the bonding at the layer's interface, which is affected by parameters such as fibre inclusion and content in new concrete, moisture condition and surface roughness of old concrete surface. This research presents an experimental study carried-out to assess the interfacial bond strength behaviour of Steel Fibre Reinforced Concrete (SFRC) and Plain Concrete (PC) substrate. The objective of this study is to quantify the interface shear bond strength affected by fibre inclusion and content in new concrete, moisture condition and surface roughness of old concrete surface. Steel wire fibre was incorporated as reinforcing agent in the FRC to determine its effect on bonding strength. To better understand the bonding mechanism at the interface, overlaid square prism specimens were fabricated with three moisture conditions (air dry, SSD, and wet). Five different fibre volume fraction of 0%, 0.5%, 1.0%, 1.5%, and 2.0% were prepared and used as the overlay concrete on three different surface texture (As Cast surface, Grooved surface, and Wire brush surface). It was observed that the bond strength of the FRC samples at all moisture condition (SSD, W and AD) is higher than that of the control specimens in the presence of the three surface texture. The bond strength of FRC with 1% fibre volume was observed to have consequently improved. This improvement is influenced through grooved surface texture at SSD moisture condition of the old concrete surface. Steel fibre of 1.0% produced sample with the highest interfacial bond strength of 15.19N/mm^2. It was observed that, the bond strength of FRC was more than the control specimen. Based on ACI Concrete Repair Guideline, all the roughened surface textures used in this study were able to meet the minimum bond strength it specified. Considering all inferences and appraisals from this research, 1% steel FRC, grooved surface treatment type and SSD surface condition are recommended in the production of retrofitting/repair concretes with the sole aim of achieving an enhanced interfacial shear bond strength.

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background to the Study

Concrete infrastructures in most countries around the world are facing a rapid loss of serviceability, safety and suffering damages from increasing and unpredictable live loads which they are exposed and subjected to in service (Shin & Wan, 2010; Banthia *et al.*, 2014). These civil infrastructures such as roads, sewers, and the built infrastructure of commercial, domestic and public buildings are the basis of any community's health, safety and prosperity. Consequently, they must be kept in good and functional state at all time (Banthia *et al.*, 2014). In response to infrastructure damaged, new construction materials that are reliable, effective and economical such as Steel Fibre Reinforced Concrete are used in constructing overlay and patching the damaged or deteriorating part of the structures (Tayeh *et al.*, 2013a; Denarié & Brühwiler, 2006). The usage of Steel Fibre Reinforced Concrete in engineering application is meant to achieve the target of creating an effective ductile and high tensile concrete.

Concrete-to-concrete interfaces are present both in new and existing structures. Two distinctive situations can be identified: (1) placing hardened concrete against hardened concrete parts, such as the case of precast members for viaducts and bridge decks; and (2) placing fresh concrete against hardened concrete parts, such as the rehabilitation and strengthening of existing structures by concrete jacketing or concrete overlay (Aysha *et al.*, 2014).

The security strength of the substantial to-concrete or Concrete to fix material interface is impacted by a few boundaries however fundamentally by the harshness of the interface mode, the utilization of holding specialists; the pressure opposition of more vulnerable concrete, the dampness substance of the substrate, the relieving conditions, the pressure state at the interface, the presence of breaking and, the measure of steel support crossing the interface among others. Similarity of the maintenance material with the current substrate is a significant thought if the maintenance is to withstand every one of the burdens prompted by impacts, for example, volume changes and compound and electrochemical impacts (Aysha et al., 2014; Casal, 1960).

Application of Steel Fibre Reinforced Concrete (SFRC) in enhancing the bonding of concretes will gradually help to increase the efficiency of the building system. The mechanism behaviour of the combination of concretes plays an important role in the structural system. Many applications involved in the bonding of concretes such as repairing, casting joints or precast element connection requires large amounts of cement in them for them to develop an adequate bond with the substrate. The use of SFRC as replacement of existing conventional concrete to be used for repairing and rehabilitation purpose may give a great impact in engineering application towards sustainability.

Investigated result has shown SFRC to have the possibilities that make it reasonable for fix, retrofitting and restoration of Supported Substantial Designs (RCS) and as new development material (Banthia et al., 2014). Any remaining pieces of the designs stay in ordinary primary concrete as these parts are exposed to generally sensible openness. Ordinarily, there consistently exists a feeble association between the bond strength of the old and new substantial constructions during reinforcing and restoration (Momayez et al., 2005; Gorst & Clark, 2003; Mu et al., 2002). To effectively rehearse restoration of decaying structures, the comprehension of the practices at the interface between the old and the new development materials is convenient (Tayeh et al., 2013a; Tayeh et al., 2013b; Ueda & Dai, 2005). The bond between the composite materials is an element of certain variables, like surface unpleasantness and surface extremity of the composite segments. In estimating the surface energies and bond strength of the composite material, a comprehension of the interfacial attachment between the fibre and the network must be resolved. This exploration will assist with understanding the Interfacial bond conduct of Concrete made with steel fibre and Plain concrete.

1.2 Statement of the Research Problem

The deterioration of concrete structures is a matter of critical concern as it threatens the durability and strength of concrete structures. SFRC can be used with advantage in new structures such as precast and cast insitu elements, as well as the strengthening, repair and rehabilitation of old structures to improve their resilience properties.

Bonded concrete overlay is a viable option to increase structural capacity and improve reliability of concrete structures. However, property mismatch of new overlaid concrete to old concrete usually create bond problems that lead to early age failure and a shortened service life of concrete composite (Momayez *et al.,* 2005; Gorst & Clark, 2003). Consequently, to better understand the bonding mechanism at the interface between new and old concrete surface, it is essential to measure bond strength at the interface and to investigate parameters that affect properties (Tayeh *et al.*, 2013a; Tayeh *et al.*, 2013b; Ueda & Dai, 2005).

1.3 Aim and Objectives

The aim of this research is to investigate the interfacial bond strength behaviour of Steel Fibre Reinforced Concrete and Plain Concrete Substrate with a view to establishing the parameters affecting the bond strength at the interface.

The objectives of the research work are to:

i. Determine the effects of three different conditions at substrate surface on the interfacial bond strength.

ii. Investigate the influence of Steel fibre content on the interfacial bond strength of the composite concrete members

iii. Determine the influence of surface roughness of the substrate on the bond strength of the interface of the composite concrete members

1.4 Scope of the Study

The research work would be experimental in nature and centres on the development and application of SFRC. Fibre volume fraction inclusion in concrete ranges from 0.5% to 2.0% at 0.5% interval at a corresponding fibre length of 40 mm. The study emphasizes on the bond strength of the composite using slant rectangular test specimens to measure the bond stress behaviour in shear. Three conditions (air dry, Saturated Surface Dry (SSD), and wet) were made on the Plain (existing/old) concrete surface. Also, three different surface texture of the old concrete substrate was used in assessing the bonding interface strength of the specimens. A constant water:cement (w/c) ratio of 0.55 was chosen as overlay (repair/rehabilitation) concrete. To assess the variation of the parameters in the result, triplicate samples were fabricated and tested.

1.5 Justification of Study

Several research studies (Aslani & Nejadi, 2013; Arango, 2010; Abdul Awal *et al.*, 2013; Swamy & Mangat, 1974) have been performed on mechanical properties of steel fibre reinforced concrete and concrete structural members reinforced with fibres under various loading conditions. However, studies on interfacial shear bond strength properties of concrete with steel fibres and plain concrete are very limited. In the present investigation, the interfacial shear bond strength behaviour of SFRC and plain concrete substrate was investigated by slant shear bond strength methods. Besides, influence of percentage of fibres, moisture condition of surface and the texture of bond surface on interfacial bond strength was studied.

The critical discoveries of this exploration will be valuable in the accompanying manners:

i. Facilitate in advancing financially savvy fix materials that has decent interfacial security strength with old Concrete thinking about the vital boundaries.

ii. This exploration will help analysts, planners, fabricators and architects to comprehend the Interfacial bond conduct of Concrete made with steel fibre and Plain concrete.

iii. Application of SFRC in upgrading the holding of Concretes will steadily assist with expanding the effectiveness of the structure framework

iv. The utilization of SFRC as substitution of existing customary Concrete to be utilized for fixing and recovery reason may give an incredible effect in designing application towards manageability.

v. Encourage creation of SFRC for fix and retrofitting decaying and break surfaces of Concrete.

vi. Aid in giving curiosity data set of interfacial bond strength of old Concrete to new substantial utilizing SFRC as a maintenance material its application in the development business.

vii. Assist fabricators and specialists in improving the nature of Concrete to substantial interfaces present in both old existing and new designs giving proper materials and strategy.

viii. Provide critical market value where the eventual outcome can be popularized as an oddity in Nigeria.

ix. The findings of this research can be directly adapted in the rehabilitation of concrete pavements and bridges.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Interfacial Stresses

Stresses on the bond interface of repairs in the field can be affected by factors such as those listed as; plastic and drying shrinkage strains in the repair material, heat generation from early heat of hydration or polymer reaction thermal stresses (including thermal shock when hot repair material is exposed to cold ambient temperatures), time dependent volume changes, such as drying shrinkage (or expansion in shrinkage compensated Concretes), autogenous shrinkage, carbonation shrinkage and creep, dead loads and changing live loads and dynamic loads, Thermal stresses from diurnal or seasonal temperature changes, or external heat sources, Frost build-up or salt crystallization pressures, other factors such as impact loads or changes in moisture gradient in the repaired system (Zhifu, 2011).

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2.1.1 Repair techniques

A few methods for fixing or potentially reinforcing structures include adding new Concrete to a current substantial substrate. To improve the security strength, it isn't unexpected to build the unpleasantness of the substrate surface. The surface harshness, the utilization of a holding specialist and the dampness substance of the substrate can have a huge impact in the security strength of the interface and disappointment method of composite substantial individuals with layers cast at various ages.

Since composite substantial individuals are projected at various ages, various Concretes are every now and again received. Indeed, even with a similar blend plan, contrasts are acquired in the compressive strength and thusly in the Young's modulus. For this situation, the most fragile substantial layer controls the disappointment of composite individuals. Moreover, differential firmness because of various Young's modulus at each layer likewise influences the conduct of the composite individuals since extra burdens are prompted at the interface (Zhifu, 2011).

2.2.1 Surface roughness

Readiness strategies, for example, wire-brushing, sandblasting, shot-impacting, chipping and hydro destruction are oftentimes used to eliminate the shallow layer. Moreover, to the unpleasantness expanding technique, a holding specialist can be utilized to improve the bond strength. For this situation, epoxy-based tars are the most regularly received in bond new/solidified to solidified substantial parts however the subsequent advantages are not broadly acknowledged by specialists. Some propose that a satisfactory security can be just accomplished by joining the utilization of holding specialists with an appropriate strategy to expand the substrate harshness basically when the substrate presents a smooth surface. The examples with the substrate surface treated with sand-impacting showed the most noteworthy upsides of security strength in shear (14.13 N/mm^2) and the least upsides of variety coefficient (8.56%) (Zhifu, 2011).

2.2.2 Bonding agents

At the point when the substrate is immersed or presents high dampness content, even with its surface dry the impact of the surface planning is less huge. In these conditions the utilization of a holding specialist is beneficial yet in addition less huge in contrast with similar conditions however with a dry substrate.

Numerous states that holding specialists are excessive given that substrate concrete is dry and appropriately roughened to uncover the totals. Besides, the impact of the surface harshness gives off an impression of being massive when concrete mortars or polymer adjusted concrete mortars are utilized, since when epoxy tars are embraced disappointments don't habitually happen at the interface. Other than unpleasantness and holding specialists, the impact of boundaries like temperature, and specifically the impact of cyclic varieties ought to be assessed for every particular circumstance since they can handle the conduct of the interface.

2.2.3 Pre-wetting

Comparable to pre-wetting the substrate surface, conclusions separate about the most suitable circumstance. Saucier and Pigeon allude to the AASHTO-AGC-ARTBA Joint Panel that suggests a dry surface of Concrete, besides in dry and sweltering mid-year days, and the Canadian Guidelines Affiliation Standard A23.1 that suggests wetting the surface for in any event 24 hour prior to manufacturing the new concrete. Emmons makes reference to that the dampness level of the substrate might be basic in accomplishing security. He expresses that an exorbitantly dry substrate may retain a lot of water from the maintenance material while extreme dampness in the substrate may stop up the pores and forestall assimilation of the maintenance material.

In this manner, an immersed substrate with a dry surface is viewed as the best. The impact of pre-wetting the substrate surface on the security strength demonstrates that this variable doesn't have a huge impact. Current practice likewise suggests pre-wetting the substrate concrete in the 24 hour that go before the cast of the new substantial layer to accomplish a soaked substrate with a dry surface. Under sweltering and dry climate conditions, pre-wetting is central to accomplish a decent bond. By and by, on account of high dampness or free water at the substrate surface security strength diminishes (Zhifu, 2011).

2.2.4 Curing

Current plan codes for substantial designs don't expressly introduce arrangements for the relieving methodology of composite individuals cast at various ages and subsequently the impact of differential shrinkage is frequently dismissed. This is a vital boundary since various Concretes with various relieving conditions for sure exist in composite individuals. It is regular prescribed to begin relieving following the cast of the additional substantial broadening it for in any event 3–7 days to improve the bond strength. Boundaries like relative stickiness and temperature, just as the openness to wind, downpour and sun powered radiation should be thought of (Pedro & Eduardo, 2010).

The bond strength between substantial layers can likewise be improved by expanding the compressive strength of Concrete and thusly the commitment of union for the shear strength. An appropriate restoring measure guarantees that the greatest burdens between the substrate concrete and the additional substantial don't prompt debonding and miniature breaking at the interface. It ought to be featured that the pressure state at the substantial to substantial interface is extremely mind boggling since it contains a mix of shear and ordinary anxieties. When following up on the material properties, specifically the compressive strength of each substantial layer, it is feasible to plan the disappointment method of composite individuals by indicating the differential solidness between layers. For similar degree of shear stresses, typical anxieties increment at the interface when the differential firmness between substantial layers increments. This implies that it is feasible to characterize the disappointment mode to be glue, due to debonding at the interface or durable by substantial pounding at the mass. By and by, the increment of the differential firmness expands pressure fixations is different zones of the interface.

2.3 Test Method

A few tests are accessible to quantify the bond strength, yet just little data is accessible on correlation of these different tests' strategies and the subsequent security strength values. There is a need to think about various tests for estimating bond strength and to build up a relationship among the qualities acquired from each test (Pedro & Eduardo, 2010).

2.3.1 Bond strength

The bond strength predominantly relies upon attachment in interface, grinding, total interlock, and time subordinate elements. Every one of these principle factors thus relies upon different factors. Attachment to interface relies upon holding specialist, material compaction, cleanness and dampness substance of fix surface, example age, and unpleasantness of interface surface.

Grinding and total interlock on interface rely upon boundaries like total size, total shape, and surface planning. Notwithstanding the above factors, the deliberate security strength is exceptionally reliant upon the test technique utilized. Size and calculation of example and the condition of weight on the contact surface are very reliant upon the picked test technique. It is noticed that specific standard tests have been created for explicit applications and condition of pressure. There are two issues that should be tended to. To start with, what kinds of tests are suitable for assessing the bond strength for the condition of pressure that is usually found in structures, i.e., shear pressure brought about by stacking and time subordinate components. Second, what relationship exists between the consequences of various test techniques (Pedro & Eduardo, 2010).

2.3.2 Existing methods

The existing tests to determine the bond between concrete substrate and repair material can be divided into several categories.

2.3.2.1 First category of tests

The first category of tests measures the bond under tension stress. Pull-off, direct tension and splitting are the main tests under this category.

1) Pull-off test

The draw off test is a pressure test and has been decided for two reasons (1) to assess the bond strength in strain of the interface and (2) it very well may be done in situ. The embraced math for the draw off examples was a 0.20 m block with the interface line at the centre. A centre of 75 mm breadth was penetrated into the additional substantial and expanding 15 mm past the interface into the substrate. A round steel plate was fortified, with an epoxy pitch, to the outside of the centre. A strain power was applied to the circle, with a business gadget at a consistent pace of 0.05 $N/mm^2/s$, until disappointment happened.

2) Direct tension test

In the immediate strain test, the tractable power is communicated to the substantial example either by stuck metal or by unique holds. An exceptionally cautious arrangement of the example in the pivot of stacking is fundamental. Indeed, even an exceptionally limited quantity of misalignment may present whimsies that will cause enormous disperse in test results. Playing out a decent strain test is troublesome and tedious. Nonetheless, an as of late proposed variety of the immediate pressure test, alluded to as pull off test, is simpler to do and can create great outcomes.

3) Indirect tension test

Roundabout strain tests incorporate the flexural test and the parting test. The flexural test offers low proficiency (the space of the fortified surface exposed to stacking is little contrasted with the example volume). For such tests, just an exceptionally little piece of the reinforced plane is exposed to the most extreme burdens. Parting test is more effective around there.

In the parting test, a crystal with roundabout or square cross-area is put under longitudinal compressive stacking. Strain stresses cause disappointment in a plane going through upper and lower tomahawks of stacking and split the example into equal parts. The parting elasticity of Concrete is viewed as a sign of its rigidity. The test strategy is easy to perform and utilizes a similar barrel shaped example and test machine as a standard pressure test. The parting tractable test according to ASTM C496/C496M (2011), as a roundabout ductile test, was led to assess the security strength between the NC substrate and Concrete (Pedro & Eduardo, 2010).

A crystal with roundabout or square cross-area is set under longitudinal compressive stacking. Strain stresses cause disappointment in a plane going through upper and lower tomahawks of stacking and split the example into equal parts. The parting elasticity of Concrete is viewed as a sign of its rigidity. The test strategy is directed in congruity with ASTM C 496/C496M (2011), as a circuitous pliable test, to assess the security strength between the new concrete and substantial substrate as represented in Plate I.

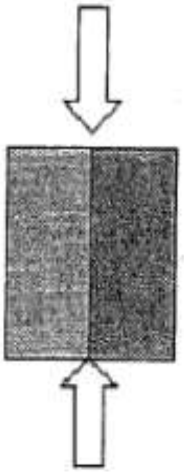


Plate I: Bond test under state of tension-square splitting

2.3.2.2 Second category of tests

The second category of tests measures the bond under shear stresses and is called direct shear methods. Several tests fall under this category, including L-shaped, mono surface shear, etc.

1) Direct shear test

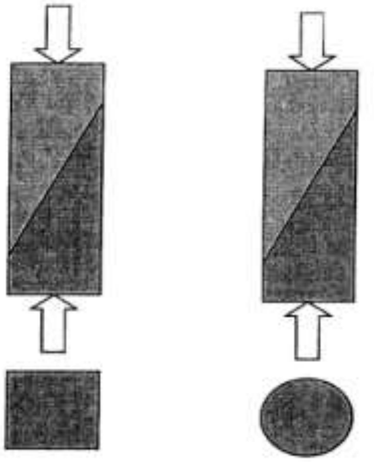
Most of the time, the bond surface for an immediate shear test is really exposed to shear pressure and a little twisting pressure. At the point when a steel plate is utilized to send the shear power along the bond line, some pressure fixation at the edge of the holding plane is incited. More modest pressure focus prompts more modest dissipate in test results.

2.3.2.3 Third category of tests

The third category measures the bond strength under a state of stress that combines shear and compression. All slant shear tests mentioned previously fall under this category.

1) Slant shear test

The inclination shear test utilizes a square crystal or a barrel shaped example made of two indistinguishable parts reinforced at 30ºor 45º and tried under hub pressure and during stacking, the interface surface is under pressure. The inclination shear test according to ASTM C882 (1999) has become the most generally acknowledged test and has been embraced by various worldwide codes as a test for assessing the security strength of resinous fix materials to substantial substrates. In any case, there is no broad understanding among scientists with regards to the fittingness of this test for non-resinous materials.



a) BS 6319 Part 5 b) ASTM C 882-99

Plate II: Slant shear test using either (a) square prism or (b) cylindrical specimen bonded at 30º or 45º and tested under axial compression loading.

2.4 Minimum Acceptable Bond Strength Range

According to ACI Concrete Repair Guide (Chynoweth *et al.*,1996), materials used in concrete repair work shall have a specified minimum acceptable bond strength based on the slant shear strength as presented in Table 2.1.

Table 2.1: Minimum Acceptable Bond Strength Range

Days	Bond Strength (S) N/mm^2
1	2.76 - 6.9
7	6.9 – 12.41
28	12.41 -20.68

Source: Chynoweth *et al.* (1996).

This guide is useful in the selection of appropriate type of repair materials for rehabilitating deteriorated concrete structures.

2.5 Constituent Materials for Fibre Reinforced Concrete

The constituent materials for creation of FRC are OPC, fine and coarse totals, water, substance admixtures, advantageous solidifying materials (SCM) and short filaments. The significant constituent materials are concrete, totals water and filaments, while then again, SCM, fillers, superplasticizer and different synthetic substances are delegated discretionary materials, contingent upon the application and execution of FRC in various conditions (Pedro & Eduardo, 2010).

2.6 Portland Concrete

Conventional Portland concrete (OPC) is by a wide margin the most broadly utilized water powered covers to deliver any sort of Concrete. It is made by beating clinker containing of calcium silicates, and much of the time includes calcium sulphate as a between ground expansion (ASTM C150/C150M, 2012). Like different sorts of Concrete, OPC is utilized alone or in blend with other SCMs underway of FRC. It is the significant segments that increase the functionality of FRC when blended in with proper measure of water (Neville & Brooks, 2010). It likewise acts a significant part in the isolation opposition of FRC by fluctuating the concrete glue framework inside the substantial blend (Shetty 2005). Ordinarily, utilization of high evaluation of concretes offers numerous advantages for assembling high strength concrete. In addition, in the wake of blending in with certain measure of water and cycle the substance responses, OPC decline the porosity of the substantial networks, attributable to the densification of the substantial in microstructure perspective. Subsequently, it prompts lower transport properties and better strength execution of Concrete.

2.7 Physical Properties of Concrete

The presentation of FRC is profoundly relies upon the actual properties of OPC. As standards for achieving required qualities, the OPC utilized in FRC ought to have a decent property as far as sufficiency and setting time. It ought to improve the new state properties of Concrete and ought to be liberated from wrong setting. Also, OPC ought to be viable with other synthetic admixtures, for example, superplasticizer, air entering specialists, and so forth OPC having a decent molecule size circulation and liberated from any protuberances ought to be utilized in the assembling of FRC. Moreover, the OPC should deliver low or moderate warmth of hydration in order to lessen the volume changes and warm breaks related with concrete (Li, 2011). The essential necessities for the actual properties of OPC for various substantial formations have been indicated in ASTM C150/C150M (2012).

2.8 Chemical Properties of Concrete

The substance examination of OPC generally uncovered that it involves different sorts of oxide compounds. These are, lime, alumina, iron and silica. It likewise comprises of two minor oxides explicitly, potassium and sodium which act a significant job of preventive soluble base total response in substantial combination. What's more, magnesia and sulphuric anhydrite regularly exist; nonetheless, they don't assume a specific part. The fundamental substance necessities for different sort of OPC for creation of Concrete have determined in ASTM C150/C150M (2012). Table 2.2 presentations a commonplace substance segments and actual properties of OPC.

Table 2.2: Approximate chemical composition limits of OPC

Chemical Composition	Mass Content (%)
Calcium Oxide (CaO)	60-67
Silicon Dioxide (SiO_2)	17-25
Aluminium Oxide (Al_2O_3)	3-8
Iron Oxide (Fe_2O)	0.5-6.0
Magnesium Oxide (MgO)	0.1-4.0
Alkalis (K_2O)	0.2-1.3
Sulphur Trioxide (SO_3)	1-3

Source: Neville and Brooks (2010)

2.9 Fibre and Its Use in Concrete

A few kinds of fibre have been utilized to support of concrete based composites. While adding strands into substantial blend, to pick the most suitable fibre, it is important to perceive the type of impact the filaments are anticipated to give. Filaments can be normal natural (kenaf and sisal), manufactured natural (polypropylene and carbon), engineered inorganic (steel and glass), common inorganic (asbestos) or strands from squander materials (squander cover filaments, steel fibre from reused tire) (Beaudoin, 1990; Bentur & Mindess, 2007; Brandt, 2008). By and by just steel, glass, polypropylene and polyester strands are generally utilized in substantial development industry. In spite of the fact that asbestos filaments had been utilized usually previously, they are quickly being supplanted by different kinds of fibre because of the wellbeing risks related with airborne asbestos strands (Bentur & Mindess, 2007). Common natural strands are a mainstream type of substantial support in some agricultural nations (Wambua *et al.*, 2003). Over most recent 30 years, creation of fibre built up concrete has been changed into an immensely divers industry. There are developing quantities of organizations worldwide that production fibre supported Concrete.

2.10 Steel fibres

Steel filaments utilized in built up concrete are typically made of gentle carbon steel or hardened steel, where the erosion safe conduct of strands is needed in structures. The elasticity of steel filaments may go between 200-2600 N/mm^2 and extreme lengthening in the scope of 0.5-5%. While its rigidity significantly higher than that of the substantial blend is required, consequently, too solid filaments may affect the building up effectiveness of strands. It is because of the more 43 serious grid spalling happened around the high elastic fibre leave point in low-strength frameworks (Yao *et al*., 2003; Bentur & Mindess, 2007; Düğenci *et al.,* 2015). One of the significant benefits of steel fibre is that, the yield limit of the fibre is sufficient so fibre crack is disregarded. The flexible modulus of steel strands is around 200 GPa, subsequently essentially higher than that of lattice (Yoo *et al*., 2014). The at first utilized straight and smooth steel strands is infrequently seen as of late in typical strength substantial combination because of its lacking bond with the network (Brandt, 2008). By the by, for high-strength substantial straight metal covered filaments are moderately normal (Gao *et al.,* 1997).

To expand the connection between the strands and network, a high viewpoint proportion (for example the proportion fibre length/distance across) is liked. Nonetheless, there is a breaking point, and exceptionally thin filaments with viewpoint proportion, lf/df > 100 will in general stick together and framing balls, in this manner diminishing usefulness and maybe prompts decrease in the mechanical properties of the substantial, attributable to a lopsided scattering of the steel strands (Nataraja *et al.,* 1999; Yoo *et al.,* 2014). As of late, to expand the connection among framework and fibre, steel filaments are delivered in different shapes and sizes. The prerequisites of steel filaments utilized in concrete have been determined in ASTM

A820/A820M (2016). Five sorts of steel filaments are characterized, which should all be sufficiently little to be scattered haphazardly in a substantial combination (Bentur & Mindess, 2007). The regular accessible twisted steel filaments are appeared in Plate III. These are: - Bits of smooth cold-drawn wire; - Bits of distorted cold-drawn wire; - Smooth or twisted cut sheet; - Dissolve removed filaments; - Factory cut or changed cold-drawn wire.

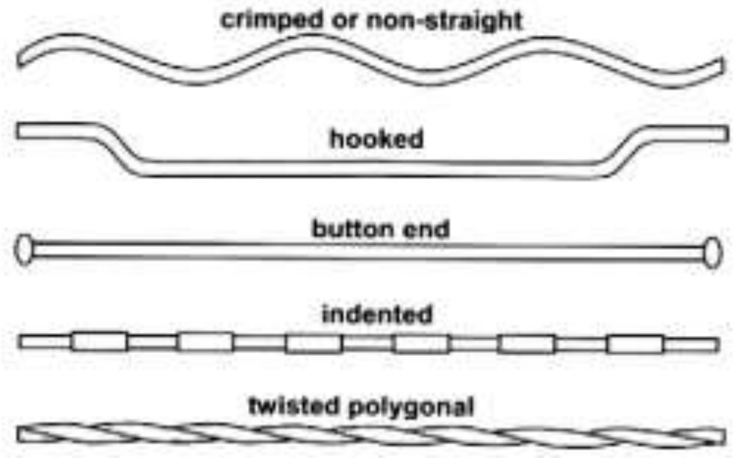


Plate III: Examples of deformed steel fibres (Brandt, 2008)

2.11 Glass fibres

Glass fibre supported Concrete (GFRC) has been set up chiefly for the development of meager sheet parts, for the most part as outside building veneer boards in understanding to ACI 544-1R (1999), with a concrete glue or mortar grid, and about 5% fibre content. Glass strands are fabricated in a cycle in which liquid glass is attracted the type of fibres, through the lower part of a warmed platinum tank or bushing. For the most part, 204 fibres are drawn at the same time and they solidify while cooling outside the warmed tank; they are then gathered on a drum into a strand comprising of the 204 fibres (Bentur & Mindess, 2007). Traditional glass strands have been found to lose their solidarity quickly as a result of the great alkalinity of the concrete based grid. From a primary functionality perspective, the most appropriate kind of glass fibre is the one fabricated from antacid safe glass (AR-GFRC).

The synthetic arrangements of this glass fibre differ from borosilicate glass filaments (E-glass) and sodalime-silica glass strands (A-glass), for the most part by the expansion of the exceptionally artificially resistive, ceramic material zirconium (Majumdar & Nurse, 1974; Beaudoin 1990). Studies have been shown that the expansion of E-and A-glass filaments in substantial composites experienced diminishing in flexural and rigid qualities and malleability whenever presented to an outside climate (Enfedaque *et al.*, 2010). In addition, contact to normal mugginess and temperature cycles will influence in recurrent volumetric dimensional 45 varieties. An alternate methodology was taken by Majumdar and Nurse (1974) to improve glass strands which are impervious to antacid assault. In creating AR-glass strands consideration was given to two fundamental viewpoints: (I) The synthetic resistivity of the glass, to upgrade its exhibition in a basic medium and (ii) The actual properties of the soften glass, to empower its manufacture in a business interaction.

Nonetheless, business AR-GFRC have been found with more noteworthy obstruction than E-glass strands to a substance assault like a basic climate. The expansion of glass strands in Concrete can handle shrinkage breaking (Mirza & Soroushian, 2002), improve the flexural and rigidities (Barluenga & Hernández-olivares, 2007) and furthermore increment the post-top pliability in pressure (Tassew & Lubell, 2014). Concerning the subsequent instrument, the hydration item for the most part answerable for composite embrittlement, for example loss of strength, is calcium hydroxide, which fills the openings between the glass fibres (Bentur & Mindess, 2007). The regular AR-glass filaments utilized in concrete are appeared in Plate IV.

Plate IV: Typical AR-glass fibres used in concrete

2.12 Synthetic fibres

Manufactured (polymer) strands are fake filaments coming about because of innovative work in the petrochemical and material ventures. These filaments slowly being utilized for the support of cementitious composites and a few existing strands have been passed on and made extraordinarily for support of Concrete and mortars (Bentur & Mindess, 2007). By and large, the manufactured strands utilized in concrete are generally filaments resultant from natural polymers and can be recorded as: polypropylene, nylon, polyethylene, polyester, carbon, acrylic and aramid. A portion of these filaments, like polypropylene, found in wide scope of utilizations and have been examined broadly by scientists (Zollo, 1997; Sun & Xu, 2009; Kun *et al.,* 2015). The properties of manufactured filaments vary broadly in regards to the rigidity and modulus of versatility, as given in Table 2.4 for some basic strands. To build the strength of the substantial composites, the strands utilized should have a modulus of versatility more prominent than that of the grid (Bentur & Mindess, 2007; Brandt, 2008). All things considered, hypothetical and test research have shown that, even strands having low modulus, huge upgrades can be acquired regarding the elastic and flexural qualities, strain limit, sway opposition, sturdiness and break control of the FRC (Zollo, 1997; Hsie *et al.*, 2008; Nili & Afroughsabet, 2010). The ordinary engineered filaments utilized in concrete are appeared in Plate V.

Plate V: Typical forms of synthetic fibres used in concrete

2.13 Carbon fibres

Carbon fibre is latent to most synthetic compounds and afterward appropriate to use in the basic climate of a substantial composites. In light of different starting assets there are two fundamental systems for creation of carbon filaments; Dish carbon strands are produced using polyacrylonitrile while pitch carbon strands are delivered from oil and coal tar pitch. Their properties may vary over a wide reach contingent upon the creation interaction. Pitch carbon fibre has an MOE values impressively lower than the Skillet strands; be that as it may, it is yet in a similar reach as the MOE upsides of the substantial combinations (Bentur & Mindess, 2007).

Carbon fibre supported concrete can reason as a piezoresistive strain sensor (Wen & Chung, 2001). The piezoresistivity is attributable to the little draw out of a break crossing over carbon strands upon pressure and the slight push-in of filaments upon pressure (Goldfeld *et al.,* 2016). Expansion of carbon strands for volume portion of around 2 to 6% have been found to productively lessen expanding and shrinkage strains of substantial combinations (Chen & Chung, 1996). It has been tracked down that the expansion of carbon strands over 1% altogether diminishes the functionality of the substantial combination (Tabatabaei *et al.* 2013). Carbon strands have a high warm conductivity, however not really that high of metals, and furthermore having a coefficient of warm development lower than that of metals and are incredibly impervious to erosion, which makes these filaments as a decent alternative for warm applications in multifunctional substantial composites, for example, the warming of structures or asphalt defrosting (Garcés *et al.,* 2012).

2.14 Fibre geometry

The properties of fibre supported Concrete with short spasmodic strands that haphazardly dispread in the grid can be influenced by numerous elements. One of the significant issues which altogether influence the attributes of the FRC in both the new and 53 solidified states is the fibre calculation and volume portion (Swamy & Mangat, 1974). The strands utilized in substantial blends can be classified into two principle gatherings: (1) discrete mono-fibre and (2) multi-fibres filaments. Discrete monofilaments strands are isolated one from the other, and are frequently utilized in FRC.

Multi-fibres strands are comprised of heaps of fibres which keep their packaged nature in the actual composite, and don't separate into particular fibres during blending or arrangement measure. For the most part, mono-fibre filaments, are chamber formed and twisted into a few shapes to foster the fibre-network communication through mechanical safe haven (Beaudoin, 1990; Bentur & Mindess, 2007) Different fibre calculations and end medicines are used to affirm that strands are secured into the framework so that heap can be moved and the full limit of the filaments can be utilized (Banthia & Gupta, 2006; Marthong & Sarma, 2016). Notwithstanding their shapes, strands are likewise arranged by their perspective (proportion of the length to the distance across) (Nguyen *et al*., 2014). Pull-out tests could be made on single fibre to decide how the fibre perspective proportion impact the pressure strain conduct just as bond strength of the substantial grid. Fibre proficiency (protection from pull-out) ascents with expanding viewpoint proportion, and is influenced by the disfigured shape (Zīle & Zīle, 2013).

2.15 Critical fibre volume

The heap bearing limit of the concrete put together composites depends with respect to the fibre volume division applied into the blends. In the fibre concrete composites, the disappointment strain of fibre is for the most part higher than that of grid which bombs first (Beaudoin, 1990). To stay away from the disappointment of strands, the heap bearing limit of the filaments should be higher than the heap applied on the substantial while the main break shows up. This was accepted that the substantial doesn't contribute any further strength past the place of first break, as the heap was completely move to the fibre that contains in the substantial. Also, the strands are able to convey extra burden, result that a definitive strength of the fibre built up concrete is higher than that of plain Concrete with no filaments (Bentur & Mindess, 2007). In this way, a condition for least fibre volume division was set up to set to rise to the heap bearing limit of the fibre concrete composite and the fibre load bearing limit. 54 The least or basic fibre volume part, Vcr, needed to add into substantial composites to support the heap after lattice break happens was accepted as condition (2.1) (Beaudoin 1990):

$$V_{cr} = \frac{\sigma_{mu}}{\sigma_{mu}+(\sigma_{fu}-\sigma'_{f})} \tag{2.1}$$

Where V_{cr} = critical or minimum fibre volume fraction, δ_f is stress on the fibres when the matrix fails at its first crack, δ_{mu} and δ_{fu} are the ultimate strength of the concrete matrix and fibre, respectively. The critical fibre volume fraction in concrete mixtures is calculated to be approximately 0.31, 0.40 and 0.75% for steel, glass and polypropylene fibres respectively (Beaudoin 1990).

2.16 Fibre distribution and orientation

The presentation of fibre supported Concrete is by and large dictated by the direction of filaments inside the framework. As direction circulation of short strands continue in different pieces of an underlying part, it is as yet a point for examination and conversations (Kang & Kim, 2011). Properties of such grid are as often as possible anisotropic, due for the most part to a non-uniform dispersion of fibre direction through the combination. The affectability of the lattice strength on the fibre directions has been appeared in numerous fibre pull-out tests under various fibre tendency points (Suuronen *et al.*, 2013). The fibre direction, thusly, relies upon the supposed 'divider impact', then again, the pattern of fibre in the spaces close to the shape to adjust itself to the formwork as demonstrated in Plate VI (Boulekbache *et al.*, 2010).

One meaning of the divider impact is that different kinds of construction will in general have distinctive direction dispersions of strands. For example, the direction of strands in a section might be entirely different near to a pillar, where the impact of the divider impact is more recognizable (Barnett *et al.*, 2010).

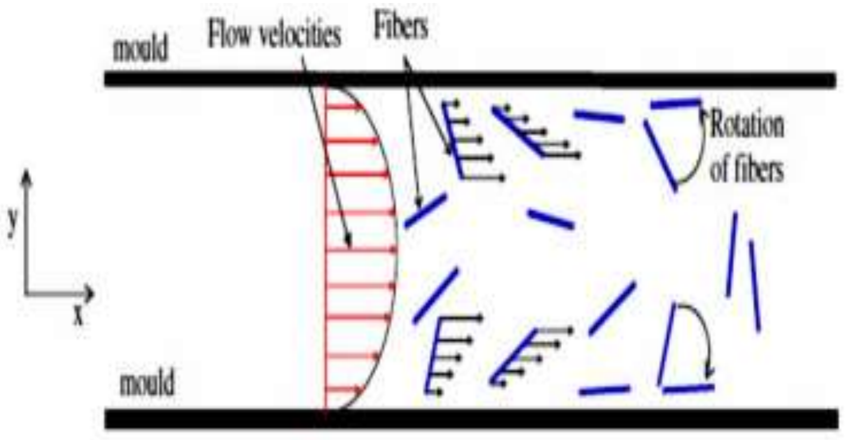


Plate VI: Orientation disturbed by the wall effect (Boulekbache *et al.*, 2010)

For the most part, "balling impact" happen in fibre supported Concrete all through blending. Balling is fundamentally a gathering of the filaments that limits scattering. As well as diminishing scattering, amassed strands can likewise make extra permeable voids in the substantial, which debilitate the interfacial change zone in the microstructure of the composite (Bentur & Mindess, 2007). This is a typical marvel in FRC especially when high fibre substance (more noteworthy than 2% by volume) are brought in with the general mish-mash, when high viewpoint proportion filaments are utilized, or when a huge amount of coarse total is utilized in a FRC blend (Banyhussan *et al.,* 2016). Plate VII shows the cross part of the substantial examples with all around orientated filaments and furthermore seriously orientated strands.

It can be noted that the orientation and distribution of fibres significantly affect the properties of FRC. According to Boulekbache *et al.* (2010), the orientation of fibres and the rheology influence considerably the flexural strength of concrete mixtures. Blends consolidating filaments with more modest breadths and high substance of fine total accomplish a more uniform dissemination during blending and situation (Kang *et al.,* 2011; Boulekbache *et al.,* 2010), the direction of filaments and the rheology impact impressively the flexural strength of substantial blends.

Blends fusing strands with more modest widths and high substance of fine total accomplish a more uniform conveyance during blending and position (Kang *et al.*, 2011; Yoo *et al.*,2014; Alberti *et al.*,2016). Moreover, there is less clustering and balling, however a totally uniform appropriation is never cultivated when utilizing discrete, spasmodic strands (Bentur & Mindess 2007). ASTM C1609/C1609M (2010) and ASTM C1399/C1399M (2010), additionally allude to "particular fibre arrangement" which has been seen subsequent to setting FRC into formwork or molds; these testing methods indicate that specific appearances of the test examples be utilized to stay away from the impacts of non-uniform appropriation.

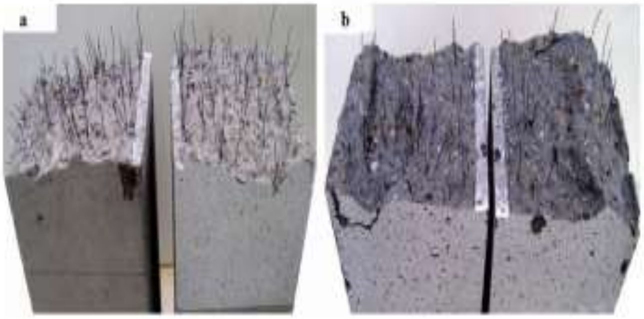


Plate VII: Fibre distribution through a section (a) well-orientated and (b) badly orientated fibres (Banyhussan *et al.*, 2016).

2.17 Fresh state properties of steel FRC

New or plastic Concrete is a newly blended material which can be shaped into any structure. The extents of concrete, totals, strands and water combined as one, control the properties of Concrete in the new state and furthermore in the solidified state. The central new properties of FRC incorporate; usefulness as far as slump and Vebe time, unit weight, air substance and warmth of hydration. The substantial should be fittingly planned so that every one of these boundaries will be satisfactorily fulfilled.

2.17.1 Workability

According to ASTM C125/C125M (2012), functionality of Concrete is characterized as the property deciding the exertion fundamental to control a newly blended measure of Concrete in with least loss of homogeneity. The term control incorporates the early-age tasks of putting, compacting, and wrapping up. Mindess *et al.* (2003) characterized the usefulness of new concrete as "the measure of mechanical work, or energy, needed to deliver full compaction of the substantial without isolation." The meaning of functionality in substantial innovation is self-evident. It is one of the significant properties that should be fulfilled. Notwithstanding the intricacy of the blend plan methodology utilized and different contemplations, for example, cost, a substantial combination that can't be set effectively or compacted completely isn't probably going to yield the normal strength and sturdiness attributes. It is notable that the consideration of any kind of short filaments to plain substantial declines the usefulness. Notwithstanding the fibre type, the decrease in usefulness is identified with the measure of the filaments utilized in substantial blend (Bentur & Mindess, 2007). Illustration of functionality test completed on stringy Concrete as indicated by ACI 544-1R (1999) is slump, Vebe time, Compacting factor, inverted cone.

2.17.2 Unit weight of fibrous concrete

Unit weight can be characterized as the mass per unit volume of new concrete. The object is to decide the unit weight and yield of newly blended Concrete. The unit weight of Concrete by and large relies upon the particular gravity of the constituent materials, the blend proportioning just as water/binder (w/b) proportion (Neville & Brooks, 2010). The unit weight of FRC diminishes when lighter sinewy materials or SCMs are utilized (Tapkin 2008; Akça *et al.*,2015). According to Karahan and Atis (2011), the unit weight of fibre supported substantial combinations containing polypropylene strands was somewhat lower than that of Concrete with no filaments. They have been additionally discovered that, as the polypropylene fibre content expanded in blend, the unit weight decreased. It very well may be ascribed to the lower explicit gravity of the polypropylene filaments (0.90-0.94). Discoveries of their work were by and large in concurrence with those acquired by Hsie *et al.* (2008).

2.18 Hardened state properties of steel FRC

As was as portrayed in past areas, concrete is by and large a strain powerless material, which is regularly broken ridden associated with solidified states, drying shrinkage, and so forth. The breaks ordinarily create with time and stresses to enter the substantial, consequently harming the solidness properties and uncovering the inside of the substantial to the dangerous fixings containing dampness, corrosive and sulphate. In this way, to refute the breaks, a battling approach has come into utilization, which blends the plain concrete in with the expansion of discrete short filaments. The steel filaments requested effect on the substantial execution presented to break opening and slippage. Besides, the filaments improved the exhibition under pressure, flexure, and strain, yet additionally under sway burdens and synthetic assaults (Zollo, 1997; Melody *et al.,* 2005; Hsie *et al.*,2008).

The mechanical Properties of FRC involves the key significant properties of FRC that empower it to opposes and send the heaps in various types of primary plan. These are likewise setting up the fundamental properties of substantial that oversee the plan of any substantial primary individuals.

2.18.1 Compressive strength

The compressive strength is quite possibly the most huge and significant properties of a wide range of Concrete. In generally primary and non-underlying applications concrete is utilized for the most part to oppose compressive burdens. In those conditions where strength in pressure or in shear is of essential significance, the compressive strength is frequently utilized as a proportion of these properties. Thusly, the few segments of substantial blend are by and large estimated as far as the compressive strength.

Moreover, it is utilized as a subjective measure for different properties of Concrete in solidified state. There is no exact quantitative relationship among compressive and flexural and rigid qualities, MOE, wear opposition, imperviousness to fire, or penetrability. All things considered, assessed or measurable connections, now and again, have been perceived and these give a lot of important data to engineers (Shetty, 2005). In the event of fibre supported Concrete, strands have moderately slight impact on the compressive strength of Concrete, and there are in everyday no unique test strategies for this property. The very tests that are utilized for the compressive strength of plain Concrete are correspondingly pertinent to FRC (Bentur & Mindess, 2007). The compressive strength of substantial blends supported with low volume parts of polypropylene strands are not altogether not quite the same as those of the plain substantial framework (Yew *et al.*, 2016; Nili & Afroughsabet, 2010), in light of the fact that the fibre content is beneath the basic volume. For sure, the compressive strength at higher fibre volume parts may here and there be diminished by around 5-10%, maybe because of the trouble in completely compacting such blends (Beaudoin 1990).

Notwithstanding, polypropylene filaments have been accounted for to be successful in expanding the malleability of Concrete (Sun & Xu 2009; Ueno et al. 2016). Opposing test outcomes have been accounted for by various specialists in regards to the impact of PP strands on the compressive strength of FRC (Zollo, 1997; Nili & Afroughsabet, 2010; Serrano *et al.,* 2016). Contrasts in the outcomes may have been brought about by the varieties in framework synthesis, kinds of fibre and volume divisions, and creation conditions. Fibre built up concrete containing pozzolanic materials has likewise been made and concentrated with ordinary Concrete (Alhozaimy *et al.*, 1996; Nili & Afroughsabet, 2010; Zhang *et al.*, 2011; Aldahdooh *et al.*, 2013).

Past analysts have tracked down that the blend of pozzolanic materials, for example, silica seethe, fly debris and palm oil fuel debris caused in more noteworthy compressive strength contrasted with that of plain Concrete especially at the later times of relieving. In addition, there is a restricted writing because of the waste rug filaments on the compressive strength of Concrete. Wang *et al.* (2000) announced that the expansion of waste rug filaments into the substantial combination brought about the decrease of compressive strength. This is a direct result of the lower strength and the nature of the strands utilized. Albeit significant work has been done on impact of PP strands on compressive strength of FC, there is no data on the consolidated impact of waste floor covering filaments and pozzolanic materials on the presentation of FC.

2.18.2 Splitting tensile strength

The elasticity is one of the essential and significant properties of Concrete. Parting rigidity test on substantial chamber is a strategy to decide the circuitous elasticity of Concrete. As depicted previously, concrete is frail in pressure in view of its fragile nature and isn't relied upon to oppose the immediate strain. The breaks create in substantial when presented to malleable burdens. Along these lines, it is fundamental to assess the rigidity of Concrete to decide the heap at which the substantial part may break (Bentur & Mindess, 2007).

The low elasticity and the high inflexibility of Concrete, incorporate it as weak materials. Extra parts are important to improve the ductile properties of Concrete. In this respects FRC has been uncovered to accomplish its capacities good (Zollo, 1997; Hsie *et al.*, 2008). Expansion of strands can generally upgrade the tractable conduct of the substantial composites, like durability, elasticity, and disappointment mode. By and large, fibre built up Concretes can be ordered into two classifications, in view of their complete elastic reactions, these are: "strain relaxing or strain solidifying".

The strain-relaxing kind of fibre built up concrete is regularly supported with a low volume of short filaments. This kind of composite, containing about 1% fibre, is typically utilized for mass field applications including colossal volumes of Concrete. For a strain-relaxing kind of disappointment, normally only one primary break is shaped in the substantial example. The strain-solidifying sort of fibre supported Concrete is ordinarily built up with a high volume of short filaments. The marvel of strain-solidifying with numerous breaks is noticed for consistent fibre built up composites, yet additionally for short fibre supported Concrete. Besides, the method of disappointment changes from strain-relaxing to strain-solidifying (Li, 2011). Strands adjusted toward the malleable pressure may achieve huge expansions in rigidity of Concrete (Alhozaimy *et al.*, 1996; Hsie *et al.*, 2008). By and by, for pretty much haphazardly circulated strands, the ascent in strength is a lot more modest, going from as little as no expansion in certain occasions to about 60% higher than that of plain concrete (Aslani & Nejadi, 2013). Dividing strain trial of FRC containing PP strands and silica rage by Nili & Afroughsabet (2010) showed the improvement in elasticity of Concrete by most extreme 14% for 0.5% fibre content when contrasted with that of plain concrete, in any case, Li *et al*. (2006) discovered an increment in parting elasticity of about 41% with 0.95% by volume PP filaments. Higher fibre volume portions, nonetheless, perform to be more compelling in strain than in pressure. Sivakumar and Santhanam (2007) discovered high elasticity of high-volume part of filaments past 2%. This upgrade in parting rigidity is unsurprising with strands as the plane of disappointment is distinct. The higher the quantity of filaments connecting the polar dividing breaks, the higher would be the parting rigidity of concrete.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Materials

The materials used to achieve the aim and objectives of the study are described in detail below. The concrete constituent materials used in this research are; Steel fibre used as binding wire by steel benders on construction site, fine and coarse aggregate, water, and superplasticizer.

3.1.1 Cement (ASTM C150/C150M, 2012)

CEM 1 (42.5 N) Portland Cement with brand name Dangote 3X was used throughout the whole series of tests in the study. The Portland Cement was stored in an airtight container in the laboratory.

3.1.2 Aggregate

3.1.2.1 Fine aggregate

River sand was utilized as fine aggregate in the concrete mix, with maximum sieve size of 4.75 mm (sieve NO. 4) following ASTM outline. The sand was evaluated; with a fineness modulus of 2.9, specific gravity of 2.6 and a water absorption of 0.70% kept up at saturated surface dry (SSD) condition before use. The SSD state of the aggregate was achieved by the addition of 3% of water content to approximately 1000 g of aggregate that was used in the production of concrete. The percentage was obtained as the ratio of the mass of SSD aggregate to the mass of equal volume of water.

3.1.2.2 Coarse aggregate

Locally available, air-dried crushed granite of 10 mm maximum size with specific gravity of 2.7 and water absorption of 0.5% was used as coarse aggregate in all the mixes. Care was taken to ensure that the aggregate is free from organic matters such as dry muds, leaves and other deleterious materials.

3.1.3 Water

Municipal tap-water supplied to the concrete laboratory was used throughout the study in mixing, curing and other purpose.

3.1.4 Admixture

A water reducing admixture was used in order to achieve a target slump. Superplasticiser (SP) of trade name CONPLAST SP 430 conforming to ASTM C494/C496M (2016) requirement was used as a water reducing admixture to enhance the workability of concrete. Owing to the high viscosity, the superplasticiser was dissolved as part of mixing water before adding to the fresh concrete mixing process.

3.1.5 Steel fibre

The Steel fibre used is from the conventional galvanized steel binding wire. The Fibre diameter measured 1.0 mm and a chopped fibre length of 40mm as presented in Plate VIII. The straight steel fibre volume fraction in the concrete varied from 0.5% to 2.0% at an interval of 0.5%.

(a) Roll of Smooth GSW (b) 40 mm chopped Smooth GSW

Plate VIII: Galvanized steel wire (GSW)

3.2 Methods

Manufacture of test specimen and test procedure for evaluating fresh and hardened state properties and the standards adopted in conducting various test on strength and durability of concrete are presented and discussed. PC and KFC that thus consistently meet the requirements of workability and strength are only achieved through the application of stringent requirements on selection of material. In this study, targeted strength of the concrete was achieved through a well-considered material proportion design and also through the use of quality materials in the concrete production. A mix proportion which is suitable for the production of PC and SFRC were determined through the preliminary test.

3.2.1 Fresh concrete test

The fresh concrete test involves the testing for workability and wet concrete density of the PC and SFRC. Details of how this test are conducted are explained in the later subsections.

3.2.2 Measurement of workability

The usefulness was estimated as far as Slump, Vebe and Compacting variable of Concrete. The goal of the test is to decide the water concrete proportion that fulfilled the plan blend, for concrete made without fibre and those containing fibre. These tests were led affected by water diminishing admixture at steady amount.

3.2.2.1 Slump of PC and SFRC (BS EN 12350-2, 2009)

Usefulness of the substantial was assessed as far as slump to give a gauge of substantial simplicity of dealing with in new state. This test technique was distinctively used to guarantee a predictable functionality. The objective slump of the substantial is in the scope of 80 - 120 mm. The method followed, in estimating the slump is as per BS EN 12350-2 (2009). Slump readings are acquired when the substantial was blended. To get a good slump of Concrete, CONPLAST SP 430 referenced before was utilized in both PC and SFRC. The slump was checked by continuous increment of SP at the pace of 1% of the total volume of concrete.

3.2.2.2 Vebe test (BS EN 12350-3, 2009)

3.2.2.3 The Vebe test portrayed in the BS EN 12350-3 (2009), measures the conduct of Concrete exposed to outer vibration which is adequate for deciding the functionality of Concrete set utilizing vibration, including SFRC. It viably assesses the portability of FRC, that is, its capacity to stream under vibration, and assists with evaluating the straightforwardness with which ensnared air can be removed.

3.2.2.4 Compacting factor test (BS EN 12350-4, 2009)

Compaction factor test is to compute the rate of compaction. This test is considered as a solid technique to assess usefulness of the substantial. The test is done in agreement to BS EN 12350-4 (2009). In the wake of doing the test, compacting factor, which is the extent of the heaviness of the somewhat compacted Concrete to totally compacted concrete, is figured. It ought to be noticed that for the scope of Concrete to be viewed as ordinary, the compacting variable ought to be inside the scope of 0.8 to 0.92. The compacting factor value is accomplished with the Equation (3.1).

$$CF = \frac{weight\ of\ partially\ compacted\ concrete}{weight\ of\ fully\ compacted\ concrete} \tag{3.1}$$

3.2.2.5 Density of fresh concrete (BS EN 12350-6, 2019)

New thickness was estimated utilizing the bowl (compartment) connected to the compacting factor gear instrument. The volume and the heaviness of void bowl were at first decided on the heaviness of bowl loaded up with new Concrete got. Example for the test is as set up in the functionality test. New thickness test in this work was done in attending with BS EN 12350-6 (2019).

3.2.3 Tests on hardened properties of PC and SFRC

The test conducted on the hardened concrete includes the compressive, tensile and the shear bond strength test. The procedure and code adopted are presented in the next subsections

3.2.3.1 Compressive strength

Compressive strength test was directed as per BS EN 12390-1 (2012) specification. Preceding the testing, the examples are properly ready, the stacking machine cleaned and the advanced unit of the machine modified with the necessary example data. A consistent stacking rate was chosen and applied until disappointment of the example. Albeit, the machine naturally produces the compressive strength information, the accompanying pressure condition was additionally used to approve the outcome.

$$f_c = F/A_c \tag{3.2}$$

Where:

f_c = the compressive strength, in newtons per mm^2

F = the maximum load at failure, in newton

A_c = the cross-sectional area of the specimen, in mm^2

3.2.3.2 Splitting tensile strength

The parting rigidity test was led as per BS EN 12390-6 (2009). Test examples of round and hollow shape adjusting to BS EN 12390-1 (2012) were utilized in this test. Flexible plywood of dimension 10±1 mm x 4±1 mm was employed in the surfaces in order to have a consistent weight spread. A steady loading rate was chosen and applied until the sample spilt into two sides of the equator. The elastic parting test results despite the fact that it was naturally produced by the testing machine; the outcomes got were additionally approved with the guide of the accompanying condition:

$$f_{ct} = 2F/\pi Ld \tag{3.3}$$

Where:

f_{ct} = tensile splitting strength, in newtons per mm^2

F = maximum load, in newtons

L = length of the specimen, in mm

d = cross-sectional dimension, in mm

3.2.3.3 Bond strength test

1) Slant shear test

A crystal test made of two indistinguishable parts fortified at 30° and tried under pivotal pressure and during stacking were utilized to quantify the inclination shear test in deciding the interface surface under pressure. The inclination shear test example size for the crystal is 100 x 100 x 200 mm in agreement to BS EN 12615 (1999) as represented in Plate IX and X.

BS EN 12615 (1999)

Plate IX: Bond Test under State of Shear and Compression Stress-square shear

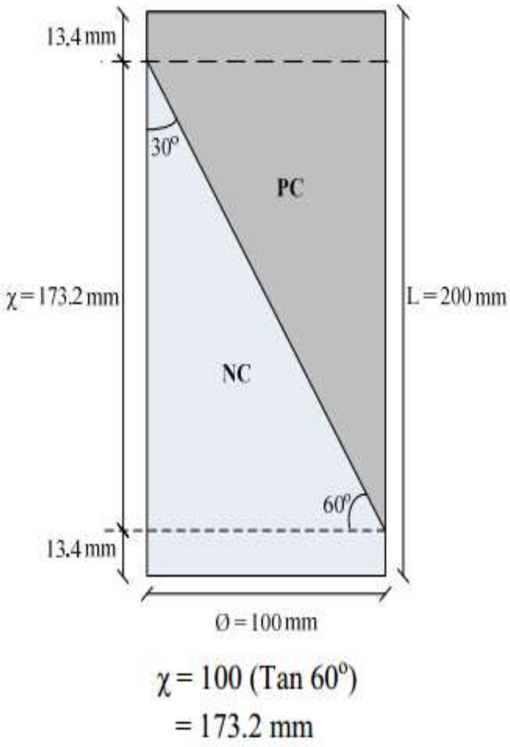


Plate X: Dimension of slanted specimen

3.3 Bond Strength Test Study Parameters (BS EN 12615 (1999).

With the end goal of this examination, three experimental parameters were utilized to comprehend the interfacial properties of overlaid concretes (new or fibrous concrete) as demonstrated in Table 3.1.

They are; (i) Moisture condition of old surface, (ii) Steel wire fibre content in new concrete and (iii) The surface texture of the old concrete substrate

Saturated Surface Dry (SSD), Wet, and Air Dry (AD) moisture conditions were made on the old concrete surface to study how the bond strength is affected by the moisture condition of the old concrete. Four different steel wire fibre volume fractions (0.5%, 1.0%, 1.5% and 2.0%) were chosen for the experiments and compared with the plain concrete (0%). steel wire fibre was added to the concrete to study its bonding effect on interfacial property.

Table 3.1 Experimental Details Showing the Study Parameters

Mix ID	Study Parameters				
	Moisture condition at the old concrete surface	Steel wire fibre volume fractions (%)	Surface texture		
			As Cast Surface	Grooved Surface	Wire Brush Surface
SSD-0	SSD	0	3	3	3
W-0	W	0	3	3	3
AD-0	AD	0	3	3	3
SSD-0.5	SSD	0.5	3	3	3
W-0.5	W	0.5	3	3	3
AD-0.5	AD	0.5	3	3	3
SSD-1.0	SSD	1.0	3	3	3
W-1.0	W	1.0	3	3	3
AD-1.-0	AD	1.0	3	3	3
SSD-1.5	SSD	1.5	3	3	3
W-1.5	W	1.5	3	3	3
AD-1.-5	AD	1.5	3	3	3
SSD-2.0	SSD	2.0	3	3	3
W-2.0	W	2.0	3	3	3
AD-2.-0	AD	2.0	3	3	3

3.4 Preparation of Plain (Old or Substrate) Concrete Specimens and Fibrous (New or Overlay halved prism samples) Concrete Specimens for Bond Test

In preparing the old concrete, one hundred and forty-seven old concrete prism sample halved at 30º (halved 100 mm x 100 mm x 200 mm) were cast at the beginning of the study. After 28 days curing, the surfaces of the halved 100 x 100 x 200 prism were referred as the old (substrate) concretes and were subsequently used as the interfaces to place new (overlay) concretes. For each test matrix, three replicas were made to find any outlier in making and testing specimens.

Air dry condition of old concrete was achieved by placing the old halved square prism sample in aggregate in the laboratory and keeping the relative humidity of 50% for two weeks before placing new concrete that is the fibrous concrete. The SSD condition was made by immersing the old concrete halved prism samples in water for one day, removing the specimen from the water, and wiping out the moisture at the surface before placing the fibrous concrete. Wet condition was made by putting the old concrete halved prism samples in water for three days, removing the specimen from the water immediately before casting new concrete without wiping surface water.

3.5 Form work Fabrication and Specimen Preparation

100 x 100 x 200 mm wooden forms were used to cast the required number of specimens at the same time. Before placing new concretes, (100x 100 x 200 mm) prism old samples with different surface moisture conditions were placed at one side of 100 x 100 x 200 mm prism samples wooden moulds (Plate XI(a) & (b)). The forms were put on the vibrating desk for vibration (about three times) until the Prism form is filled with the mixture as illustrated in Plate XI(c).

(a) Plain Concrete (Old Concrete) in form

(b) halved (100x 100 x 200 mm) prism

(c) Vibrating halved (100x 100 x 200 mm) prism in form

Plate XI: Plain Concrete specimen casting in progress (Old Concrete)

3.6 Mix Proportion

A typical concrete mix design used in this study is in accordance to the DOE method and the mix proportion is presented in Table 3.3. The maximum coarse aggregate size was 10 mm. CEM 1 Portland cement was used as cement. For all mixtures, 0.5% Superplasticizer Conplast SP 430 was used as the water reducing agent at a constant quantity with w/c ratio of 0.48. The overlaid concrete specimens were moisture cured for 28 days before the bond tests.

Table 3.2 Mix Proportion for the Plain and Fibrous Concrete

Mix No	Mix ID	Moisture condition at the old concrete surface	Steel wire fibre volume fractions (%)	Water (Kg)	Concrete (N/mm^2)	Coarse Aggregate (N/mm^2)	Fine Aggregate (N/mm^2)
1	SSD-0	SSD	0	250	521	748.5	748.5
2	W-0	W	0	250	521	748.5	748.5
3	AD-0	AD	0	250	521	748.5	748.5
4	SSD-0.5	SSD	0.5	250	521	748.5	748.5
5	W-0.5	W	0.5	250	521	748.5	748.5
6	AD-0.5	AD	0.5	250	521	748.5	748.5
7	SSD-1.0	SSD	1.0	250	521	748.5	748.5
8	W-1.0	W	1.0	250	521	748.5	748.5
9	AD-1.-0	AD	1.0	250	521	748.5	748.5
10	SSD-1.5	SSD	1.5	250	521	748.5	748.5
11	W-1.5	W	1.5	250	521	748.5	748.5
12	AD-1.-5	AD	1.5	250	521	748.5	748.5
13	SSD-2.0	SSD	2.0	250	521	748.5	748.5
14	W-2.0	W	2.0	250	521	748.5	748.5
15	AD-2.-0	AD	2.0	250	521	748.5	748.5

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 Characteristics of Coarse Aggregate

Coarse aggregate used in this research study was characterized based on its sieve analysis grading and physical properties before it is incorporated in design and mixing of concrete.

4.1.1 Physical properties of coarse aggregate

Table 4.1 presents the result of the tests carried out on the coarse aggregate to determine its physical properties. The coarse aggregate was seen to have the ability that makes it appropriate for the production of Steel Fibre Reinforced Concrete (SFRC). However, the mass passing 75μm sieve was within the maximum allowable limits given by ASTM C117/C117M (2017).

Table 4.1 Physical Properties of Coarse Aggregate

Property	Test Value	Maximum Allowable Value
Material finer than 75μm	0.7%	1%
Bulk Density (unit weight)	1432.2	1200-1750kg/m^3
Specific gravity on saturated dry density	2.67	2.40-2.90
Total Evaporated moisture content	0.65	0.10-1.13%
Void content	40%	30 – 45%

The oven dry basis bulk density was 1432.2 kg/m^3, this agrees with the report of Kosmarka *et al.*,(2002). Kosmatka, *et al.*,(2002) reported that the bulk density of coarse aggregate generally varies from 1200 to 1750kg/m^3. The specific gravity on saturated dry basis was 2.67 which was found satisfactory because most natural aggregates have specific gravity ranging between 2.4 to 2.90 (Neville, 2011).

4.1.2 Grading of coarse aggregate

The result of the sieve analysis and grading of the coarse aggregate is presented in Figure 4.1. The coefficient of gradation (Cc) from the grading curve of the coarse aggregate was 1.96. It indicates that the coarse aggregate used was well graded. A well graded aggregate, usually has a coefficient of gradation in the range of 1 to 3 (Das, 1999).

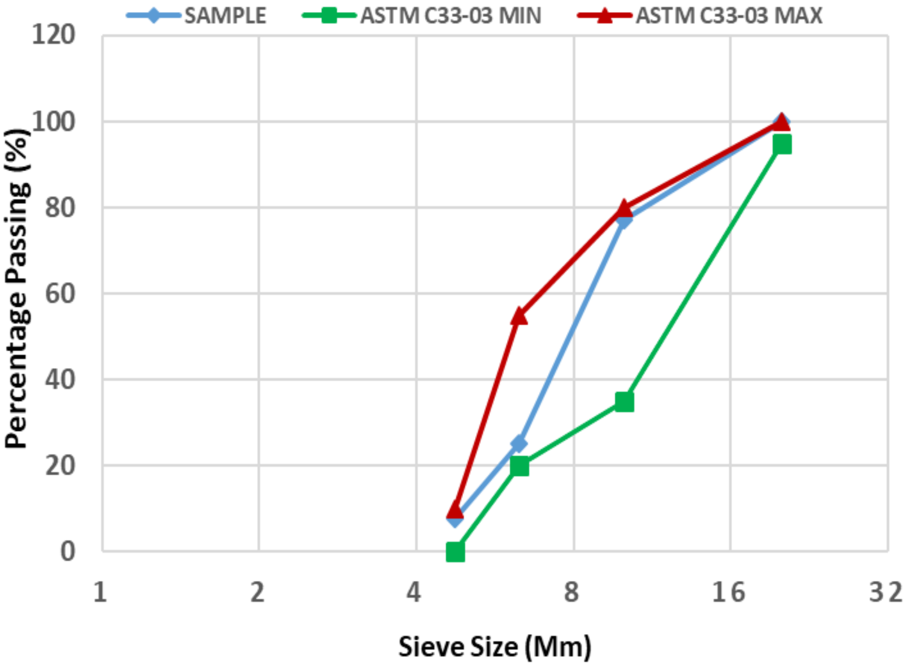


Figure 4.1: Grading of coarse aggregate

4.2 Characteristics of Fine Aggregate

The fine total was portrayed dependent on its actual properties and reviewing from strainer investigation before it was utilized into the plan and creation of the Plain concrete and steel stringy built up concrete.

4.2.1 Physical properties of fine aggregate

The aftereffect of the physical properties of the fine aggregate is given in the Table 4.2. The outcome shows that the fine total has fulfilled the essential condition for the creation of concrete. The mass aggregate passing the 75µm sieve of the fine aggregate were below the maximum permissible limits specified by the ASTM C 33 (2013).

Table 4.2 Physical Properties of Fine Aggregate

Property	Test value	Max. Allowable value
Material finer than 75µm	0.4%	1%
Oven dry basis, bulk density	1611	1200 – 1750kg/m^3
Specific gravity on saturated surface dry basis	2.64	2.40 – 2.90
Total evaporated moisture content	1.0%	0.10 – 1.13%
Void content	33.8%	40 – 50%

The oven dry basis, mass thickness of the fine aggregate was 1611 kg/m^3, the bulk density of fine aggregates is higher than that of coarse aggregate because of the decrease in void content. The void content of the fine aggregate was 33.8% which is lower compared with that of the coarse aggregate. The specific gravity on saturated surface dry basis was 2.64, which is very similar with the value for coarse aggregate. However, it was noted that there is no significance difference between the coarse and fine aggregate specific gravity.

4.2.2 Grading of fine aggregate

Figure 4.2 shows the result of fine aggregate as determined from the sieve analysis test. The coefficient of gradation is 1.0 which is not less than 1. In lieu of that, the fine aggregate was viewed as well graded.

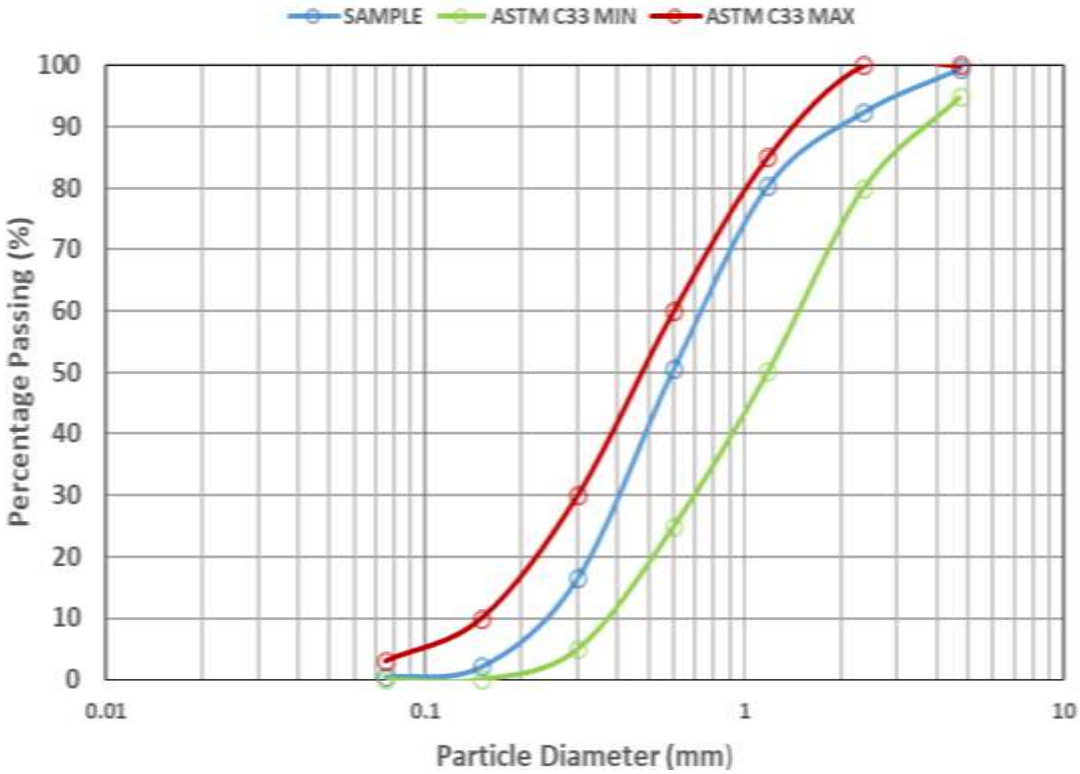


Figure 4.2: Gradation curve for fine aggregate

4.3 Results of Fresh State Properties of PC and SFRC

Two distinctive concrete mixes involving Plain concrete mix which serves in as the Old concrete for the experiment. Steel fibre reinforced concrete mix at four differing volume fraction which portrays the new cast concrete. These mixes were tested for workability and fresh density.

4.3.1 Workability tests

It has been established from past work done that steel fibre influence the workability of fibre reinforced concrete. Concrete mixture workability is a fundamental property in knowing the exact proportion of fibre volume and length. The workability property of concrete blends is measured by conducting slump cone test as indicated by BS EN 12350-2 (2009) Standard and Vebe time conforming to BS EN 12350-3 (2009). The slump value and the Vebe time of fresh concrete containing steel fibre at various level of fibre content is presented in the Table 4.3. As demonstrated in the Table 4.3, slump values of concrete diminished as the fibre volume fraction increased. The fibre reinforced concrete displayed a low slump as the fibre content increased contrasted with the fibre less concrete. This was because of the increment in the inside voids and the volume space involved by the steel strands which may bring about expanding contact between the new substantial fixings.

Meanwhile, Vebe time of concrete increased as the fibre volume fraction increased. For fibre volume of 1% and above the workability of concrete is dramatically decreased. It was observed that the interlocking of fibres resists the flow of fresh concrete, and thus affecting the workability of concrete. The test results acquired in this examination are in close concurrence with the exploration discoveries from Yazici *et al.* (2007). It has been shown that slump of Concrete diminished as the fibre volume part of steel fibre expanded. Like that of slump value, the Vebe time additionally discovered to be impacted by the fibre volume part of steel strands. With an expansion in the fibre substance of 1% to 2%, the Vebe season of the SFRC has been discovered to be pretty much twofold. This is normal since lower measure of fibre can undoubtedly scatter in the substantial network. With further addition the fibres start to clump together display a balling effect. Likewise, the interlocking and entrapment around aggregate particles significantly diminish the workability of concrete. A similar observation has been made by Uygunoglu (2010) who found that the unit weight of SFRC increased with increase in steel fibre content.

Table 4.3 Fresh Properties of the Plain and Fibre Reinforced Concrete

Mix No	Mix ID	Steel wire fibre volume fractions (v_f) (%)	Slump (mm)	Vebe time (Sec)	Fresh Density (g/mm^3)
1	PC-0	0	175	2.93	2405
2	SFRC-1	0.5	160	3.85	2420
3	SFRC-2	1.0	135	6.01	2430
4	SFRC-3	1.5	80	8.07	2445
5	SFRC-4	2.0	45	13.12	2460

4.3.2 Fresh density of concrete

Density of concrete essentially rest on the unit weight of the aggregate used in the mixture. The study of the fresh density of concrete presented in the last column in Table 4.3 shows that fresh density values increased as the steel fibre content increased in the concrete.

The result on unit weight of concrete, presented in Table 4.3 reveals that the unit weight of concrete increased uniformly with the increase in fibre volume fraction. This is obvious as the specific gravity of steel fibres is higher than those of other components of concrete. Regardless of fibre volume, it was further observed that the unit weight of the SFRC decreased by the increase of fibre volume fraction because of air content in the concrete by orientation and distribution of long fibres.

It can be seen that, although the fresh density was lower in Plain concrete as compared to those of SFRC. The SFRC unit weight is higher than 2400 kg/m3 specified by the BS code of practice (BS EN 12350-6, 2019). However, the density values for those of SFRC are in the range of 2420 – 2460 kg/m^3. Comparative observation with SFRC showed somehow a similar trend. For example, a fresh density of 2328 and 2384 kg/m^3 were reported of concrete containing 0.2% to 0.8% steel fibre (Tayfun, 2008), while 2440 – 2470 kg/m^3 was obtained by Abdul Awal *et al.* (2013) for concrete containing 0.5% to 2% recycled steel fibre.

4.4 Result of Hardened Properties of PC and SFRC

The mechanical properties of steel fibre reinforced concrete investigated in this study are compressive strength, splitting tensile strength and shear bond strength. The results obtained for all categories of strength investigated are presented in Table 4.4.

4.4.1 Compressive strength

The 28-day compressive strength values in N/mm^2 and Relative variation in Compressive strength in percent for both the Plain Concrete (Old Concrete) and the SFRC (New concrete/overlay) specimen are presented in Table 4.4. It can be seen that on average, compressive strength of SFRC are about 5.77-7.97% higher than that of Plain Concrete (Old Concrete) mixture. SFRC with fibre volume fraction of 1.0% showed the highest compressive strength. A comparable observation has been made by Abdul Awal *et al*. (2013) who reported that an addition of 1.5% steel fibres in concrete resulted in an increase of approximately 6% in compressive strength. The compressive strength of SFRC was considerable affected by the incidence of fibre in the concrete, the failure mode, nevertheless, showed a considerable transformation from brittle to ductile state. Due to bridging influence of the fibre, the cube specimens did not crush catastrophically, but held their integrity up to the completion of the test. Figure 4.4 illustrates the typical failure mode of plain concrete and steel fibre reinforced concrete.

(a) Plain concrete (b) Steel fibre reinforced concrete.

Plate XII: Typical failure mode of plain concrete and steel fibre reinforced concrete.

Table 4.4: Strength Properties of Different Concrete Mixes

Mix No	Mix ID	Steel wire fibre volume fractions (v_f) (%)	28 day Compressive strength, f_c (N/ mm^2)	Relative variation in Compressive strength R_{fc} (%)	28 day Splitting tensile strength, f_{st} (N/ mm^2)	Relative variation in Splitting tensile strength R_{fc} (%)
1	PC-0	0	45.57	0	3.11	0
2	SFRC-1	0.5	48.30	5.99	5.75	84.89
3	SFRC-2	1.0	49.20	7.97	9.23	196.79
4	SFRC-3	1.5	48.90	6.65	7.97	156.27
5	SFRC-4	2.0	48.60	5.77	6.40	105.79

4.4.2 Splitting tensile strength

The rigidity of the SFRC was found to increase with increasing measure of fibre. The relative splitting tensile strength values of SFRC according to fibre volume fraction are also given in Table 4.3. The test results indicated that splitting tensile strength of SFRCs is about 84.89-196.79% higher than plain concrete mixture. Essentially, steel fibres considerably improved the splitting tensile strength of concrete as related to compressive strength. The results obtained in this study are consistent with preceding study (Abdul Awal *et al.,* 2013).

During the splitting tensile test, the effect of the steel fibres was apparent. The steel fibres appear to control the cracking of SFRC and alter the post cracking behaviour. The steel fibres seem to provide a load redistribution mechanism after initial cracking. Unlike in fibreless concrete, it was difficult to separate the fractured specimens because the steel fibres were bridging the gap that kept the two concrete parts together, as shown in Plate XIII.

(a) Plain concrete (b) Steel fibre reinforced concrete.

Plate XIII: Failure mode of plain concrete and steel fibre reinforced concrete cylinder.

4.4.3 Shear bond strength test

Figure 4.5 displays cast surface of old concrete cube. Plate XIV(a-c), the old concrete (substrate) prism sample halved at 30º (halved 100 x 100 x 200 mm). Grooved surface exposes aggregate compared to smooth surface.

(a) The old concrete prism sample halved at 30º (halved 100 x 100 x 200 mm) Grooved surface exposes aggregate

(b) The old concrete prism sample halved at 30º (halved 100 x 100 x 200 mm) As Cast (smooth) surface

(c) The old concrete prism sample halved at 30º (halved 100 x 100 x 200 mm) Wire Brush surface texture

Plate XIV: Prism sample surface texture of cast old concrete (Plain Concrete)

4.4.4 Placing overlay (New Concrete/Fibrous Concrete)

New concrete mixture was poured into old concrete prism forms and the Overlaid Concrete Prism Specimen for Interfacial Bond testing was produced as presented in Plate XV.

(a) Placing Overlay in Form (b) Overlaid Prism (c) Weighing Overlaid Concrete Prism Specimen

Plate XV: Overlaid Concrete Prism Specimen for Interfacial Bond testing

Using the Slant shear bond test results, the measured interface shear bond strength was compared between the various surface treatment, moisture content condition and fibre volume fraction of new overlay concrete as shown in Table 4.5 and Figure 4.6. The detailed slant shear test results are presented in Table D1 in Appendix D.

4.5 The effect of three different moisture conditions at plain and fibre reinforced concrete surface on the interfacial bond strength of the composite concrete

Table 4.5 shows the interface shear bond strength results for the PC and SFRC mixture with fibre volume fraction of 0%, 0.5%, 1.0%, 1.5%, and 2.0% and moisture condition of SSD, AD and wet, respectively. From these Table 4.5, it is observed that the bond strength of the FRC samples at all moisture condition (SSD, W and AD) is higher than that of the control specimens in the presence of the three-surface texture. The bond strength of FRC with 1% fibre volume had thus improved. This improvement is influenced through grooved surface texture at SSD moisture condition of the old concrete surface.

Table 4.5: Bond Strength of Three Different Types of Surface Texture

Study Parameters					
Mix ID	**Moisture condition at the old concrete surface**	**Steel wire fibre volume fractions (%)**	**Surface texture**		
			As cast Surface S (N/mm^2)	**Grooved Surface S (N/mm^2)**	**Wire brush Surface S (N/mm^2)**
SSD-0	SSD	0	9.69	13.13	11.77
W-0	W		8.26	10.08	9.23
AD-0	AD		7.32	9.74	8.66
SSD-05	SSD	0.5	10.25	13.60	12.09
W-0.5	W		8.68	10.52	9.94
AD-0.5	AD		8.15	10.06	9.43
SSD-1.0	SSD	1.0	11.70	15.19	13.87
W-1.0	W		9.85	13.25	11.57
AD-1.0	AD		7.10	10.96	9.81
SSD-1.5	SSD	1.5	9.77	12.07	10.35
W-1.5	W		9.16	11.25	10.38
AD-1.5	AD		8.82	9.78	9.25
SSD-2.0	SSD	2.0	9.36	10.84	9.55
W-2.0	W		8.59	9.52	8.98
AD-2.0	AD		7.95	8.51	8.41

4.6 Influence of steel fibre Content on the interfacial bond strength of the composite concrete

To research the impacts of Steel fibre content on bond strength, full prism samples were set up as represented in Plate XV. Here, the substrate concrete was steel fibre free and the overlay concrete was cast with volume fraction of 0%, 0.5%, 1.0%, 1.5% and 2.0% steel fibre of constant length of 40 mm. The slant shear strengths of full square prism specimens were measured after curing in ambient conditions and for curing period of 28 days. The results are presented in Figures 4.3 with their details in Table D1 in Appendix D. This table contains the distinctive values for all specimens involved; control samples (fibre less concrete sample), the test samples containing Steel fibre with varying volume fraction of 0.5%, 1.0%, 1.5% and 2.0% throughout bond strength tests. To have a handy comparison of the results, the mean bond strengths and standard deviations are presented in Table D1 in Appendix D. According to Table D1 in Appendix D, the deviation of the values is not significant so the results are reliable.

Referring to the experimental results of this study, we get closer to the fact that the presence of steel fibre in the repair material with grooved and wire brush surface treatment as a surface texture type between new and old concrete surface, which has made the formation of the transition zone quite different. It was observed that the use of plain concrete mix decreased the bond strength while the use of fibre reinforced concrete mix as an alternative thus enhance the interfacial bond strength. Steel fibre of 1.0% produced sample with the highest interfacial bond strength of 15.19 N/mm^2 as illustrated in Figure 4.3. A rigid zone is a consequence of bridging effect formed in the overlay through the application of the steel fibre and the high elastic modulus of the fibre. It was observed that, the bond strength of samples repaired by FRC with increasing fibre content repair materials was more than the control specimen.

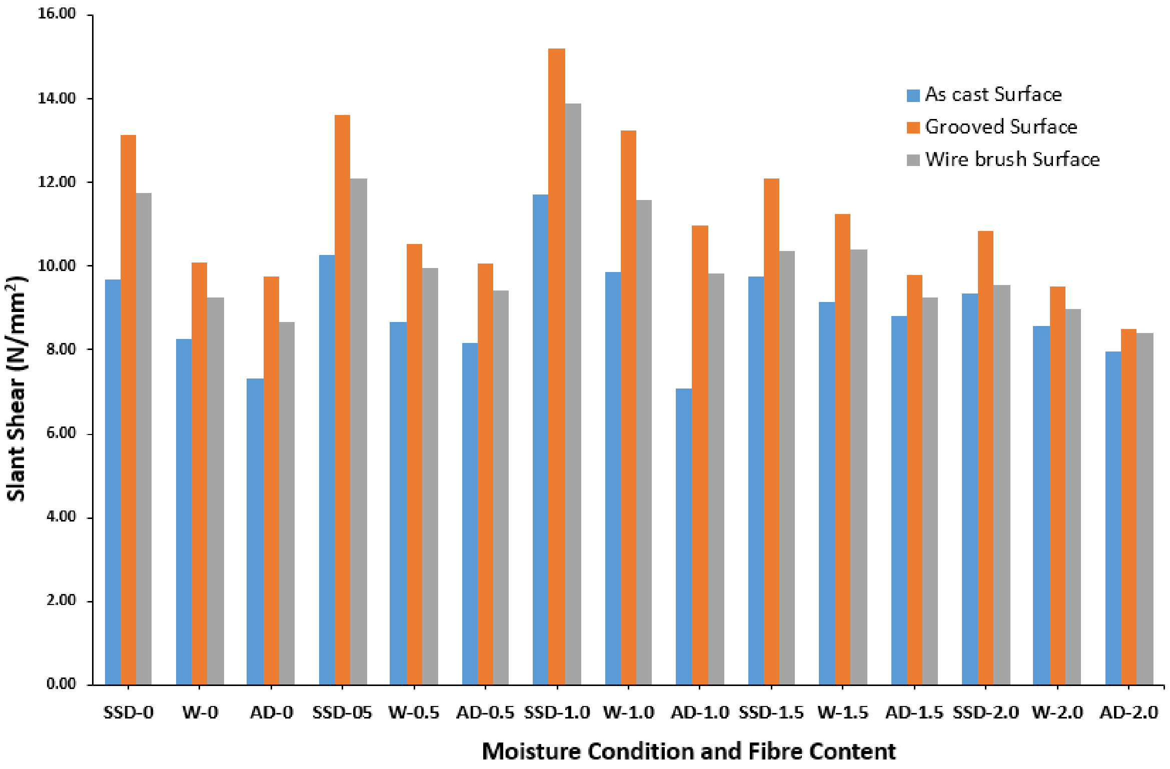


Figure 4.3 Slant Shear Strength of Concrete samples at Different Moisture Content and Fibre Volume Fraction of three different surface treatment

4.7 Influence of surface roughness (Texture) of the substrate on the interfacial bond strength of the composite concrete

In other to examine the effect of the interfacial surface texture on the bond strength of repaired concrete, three different types of surface texture were evaluated for comparison with each other. As Cast surface texture, Grooved surface texture and Wire Brush surface texture are the three different categories of surface texture used on the interfacial surface prior to pouring the repair material (FRC) on the old concrete specimen known as the substrate. The interfacial bond strength results for specimens in presence of three types of surface texture are illustrated in Figure 4.3. The observations in Figure 4.3 indicate significant difference of about 35% between the results for Grooved, Wire brush and As Cast surface texture.

The experimental results showed that the interfacial bonding for almost all the grooved surface specimens examined in this research was generally good and strong enough as the interfacial failure mostly occurred after the substrate experiencing some degree of damages. In some of the specimens, the bond strength was distinctively stronger than that of the plain concrete substrate because failure occurred mainly in the substrate without interfacial separation or debonding between the Plain Concrete substrate and the SFRC.

Figure 4.3 presents the slant shear test results corresponding to different surface texture at different fibre content of the specimens. The results generally exhibit a gradual increase in interfacial bond strength with fibre content which could be linked to the hydration of cement producing calcium silicate hydrate and increasing the strength of the SFRC as well as the interfacial bond strength of the composite. For example, in the case of no surface preparation (As Cast specimens), the average measured shear strengths were 9.69, 8.26 and 7.32 N/mm^2 for SSD, W and AD at 0% steel fibre content, respectively. The grooved surface specimens record the highest 28-day average shear bond strength of 15.19 N/mm^2 followed by specimens with wire brushed (WB) surface, with shear bond strength of 13.87 N/mm^2, respectively. Hence, the results clearly portray that the different surface preparation methods undertaken, significantly improved the shear bond strength of the composite samples when compared with the As Cast reference samples. The tremendous enhancement in the shear bond strength could generally be attributed to greater adhesion and interlocking between the SFRC and the roughened NC substrate surfaces.

According to ACI Concrete Repair Guide (Chynoweth *et al.*,1996), materials used in concrete repair work shall have a specified minimum acceptable bond strength based on the slant shear strength (refer to Table 2.1).

This guide is useful in the selection of appropriate type of repair materials for rehabilitating deteriorated concrete structures. Based on this guideline, all the roughened surface textures used in this study were able to meet the minimum bond strength as specified in Table 2.1, with the grooved method giving the highest slant shear bond strength. Furthermore, it is very obvious that the 28-day shear bond strength of 11.70 N/mm^2 for the As cast reference composite does not comply with the specified minimum value (ACI 546, 2014), which further emphasizes the necessities for surface preparation of concrete substrate in concrete repair scenario. The findings of the present study are generally in agreement with the results of previous research (Tayeh *et al.*, 2012; Garbacz *et al.*, 2005) on the influence of roughness and surface treatment on bond in concrete repair, i.e. surface preparation has strong influence on bond.

4.8 Summary of Findings

i. The average compressive strength of SFRC are about 5.77-7.97% higher than that of Plain Concrete (Old Concrete) mixture. SFRC with fibre volume fraction of 1.0% showed the highest compressive strength.

ii. The test results indicated that splitting tensile strength of SFRCs is about 84.89-196.79% higher than plain concrete mixture. Essentially, steel fibres considerably improved the splitting tensile strength of concrete as related to compressive strength.

iii. It is observed that the bond strength of the FRC samples at all moisture condition (SSD, W and AD) is higher than that of the control specimens in the presence of the three-surface texture. The bond strength of FRC with 1% fibre volume as had consequently improved. This improvement is influenced through grooved surface texture at SSD moisture condition of the old concrete surface.

iv. The presence of steel fibre in the repair material with grooved and wire brush surface treatment as a surface texture type between new and old concrete surface, which has made the formation of the transition zone quite different. It was observed that the use of plain concrete mix decreased the bond strength while the use of fibre reinforced concrete mix as an alternative thus enhance the interfacial bond strength. Steel fibre of 1.0% produced sample with the highest interfacial bond strength of 15.19N/mm^2 as illustrated in Figure 4.5. A rigid zone is a consequence of bridging effect formed in the overlay through the application of the steel fibre and the high elastic modulus of the fibre. It was observed that, the bond strength of samples repaired by FRC with increasing fibre content repair materials was more than the control specimen.

v. The results generally exhibit a gradual increase in interfacial bond strength with fibre content which could be linked to the hydration of cement producing calcium silicate hydrate and increasing the strength of the SFRC as well as the interfacial bond strength of the composite. For example, in the case of no surface preparation (i.e. As Cast specimens), the average measured shear strengths were 9.69, 8.26 and 7.32 N/mm^2 for SSD, W and AD at 0% steel fibre content, respectively. The grooved surface specimens record the highest 28-day average shear bond strength of 15.19 N/mm^2 followed by specimens with wire brushed (WB) surface, with shear bond strength of 13.87 N/mm^2, respectively. Hence, the results clearly portray that the different surface preparation methods undertaken, significantly improved the shear bond strength of the composite samples when compared with the As Cast reference samples. The tremendous enhancement in the shear bond strength could generally be attributed to greater adhesion and interlocking between the SFRC and the roughened NC substrate surfaces.

vi. Grooved surface treatment method gave the highest slant shear bond strength. it is very obvious that the 28-day shear bond strength of 11.70 N/mm^2 for the As cast reference composite does not comply with the specified minimum value (ACI 546, 2014), which further emphasizes the necessities for surface preparation of concrete substrate in concrete repair scenario.

CHAPTER FIVE

5.0 CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

This research examined the interfacial bond strength conduct of Steel Fibre Reinforced Concrete and Plain Concrete Substrate to clarify the conduct at the interface between old construction material and new rehabilitation material since the interface is the weakest connection. The compressive strength and slant shear properties of the interface between plain concrete substrate and SFRC in the examination showed that the bond strength in the slant shear test was very strong, as the interfacial failure occurred in the plain concrete substrate without interfacial separation or debonding between the plain concrete substrate and FRC.

The results of splitting tensile test show that the failure mostly occurred in the plain concrete substrate. This meant that FRC bonded very strongly and efficiently with the plain concrete substrate, resulting in composite that behaves almost monolithically.

It is observed that the bond strength of the FRC samples at all moisture condition (SSD, W and AD) is higher than that of the control specimens in the presence of the three-surface texture. The bond strength of FRC with 1% fibre volume was observed to have consequently improved. This improvement is influenced through grooved surface texture at SSD moisture condition of the old concrete surface.

Steel fibre of 1.0% produced sample with the highest interfacial bond strength of 15.19N/mm^2. A rigid zone is a consequence of bridging effect formed in the overlay through the application of the steel fibre and the high elastic modulus of the fibre. It was observed that, the bond strength of samples repaired by FRC with increasing fibre content repair materials was more than the control specimen. Based on ACI Concrete Repair Guideline, all the roughened surface textures used in this study were able to meet the minimum bond strength it specified.

5.2 Recommendations

i. Considering all inferences and appraisals from this research, 1% steel FRC, grooved surface treatment type and SSD surface condition are recommended in the production of retrofitting/repair concretes with the sole aim of achieving an enhanced interfacial shear bond strength.

ii. Further study should be performed in order to investigate the influence of pozzolan on the shear bond strength of FRC on plain concrete substrate.

iii. Further research work should be conducted to provide a simplified formula to evaluate the shear bond strength in terms of the relative compressive strength of concrete and the relative shear bond strength for the different bonding surface conditions.

iv. Further research should look into the use of different grooving method, such as zigzag grooving, double directional grooving etc.

5.3 Contribution to Knowledge

The study revealed that the bond strength of the FRC samples at all moisture condition (SSD, W and AD) is higher than that of the control specimens in the presence of the three surface texture. The bond strength of FRC with 1% fibre volume was observed to have consequently improved. This improvement is influenced through grooved surface texture at SSD moisture condition of the old concrete surface. Steel fibre of 1.0% produced sample with the highest interfacial bond strength of 15.19N/mm^2. It was observed that the bond strength of FRC was more than the control specimen.

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APPENDIX

APPENDIX A: DETAILS FOR MIX DESIGN

Appendix A1: Mix Design

STAGE 1

Mean Characteristic Strength: 30N/mm^2 28 days with Proportion Defective 5%

Standard Deviation: 8 N/mm^2

Margin: k = 1.64

1.64 x 8 = 13

Target Mean Strength: 30 + 13 = 43 N/mm^2

Fine Aggregate Type: Uncrushed

Coarse aggregates type: Crushed

Free Water Cement Ratio: 0.55

STAGE 2

Slump: 60-180 mm

Aggregate Size: 10 mm

Water Content: 250 kg/m^3

STAGE 3

For Cement Content: 250 / 0.48 = = 521 kg/m^3

STAGE 4

Relative Density of Aggregate: 2.64 assume

Concrete Density: 2268 kg/m^3

Total Aggregate Content: 2268 – 250 – 521= 1497 kg/m^3

STAGE 5

Grading of Fine Aggregate: Percentage passing 600 µm sieve 50.6%

Proportion of Fine Aggregate: 50%

Fine Aggregate Content: 1479 x 0.5 = 748.5 kg/m^3

Coarse Aggregate Content: 1479 – 8748.5 = 748.5 kg/m^3

Quantities	Cement (kg)	water (kg)	Fine Aggregate (kg)	Coarse Aggregate (10mm) (kg)
Per m^3 (to nearest 5 Kg)	521	250	748.5	748.5
Per trial mix of 0.06782m^3	26.73	13.09	59.31	66.88

Appendix A2: Batch Mix for concrete

i. Cube one Mould = 100x100x100 mm = 0.001m^3*9 NOS = 0.009 m^3

Add 20% waste = **0.009x 0.2** = 0.0018

Total volume = **0.0108 m^3**

ii. Bond prism Mould = 100x100x200 mm =0.002m^3*3 NOS = 0.006m^3

Add 20% waste = **0.006x 0.20** = 0.0012

Total volume for Full specimen = **0.0012 m^3**

Total volume for Slant specimen = **0.0006 m^3**

APPENDIX B: MIXER CAPACITY REQUIRED VOLUME = NO OF MIX

Appendix B1: Compressive Strength Cube

Cement = 521 Kg * 0.0108 **m^3** = **5.63 Kg/m^3**

Water = 250 Kg * **0.0108 m^3** = **2.7 Kg/m^3**

Fine Aggregate (FA) = 748.5Kg * **0.0108 m^3** = **8.1 Kg/m^3**

Coarse Aggregate (CA) = 748.5 Kg * 0.0108m^3 = 8.1**Kg/m^3**

Appendix B2: Bond Test Prism

i. Full Prism Specimen

Cement = 521 Kg * 0.0012 m^3 = 28.13 Kg/m^3

Water = 250 Kg * 0.0012 m^3 = 13.5Kg/m^3

Fine Aggregate (FA) = 748.5Kg * 0.0012 m^3 = 40.42Kg/m^3

Coarse Aggregate (CA = 748.5 Kg * 0.0012 m^3 = 40.42 Kg/m^3

ii. Halve Square Prism Specimen

Cement = 521 Kg * 0.0006 m^3 = 28.13 Kg/m^3

Water = 250 Kg * 0.0006 m^3 = 13.5Kg/m^3

Fine Aggregate (FA) = 748.5Kg * 0.0006 m^3 = 40.42Kg/m^3

Coarse Aggregate (CA = 748.5 Kg * 0.0006 m^3 = 40.42 Kg/m^3

Appendix B3: Fiber Volume Calculation

i. Full Prism Specimen

Density of steel fibre, ρ = 7850kg/m^3

Volume of cube mould (V_{y1}) = 0.0108m^3

For 0.5% fibre

Volume of fibres required per batch, $V_f = P_f \text{ x } V_p$ = 0.5/100 x 0.0108= 0.000054 m^3
Weight of fibre required per batch, W_f = volume of fibre req. x density of steel fibre
= V_f x ρ
= 0.000054 m^3 x 7850kg/m^3 = 0.424 kg
For 1.0% fibres = 0.424 x 2 =0.848 kg

ii. Slant Prism Specimen

Density of steel fibre, ρ = 7850kg/m^3

Volume of Full prism mould (V_{y1})= 0.0108m^3

For 0.5% fibre

Volume of fibre required per batch, $V_f = P_f \text{ x } V_p$ = 0.5/100 x 0.0108= 0.000054 m^3

Weight of fibre required per batch, W_f = volume of fiber req. x density of steel fiber = V_f x ρ

= 0.000054 m^3 x 7850kg/m^3 = 0.424 kg

For 1.0% fibre = 0.424 x 2 =0.848 kg

APPENDIX C: RESULT OF PHYSICAL PROPERTIES OF CONSTITUENTS

C1: Sieve Analysis

Table C1: Specific Gravity Of Coarse Aggregate

Weight of empty pycnometer (W1) (kg)	Weight of Pycnometer + surface dried sample (W2) (kg)	Weight of pycnometer + sample + water (W3) (kg)	Weight of pycnometer + water (W4) (kg)	Specific gravity (G)
0.116	1.153	1.702	1.063	2.90

Table C2: Bulk Density of Fine Aggregate

Weight of loose fine aggregate (kg)	Weight of compacted fine aggregate (Kg)	Volume of aggregate $(m)^3$	Bulk density of loose fine aggregate (Kg/m^3)	Bulk density of compacted fine aggregate (kg/m^3)
3.82	4.27	2.65×10^{-3}	1279.3	1611

Table C3: Bulk Density of Coarse Aggregate

Weight of loose fine aggregate (kg)	Weight of compacted fine aggregate (Kg)	Volume of aggregate $(m)^3$	Bulk density of loose coarse aggregate (Kg/m^3)	Bulk density of compacted coarse aggregate (kg/m^3)
3.692	4.333	2.65×10^{-3}	1268	1432.2

Table C4: Sieve Analysis of Fine Aggregate

S No	IS sieve designation	Weight of sieve (g)	Weight retained (g)	%of weight retained	Cumulative % of weight retained	Percentage passing (%)
1	4.75mm	376	5	0.5	0.5	99.5
2	2.36mm	397	71	7.1	7.6	92.4
3	1.18mm	367	121	12.1	19.7	80.3
4	600μm	380	297	29.1	49.4	50.6
5	300	366	341	34.1	83.5	16.5
6	150	335	144	14.4	97.9	2.1

7	75	369	17	1.7	----	-----
8	Pan	310	4	0.4	---	---
			1000	100		

Total = 258.6
Fineness modulus = 2.59

Table C5: Specific Gravity of Fine Aggregates

Weight of empty pycnometer (W1) (g)	Weight of pycnometer + surface dried sample (W2) (g)	Weight of pycnometer + sample + water (W3) (g)	Weight of pycnometer + water (W4) (g)	Specific gravity (G)
79	113	173	152	2.64

Table C6: Sieve Analysis of Coarse Aggregate

S/N	Sieve Designation (mm)	Mass Retained (g)	Percentage Retained (%)	Cumulative Percentage Retained (%)	Percentage Passing (%)
1	20	0	0	0	100
3	10	229	22.9	22.9	77.1
4	6.3	519	51.9	74.8	25.2
6	4.75	176	17.6	92.4	7.6
7	Pan	76	7.6		

APPENDIX D: DETAILS ON SLANT SHEAR TEST

Mix ID	Study Parameters							
	Moisture condition at the old concrete surface	Steel wire fibre volume fractions (%)	Surface texture					
			As cast Surface		Grooved surface		Wire brush Surface	
			P (kN)	S (N/mm^2)	P (kN)	S (N/mm^2)	P (kN)	S (N/mm^2)
SSD-0	SSD	0	193.25	9.66	255.76	12.79	236.87	11.84
			194.62	9.73	263.43	13.17	234.44	11.72
			193.38	9.67	268.54	13.43	234.65	11.73
			mean	9.69	mean	13.13	Mean	11.77
			sd	0.03	sd	0.26	sd	0.05
			Bond Quality	NBS	**Bond Quality**	ABS	**Bond Quality**	NBS
W-0	W		161.32	8.07	202.65	10.13	187.90	9.40
			168.34	8.42	203.23	10.16	183.82	9.19
			166.22	8.31	199.14	9.96	182.27	9.11
			mean	8.26	Mean	10.08	Mean	9.23
			sd	0.15	sd	0.09	sd	0.12
			Bond Quality	NBS	**Bond Quality**	NBS	**Bond Quality**	NBS
AD-0	AD		148.07	7.40	197.49	9.87	173.75	8.69
			148.36	7.42	194.77	9.74	173.26	8.66
			142.84	7.14	192.43	9.62	172.82	8.64
			mean	7.32	mean	9.74	Mean	8.66
			sd	0.13	sd	0.10	sd	0.02
			Bond Quality	NBS	**Bond Quality**	NBS	**Bond Quality**	NBS
SSD-0.5	SSD	0.5	208.92	10.45	268.65	13.43	239.92	12.00
			203.84	10.19	269.16	13.46	243.84	12.19
			202.5	10.13	278.1	13.91	241.50	12.08
			mean	10.25	mean	13.60	Mean	12.09
			sd	0.14	sd	0.22	sd	0.08
			Bond Quality	NBS	**Bond Quality**	ABS	**Bond Quality**	NBS
W-0.5	W		175.76	8.79	205.25	10.26	194.55	9.73
			173.32	8.67	206.12	10.31	199.63	9.98
			171.67	8.58	219.73	10.99	202.49	10.12
			mean	8.68	Mean	10.52	Mean	9.94
			sd	0.08	sd	0.33	sd	0.16
			Bond Quality	NBS	**Bond Quality**	NBS	**Bond Quality**	NBS
AD-0.5	AD		163.75	8.19	201.65	10.08	188.97	9.45
			163.44	8.17	203.33	10.17	188.33	9.42
			161.98	8.10	198.91	9.95	188.24	9.41
			mean	8.15	mean	10.06	Mean	9.43
			sd	0.04	sd	0.09	sd	0.02
			Bond Quality	NBS	**Bond Quality**	NBS	**Bond Quality**	NBS
SSD-1.0	SSD	1	232.21	11.61	307.21	15.36	277.65	13.88
			237.22	11.86	301.22	15.06	277.11	13.86
			232.84	11.64	302.84	15.14	277.27	13.86
			mean	11.70	mean	15.19	Mean	13.87
			sd	0.11	sd	0.13	sd	0.01
			Bond Quality	NBS	**Bond Quality**	ABS	**Bond Quality**	ABS
W-1.0	W		195.64	9.78	264.62	13.23	229.55	11.48
			196.95	9.85	262.2	13.11	231.94	11.597
			198.22	9.91	268.2	13.41	232.43	11.6215
			Mean	9.85	mean	13.250333	Mean	11.565333
			sd	0.05	sd	0.1232	sd	0.0629
			Bond Quality	NBS	**Bond Quality**	ABS	**Bond Quality**	NBS
AD-1.-0	AD		141.31	7.07	212.11	10.61	197.16	9.86
			143.3	7.17	218.74	10.94	195.60	9.78
			141.27	7.06	226.55	11.33	195.84	9.79
			Mean	7.10	mean	10.96	mean	9.81
			sd	0.05	sd	0.30	sd	0.03
			Bond Quality	NBS	**Bond Quality**	NBS	**Bond Quality**	NBS
SSD-1.5	SSD	1.5	196.89	9.84	238.65	11.93	206.23	10.31
			194.67	9.73	243.65	12.18	206.98	10.35
			194.76	9.74	242.12	12.11	207.83	10.39
			Mean	9.77	mean	12.07	Mean	10.35
			sd	0.05	sd	0.10	sd	0.03
			Bond Quality	NBS	**Bond Quality**	NBS	**Bond Quality**	NBS
W-1.5	W		183.32	9.17	225.85	11.29	207.53	10.38
			181.76	9.09	224.03	11.20	208.12	10.41
			184.54	9.23	225.10	11.26	207.41	10.37
			Mean	9.16	mean	11.25	mean	10.38
			sd	0.06	sd	0.04	sd	0.02
			Bond Quality	NBS	**Bond Quality**	NBS	**Bond Quality**	NBS
AD-1.-5	AD		176.99	8.85	196.04	9.80	184.20	9.21
			175.87	8.79	193.85	9.69	186.87	9.34
			176.17	8.81	196.92	9.85	184.08	9.20
			mean	8.82	mean	9.78	mean	9.25
			sd	0.02	sd	0.06	sd	0.06
			Bond Quality	NBS	**Bond Quality**	NBS	**Bond Quality**	NBS
SSD-2.0	SSD	2	187.76	9.39	216.00	10.80	191.93	9.60
			186.89	9.34	217.19	10.86	190.00	9.50
			187.06	9.35	217.12	10.86	190.94	9.55
			mean	9.36	mean	10.84	Mean	9.55
			sd	0.02	sd	0.03	sd	0.04
			Bond Quality	NBS	**Bond Quality**	NBS	**Bond Quality**	NBS
W-2.0	W		172.57	8.63	190.87	9.54	178.88	8.94
			171.36	8.57	189.94	9.50	179.87	8.99
			171.24	8.56	190.26	9.51	179.96	9.00
			mean	8.59	mean	9.52	mean	8.98
			sd	0.03	sd	0.02	sd	0.02
			Bond Quality	NBS	**Bond Quality**	NBS	**Bond Quality**	NBS
AD-2.-0	AD		159.83	7.99	169.00	8.45	168.66	8.43
			157.38	7.87	170.36	8.52	166.98	8.35
			159.96	8.00	171.29	8.56	168.86	8.44
			mean	7.95	mean	8.51	mean	8.41
			sd	0.06	sd	0.05	sd	0.04
			Bond Quality	NBS	**Bond Quality**	NBS	**Bond Quality**	NBS