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Mechanical Properties of Concrete Reinforced by Agave Sisalana Fiber

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Abstract:

Because of the rise in global population,the construction industry is in greater need than ever. Concrete is the most commonly used construction material due to its distinctive inherent characteristicssuch as high compressive strength, good durability, fire resistance, and low permeability, is heavily relied upon by the industry.In addition to these useful traits, the material also has some weakness such as, low tensile strength, brittleness, low resistance to cracking, and low impact resistance. To avoid these shortfalls and reinforce the concrete, fibers have been rarely added into concrete mixes. The compressive, splitting tensile and flexural strength of the concrete can be improved by adding sisal fiber to the concrete mix. Sisalfiber is one of many natural fibers that have shown great promise in recent years; it has many useful properties, including good durability, high tensile modulus, and low cost.The main aim of this research is to propose low costfiber reinforced concrete, by determining and improving the mechanical properties of sisal fiber reinforced concrete. The purpose of this study is to investigate the effect of variation in fiber content on mechanical and fresh properties of concrete reinforced with sisal fiber, as well to find the effect of water reducing agent and flyash on mechanical and fresh properties of sisal fiber reinforced concrete. For this purpose the mechanical properties, slump and density of OC, SFRC, SFRCW and SFRCFA are determined experimentally as per ASTM standards. The properties of OC are used as a reference. The proportion of 1:1.7:2.95:0.56 (cement: sand: aggregate: water) is used for OC mix. The SFRC specimens are prepared by addition of sisal fiber with 20 mm length and an amount of 1%, 2% and 3% by weight of cement, and water reducer agent is added to the SFRC mix to improve the workability of concrete as well flyash is used by partial replacement of cement.The specimens of OC, SFRC, SFRCW and SFRCFA were tested in the fresh and hardened state. The slump and densities of SFRC were less than OC for the same W/C ratio. Thus the slumps of SFRC1, SFRC2, and SFRC3 are reduced by 52%, 68%, and 92%, respectively, as compared to OC and the densities of SFRC1, SFRC2 and SFRC3 were also decreased by 14%, 16.7% and 18.5%, respectively, as compared to OC. Compressive strength of SFRC was same as OC, while by adding of WRA, the CS was slightly increased In comparison to OC. As well by adding sisal fiber to the concrete mix, an increase was also observed in the splitting-tensile and flexural strengths of SFRC, SFRCW and SFRCFA specimens

Keywords **—Sisal fiber; sisal fiber reinforced concrete (SFRC); fiber reinforced concrete; agave Sisalana and natural fiber**

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1. INTRODUCTION

Concrete is a broadly used material in construction area which is the key element of the construction industry. Due to its broad usage it has some major benefits such as low cost, high compressive strength, ability to cast in to various shapes, energy efficient, water resistant and high temperature resistant [20], while it also has some weakness such as low tensile and flexural strength, by using steel fibers become expensive, experiencing some major and minor cracks, low ductility and high weight [2, 9].Fibers are small-to-short discrete reinforcing materials produced from a combination of materials such as plastic, carbon, steel, glass and natural materials in anumber of size and forms[25]. Sisal has been one of many natural fibers that have demonstrated significant potential; it has many suitable characteristics, including durability, high tensile modulus, and low cost[26]. Kenya, Brazil, and Tanzania are the majorproducingcountries of sisal. It can be blended into the cement-based matrix to increase mechanical properties, creating sisal fiberreinforced concrete (SFRC).Addition of sisal fibers can be a solution to improve the tensile and flexural strength of concrete, minimize cracks and develop light weight concrete [4, 10].Different types of fibers such as Steel, Synthetic, Glass and Natural fibers have been used as an effective method to reinforce the concrete. In these types, natural fibers can be more cost effective to improve the mechanical and durability properties of the concrete, especially Sisal fibers due to its easy availability, low cost and impact on the environment in preventing pollution and waste materials.The main purpose of this study is to propose low cost concretereinforced with sisalfiber, by determining and improving the mechanical properties of sisal fiber reinforced concrete. The purpose of this study is to investigate the effect of variation in fiber content, as well the effect of water reducing agent and flyash onsplit tensile, flexural andcompressivestrength, workability and density of concrete reinforced with sisal fiber.

2. MATERIALS and MIX DESIGN

2.1. Materials

Portable clean water, ordinary Portland cement, locally available aggregates andsand, Water Reducer Agent, Flyash and Sisal fiber are among the components used to make OC and FRC.The aggregates utilized have a maximum size of 25 mm. As a Water reducer agent Ultra (R-310) agent is used which is a product of Ultra Construction Chemicals (PVT) LTD Pakistan. Flyash material which is a product of China and Grade E-53 ordinary Portland fresh Cement which is a product of Pakistan having strength of 10500 PSI after 28 days are used.

2.1.1.Agave Sisalana (Sisal Fiber)

Sisal fiber which was utilized in this investigation is a product of Kenyaand taken from the market which comes throughout Saudi Arabia, in the local market of Pakistan it is famous by the name of Shar (شعر). Sisal fibers are naturally available in 80-120 cm length.Table3.1 and Table 3.2 show the physical and mechanicalproperties as well the chemical compositionof sisal fiber. In this study, the fiber was cut to a length of 20 mm and blended with various amounts of 0%, 1%, 2%, and 3% added by mass of cement, respectively.

Table: Chemical composition of sisal fiber [7].

Cellulose (%)	Lignin (%)	Hemicellulose (%)
65	9.9	12

Table : Physical and mechanical properties of sisal fiber [7].

Density (g/cm^3)	Tensile strength (MPa)	Young's modulus (GPa)	Elongation on rupture (%)
1.33	600-700	38	2-3

Figure 1: Shows the fiber in cut shape [7].

Figure 2: Shows the fiber in natural shape [10].

Figure 3: Shows the plant of fiber [10].

2.2. Mix Design and Casting Procedure

The method used for concrete mix design was as per ACI 211.1-81. The aggregate maximum size was selected 25 mm. Slump and W/C ratio was selected as per ACI 211.1-81 and ACI 318-83 respectively. After several trails, the mix proportions of, cement, sand and aggregates are determined by ratio of 1:1.7:2.95 (2800 PSI) respectively with water cementratio (W/C) of 0.56.A saturated surface dry condition is used; thereforefor the concrete mix a usual w/c ratio is used.The SFRC and SFRCW mix design is the same as the OC mix design except those having content of 15%, 30% and 45% of cement partially replaced by flyash as well Water Reducer Agent are added. All materials are batched by weight.

The Automatic rotating type drum concrete mixer is used to mix the concrete. The drum of the mixer is filled with all of the components, including the water for the production of OC, and for three minutes, the mixer is rotated.

Before pouring the OC into the molds, a slump test is performed.One-third of all dry components (sand,aggregates, cement and fiber) are placed in layers in a concrete mixer to make SFRC, SFRCW and SFRCFA mixes.The process is then carried out once more in the mixer to add the remaining dry elements in the previous order. The concrete mixer is initially filled with two-thirds of the entire water and rotated for three minutes (according to a Water Cement ratio of 0.56), comparable to OC).The remaining water is pouredin the last phase, and for three minutes, the mixer is rotated again.At this point, all FRCs blends are usable, and the fibers distribution isequal.Before putting the ingredients into molds, for the OC, SFRC, SFRCW and SFRCFA,the slump tests are also conducted.These tests are carried out in the same way as testing for OC are carried out.The standard method (i.e.using three layers to fill molds and 25 blows from a 16 mm diameter rod to temper each layer) is used to fill the molds with OC.However, when filling molds with FRC Concrete, in addition to standard method, the method of elevating molds to a distance of between 165 mm – 230 mm and subsequently letting them to freely fall to the ground is used to ensurethe prevention of voidsand self-compaction caused by air from the SFRCs. It is suggested that the mostacceptableapproach among the various approaches for achieving an improved slump of SFRCs has been chosen.All specimens are cured for 28 days, except those of SFRC with Flyash are cured for 56 days before being tested.

2.3. Specimens

For OC and FRCs, cylinders are prepared with a height of 200 mm and diameter of 100 mm for splitting-tensile and compressive strength tests, as well for flexure strength testing beam shaped specimens of 150 mm wide, 150 mm deep, and 600 mm long are prepared. Theparameters of concrete in hardened state are calculated using the average of two readings. Otherresearchers have also presented their findings by averaging two results reading, including the average of the crack length (Lim et al. 2000). The average of two is also recommended by ASTM C39. Atotal of 72 specimens are prepared, including 48 cylinders and 24 beam-lets. Detail of 48 cylinders is that 12samples with OC, 4 samples for each percentage of 1%, 2% and 3% SFRC, 4 samples for each percentage of 1%, 2% and 3% of SFRCW and 4 samples with eachpercentage of 15%, 30|% and 45% of SFRCFA and detail of 24 beam-letsmean that 6 samples with OC, 6 samples with each percentage of 1%, 2% and 3% of SFRCand 6 samples with each percentage of 15%, 30% and 45% of SFRCFA after 28 and 56 days of curing testing. For OC, SFRC, SFRCW and SFRCFA samples,the labels OC, SFRC, SFRCW and SFRCFA are given respectively. The symbols C, S, and F are added tothe labels to mark the specimens used in the compressive, splitting-tensile, and flexurestrength tests, respectively. 1 and 2 were used to define the sample mark for each specimen,along with labels. And final 0%, 1%, 2%, 3%, 15%, 30% and 45% marks are used toindicate the percentage of fiber and flyash.

2.4. Testing Procedures

2.4.1 Slump and Density tests

The ASTM C143/C143M15astandard is used to determine the workability of both fresh OC and SFRC. Both OC and SFRC's hardness phase density are determined in accordance with ASTM standard C642-13. Due to the lack of appropriate standards for SFRC, the technique for determining their workability and density is same to that for OCs.

2.4.2 Compressive strength test

AUniversal testing machine (IBMU4-2000) is employedfor compressive strength in accordance with ASTM standardC39/C39M-17. Before testing, each cylinder is capped with rubber type of plate to obtain uniformload distribution.

2.4.3 Splitting-tensile strength test

A Universal testing machine (IBMU4-2000)is used to test cylindrical specimens of OC and FRCs according to ASTM C496/C496M-11standard. Splitting-tensile strength is the test output.4

2.4.4 Flexural strength test

All beam-lets are flexural strength tested using a Universal testing machine (IBMU4-2000)in accordance with ASTM standard C293 / C293M-16. To determine the modulus of rupture (MoR) Flexure strength tests are carried out.

3. TEST RESULTS and DISCUSSION

3.1. Slump and Density

The 2nd column of Tables III and Table IV shows the slump values for fresh OC, SFRC, SFRCW, and SFRCFA. The slump values of OC, SFRC-1%, SFRC-2%, and SFRC-3% are 25 mm, 12 mm, 08 mm, and 02 mm, respectively, slump values for SFRCFA is same as SFRC and the value of slump for SFRCW-1%, SFRCW-2% and SFRCW-3% is found 25mm for Water reducer agent dosage of 1%, 1.8% and 2.5% by weight of cement respectively. When compared to OC for the same water cement ratio, the SFRC has less workability. Slump values are observed to be lower in the case of SFRC than OC due to the confinement effect and hydrophilic nature of the natural fiber. When comparing SFRC samples to OC samples, a reduction in slump of 13 mm, 17 mm, and 23 mm has been noted.As a result, for the same Water cement ratio, SFRC1, SFRC2, and SFRC3slump values are reduced by 52%, 68%, and 92%, respectively, compared to that of OC.In case of SFRC3 the most reduced value of slump was observed as compared to OC, SFRC1 and SFRC2 which was because of the high percentage of sisal fiber. Other researchers also indicated that adding fibers to the concrete mixture reduces its workability [5, 7 and 28].

The densities of the specimens of hardened OC and SFRC are shown in Table III's third column, while Table IV's third column shows the densities of SFRCW and SFRCFA. Due to the low unit weight of sisal fibers, the addition of sisal fibers to the concrete mixcaused a reduction in SFRC densities as compared to OC.The densities of OC, SFRC1, SFRC2, SFRC3, SFRCW1, SFRCW2 and SFRCW3 are 137.97lb/ft3, 118.61lb/ft3, 114.87lb/ft3, 112.37lb/ft3, 134.84lb/ft3, 131.1lb/ft3 and 134.84lb/ft3 respectively and the density of SFRCFA is same as SFRC. When compared to OC, a decrease of 19.36lb/ft3, 23.1lb/ft3, 25.6lb/ft3, 3.13lb/ft3, 6.87lb/ft3 and 3.13lb/ft3 is observed in densities of SFRC1, SFRC2, SFRC3, SFRCW1, SFRCW2 and SFRCW3, respectively. Hence, the densities of SFRC1, SFRC2, SFRC3, SFRCW1, SFRCW2 and SFRCW3 are reduced by 14%, 16.7%, 18.5%, 2%, 4.9% and2%, respectively in comparison to that of OC, while density of SFRCFA is reduced same as SFRC. As a result, SFRC3 has the lowest density among the SFRC. This is because the high percentage of sisal.

Table □:W/C ratio, slump and density of OC and SFRC

Batch (1)	Slump (mm) (2)	Density (lb/ft^3) (3)
OC	25	137.97
SFRC-1%	12	118.61
SFRC-2	08114.87	
SFRC-3%	02	112.37

Table □:W/C ratio, slump and density of OC, SFRCW and SFRCFA

Batch (1)	Slump (mm) (2)	Density (lb/ft^3) (3)
OC	25	137.97
SFRC1-W1	25	134.84
SFRC2-W1.8	25131.1	
SFRC3-W2.5	25	134.84
SFRC1-FA15	12	118.61
SFRC2-FA30	08	114.87
SFRC3-FA45	02	112.37

Figure 4: Shows slump values of OC, SFRC1, SFRC2, and SFRC3

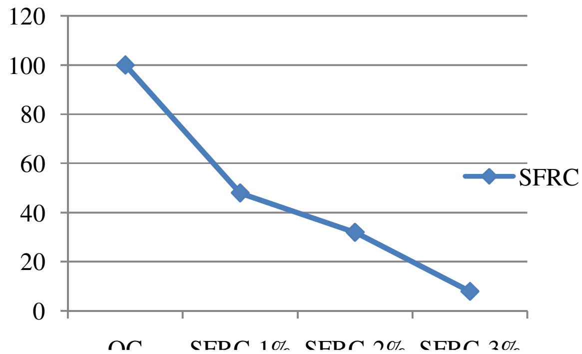
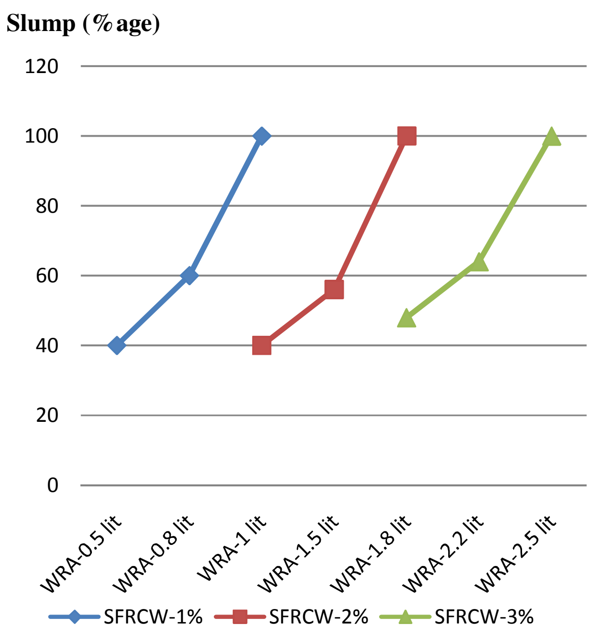


Figure 5: Shows slump values of OC, SFRCW1, SFRCW2, and SFRCW3

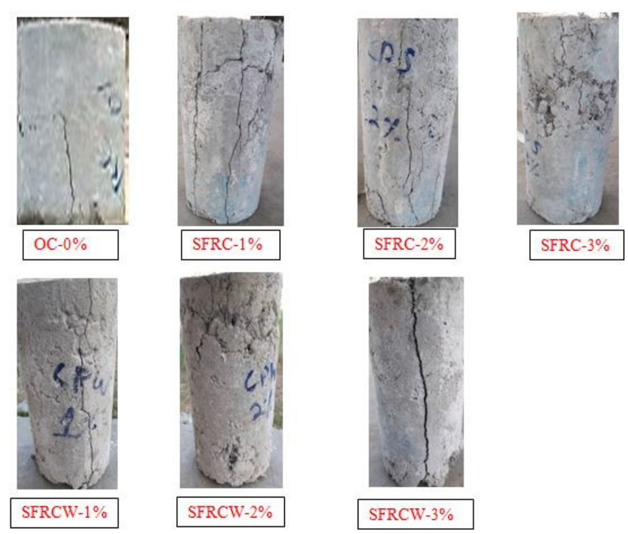


Compressive Properties

3.2.1. Compressive Behavior

Figure 6 shows cracks development in the cylinder-shaped specimens of SFRC and SFRCW under compressive forces respectively. In this research work, it was found that SFRC, SFRCW, and SFRCFA under peak load has less cracks and those mentioned cracks were shorter and has less width than those in OC. The SFRC specimens show a relative ductile/tough mode of failure and do not split apart when subjected to maximum load. On the other hand, OC results in a detached portion of the specimen. Concrete with sisal fiber bridges the cracks to prevent deformation. Sisal fiber usage results in more frequent, close-spaced cracks with smaller and shorter crack lengths. Duetoits low crushing strength, OC specimen final failure occurs along a narrow region, where the aggregate particles were surrounded by fewer cement particles, Aggregate breaking is also seen in thecase of OC. While In the case of SFRC, SFRCW, and SFRCFA,at the maximum load after the test was finished, when the specimens were intentionally broken mostly Instead of fiberbreaking, the de-bonding of fiber in the concrete mix was observed.

Figure 6: Shows development of cracks in the cylindrical specimens of SFRC and SFRCW under compressive load



3.2.2. Compressive Strength

The compressive strength of 2800PSi, 2655PSi, 2728PSi, and 2831PSiwas observed for OC, SFRC1, SFRC2, and SFRC3, respectively. While on the other hand, the compressive strength of SFRCW1, SFRCW2, SFRC3, SFRCFA1, SFRCFA2 and SFRCFA3 was observed 3311PSi, 2853PSi, 2408PSi, 2270PSi, 2038PSi, and 1902 PSi respectively. In comparison to compressive strength of OC, a reduction of 145Psi, 72 Psi, 392 Psi, 530 Psi, 762 Psi and 898 PSi was observed in compressive strength of SFRC1,SFRC2, SFRCW3, SFRCFA1, SFRCFA2 and SFRCFA3 respectively. While in comparison to that of OC, an increase of 31 Psi, 511 Psi and 53 Psi was observed in compressive strength of SFRC3, SFRCW1, and SFRCW2 respectively. As a result the high increase in the compressive strength was observed 511 Psi for SFRCW1. [5]Also reported that sisal fiber cannot improve the compressive strength of concrete, while in SFRC3 a slight increase is observed in CS.Better compaction in OC, SFRCW1 and SFRCW2 than in SFRC1 and SFRC2 may be the cause of their considerably high compressive strength. The addition of lower sisal fiber may be the cause of the SFRC1 and SFRC2's decreased compressive strengths or another possible reason may be the fiber length. While the cause of reduction in CS for SFRCW3 could be the high percentamount of WRA. [28]Also reported that with increase in the ratio of super plasticizer, compressive strength is decreased. In order to reduce deformation, the addition of fiber has reduced the size of cracks and bridged them. As a result use of WRA improves the workability of concrete; fill the pores in the concrete which results to obtain well compacted concrete, thus the compressive strength of the concrete can be improved by addition of sisal fiber with WRA.

Table □: Compressive Strength (Psi) of OC, SFRC and SFRCW

Fiber amount	**Concrete type**				
	OC (1)	**SFRC (2)**	**SFRCW1 (3)**	**SFRCW1.8 (4)**	**SFRCW2.5 (5)**
0%	2800	-	-	-	-
1%	-	2655	3311	-	-
2%	-	2728	-	2853	-
3%	-	2831	-	-	2408

Table VICompressive Strength (Psi) of OC and SFRCFA

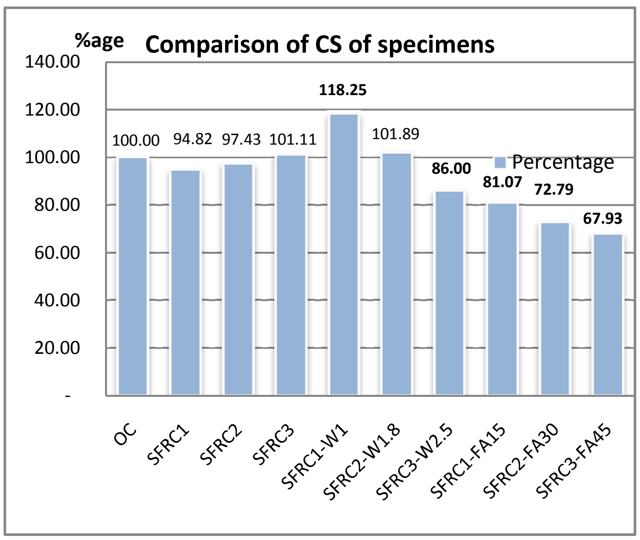
Fiber amount	**Concrete type**			
	OC (1)	**SFRFA15 (2)**	**SFRFA30 (3)**	**SFRCFA45 (4)**
0%	2800	-	-	-
1%	-	2270	-	-
2%	-	-	2038	-
3%	-	-	-	1902

The comparison of compressive strength ofOC, SFRC1, SFRC2, SFRC3, SFRCW1, SFRCW2, SFRCW3, SFRCFA1, SFCRFA2 and SFRCFA3 can be presented in the Figure 7. In compressive strength of SFRC1, SFRC2 and SFRCW, the reduction of 5.18%, 2.57% and 14% was observed than that of OC. The SFRC1 and SFRC2compressive strength is slightly decreased, which is in the limit as per (ACI 26.12.4.1). While the SC of SFRCW3 was decreased, may be because of high percentage or WRA. As well a decrease of 18.93%, 27.21% and 32.07% in the CS of SFRCFA1, SFRCFA2 and SFRCFA3 is observed respectively. That is because of the partial replacement of cement by flyash, in which the partial replacement of cement is 15%, 30% and 45% respectively, another reason may be the reduced strength at the early stage of the concrete.[18]Have also reported that by using flyash at the age of 56 up to 180 days, there was a considerable increase in concrete strength.

Additionally an improvement of 1.11%, 18.25% and 1.89% is observed in CS of SFRC3, SFRCW1 and SFRCW2, respectively. The improvement may be because of the better compaction and filling up the pores due to the usage of WRA. So, by using lowerlength of sisalfiber the compressive strength of concrete may beincreased.

The SFRC demonstrates better results in terms of improved CS by comparing the compression strength test results of the tested specimens. This ensures that SFRC with WRA can have a better compressive strength result than that of OC.

Figure 7: Shows Comparison of compressive strengths of OC, SFRC, SFRCW and SFRCFA



3.3.Splitting-TensileProperties

3.3.1. Splitting-Tensile Behaviour

In order to determine a concrete cylinder's tensile strength, this method of indirect tension testing is used.The anticipated splitting-tensile behavior is seen throughout the testing of OC, SFRC, SFRCW, and SFRCFA specimens. Figure 8 show the crack development in OC,Figure 9 show the crack development inSFRC and Figure 10show the crack developmentin SFRCW. The OC specimen breaks into pieces immediately after the first crack appears, without a time lag, whereas the SFRC specimens are kept together by the confining effect of the fiber in the samples.In SFRC, SFRCW, and SFRCFA, the observed number of cracks, crack length, and crack width at the peak load are lower than in OC.To study the behavior of the specimen,even after the peak load the test is kept going. There are several cracks at the extreme load, with OC having the largest crack.As anticipated, the first crack in all three cases SFRC, SFRCW, and SFRCFA is smaller than the cracks generatedby theextreme andpeak loads.This demonstrates that when the concrete began to crack, the fiberinsures that the material would behave toughly by preventing the development and propagation of cracks.Therefore, by adding sisalfiber, concrete can enhance its post-cracking behavior and avoid being as brittle.In order to observe the fiber failure in the case of the SFRC, the cylinders were appropriately split into two parts. As per to the visual inspection of the SFRC cylinders, the ratio of fiber pull-out to fiber fracture on the ruptured surface is approximately 20:80. Because of its weak bond strength and higher tensile strength, sisal fiber exhibit that highest de-bonding and least amount of fiber fracture. Because the fibers were only partially embedded in eachof the half broken side of cylinder, there was a fiber pull-out.

Figure 8: Shows development of cracks in the cylindrical specimens of OC under splitting-tensile load

Figure 9: Shows development of cracks in the cylindrical specimens of SFRC under splitting-tensile load

Figure 10: Shows development of cracks in the cylindrical specimens of SFRCW under splitting-tensile load

3.3.1. Splitting-Tensile Strength

The maximum load value from the splitting tensile load time histories is taken for the consideration anddetermining of the splitting tensile strength (STS). Table VII and TableVIII displays the STS of OC, SFRC1, SFRC2, SFRC3,SFRCW1, SFRCW2, SFRCW3, SFRCFA1, SFCRFA2 and SFRCFA3. The STS of 341 PSi, 349 PSi, 361 Psi, 300 Psi, 342 Psi, 349 Psi, 296 Psi, 330 Psi, 366 Psi and 288 PSi are observed for OC, SFRC1, SFRC2, SFRC3, SFRCW1, SFRCW2, SFRCW3, SFRCFA1, SFCRFA2 and SFRCFA3, respectively. In comparison to STS of OC, a decrease of 41 PSi, 45 Psi, 11 PSi and 53 PSiwereseen in the STS of SFRC3, SFRCW3, SFRCFA1 and SFRCFA3, respectively. Additionally the STS of SFRC1, SFRC2, SFRCW2 and SFRCFA2 have increasesby8 Psi, 20 PSi, 8 Psi and 25 PSirespectively.As observed in the current investigation by addition of sisal fiber, in case of SFRC[2 and 5]alsofound an increased value in STS of concrete.

Table I: Splitting-tensilestrength (Psi) of OC, SFRC and SFRCW

Fiber amount	Concrete type				
	OC (1)	SFRC (2)	SFRCW1 (3)	SFRCW1.8 (4)	SFRCW2.5 (5)
0%	341	-	-	-	-
1%	-	349	341	-	-
2%	-	361	-	349	-
3%	-	300	-	-	296

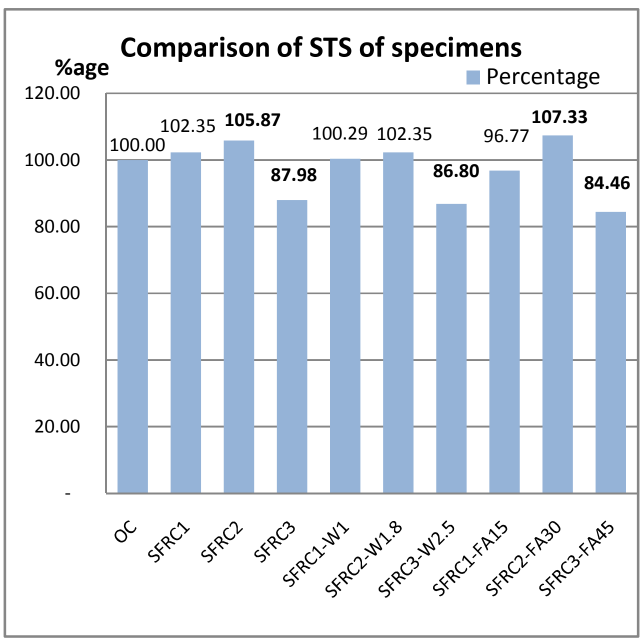
Table II: Splitting-tensilestrength (Psi) of OC and SFRCFA

Fiber amount	Concrete type			
	OC (1)	SFRCFA15 (2)	SFRCFA30 (3)	SFRCFA45 (4)
0%	341	-	-	-
1%	-	330	--	
2%	-	-	366-	
3%	-	-	-	288

The STS of OC, SFRC, SFRCW and SFRCFAis compared in Figure 11. When compared to OC, a reduction of 12.02%, 13.2%, 3.23% and

15.54% is observed in STS of SFRC3, SFRCW3, SFRCFA1 and SFRCFA3, respectively.In comparison to that OC,an improvement of 2.35%, 5.87%, 2.35%, and 7.33% is found in the STS of SFRC1, SFRC2, SFRCW2, SFRCFA2 respectively. According to the test results of the splitting-tensile tests performed on the OC, the SFRC2, SFRCW2, and SFRCFA2 demonstrate better results in terms of improved STS than that of OC. The increase in the STS for SFRC2 may be becauseof thehigh tensile strength anduniformly distributionof sisal fiber. The uniformly distribution of fiberutilizes that the maximum number of fiber is used to increase the SFRC's strength. Due to its better splitting-tensile properties, it can be derived that cracks can be effectively controlled by using SFRC caused by tensile stresses.

Figure 11: Shows Comparison of splitting-tensile strengths of OC, SFRC and SFRCFA

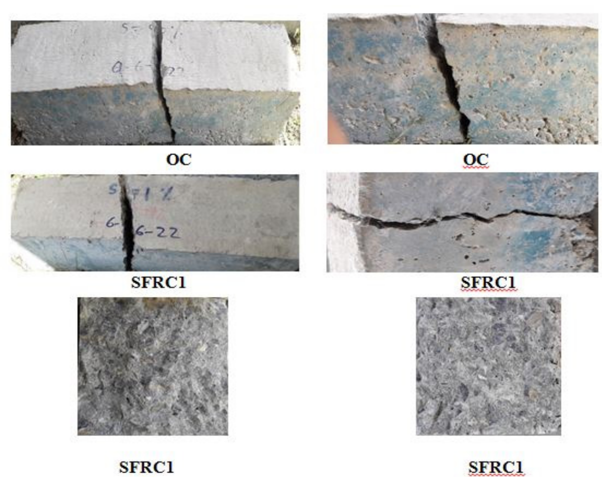


3.4.FlexuralProperties

3.4.1. Flexural Behaviour

Figure 12 shows the crack development in OC and SFRC beam-lets.In comparison to OC beam-lets, the length and width of the first crack in SFRC beam-lets is considerably smaller.All of the OC and SFRC beam-lets can be seen to break apart into two pieces.SFRC, SFRCW, and SFRCFA showed less cracks with a shorter length and width as compared to OC.The SFRC beam-lets are carefully split into two parts to inspectand observe failure of fiber.Visual examination of the surfaces fracturedincase of SFRC and SFRCW reveals that the ratio offiber pull-out from the matrix to thefiberfracture is approximately 20:80. For the pull-out and fracture of fibers on the broken surface of the samples, a failure of fiber ratio of approximately 30:70 is noted in SFRCFA beam-lets.Visual examination of the broken surfaces of the SFRC beam-shape specimens reveals that sisal fibers are much more uniformly distributed and dispersed in the concrete mixture.The reasons why the fibers in the flexure test pulled out and broken were the same as those covered in the chapter on "splitting-tensile behaviour.

Figure 12: Shows the crack development in OC and SFRC beam-lets



3.4.2. Flexural Strength

It should be noted that for the OC beam-let, the load at first crack and peak load are identical because the beam-let was split in half at these points. Table IX and Table X display the MoR of OC, SFRC, SFRCW, and SFRCFA. The values of 640 PSi, 803 PSi, 681 PSi, 664 Psi, 685 Psi, 721 Psi, 744 Psi, 640 Psi, 586 Psi and 560PSi, are observed for MoR of OC, SFRC1, SFRC2, SFRC3, SFRCW1, SFRCW2, SFRCW3, SFRCFA1, SFRCFA2 and SFRCFA3, respectively. As compared to that of OC, the MoR of SFRC1, SFRC2, SFRC3, SFRCW1, SFRCW2 and SFRCW3 improves by an amount of 163 PSi, 41 Psi, 24 Psi, 45 Psi, 81 Psi and 104 PSi respectively. Additionally, according to a similar pattern, an increase in the MoR for sisal fiber was also reported by [8 and 4].

Table IX: Flexuralstrength (Psi) of OC, SFRC and SFRCW

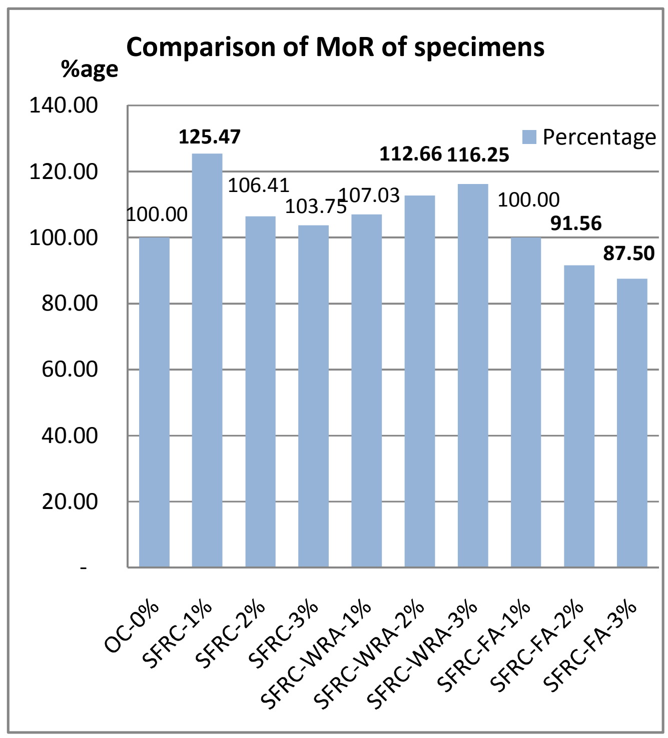
Fiber amount	Concrete type				
	OC (1)	SFRC (2)	SFRCW1 (3)	SFRCW1.8 (4)	SFRCW2.5 (5)
0%	640	-	-	-	-
1%	-	803	685	-	-
2%	-	681	-	721	-
3%	-	664	-	-	744

Table X: Flexuralstrength (Psi) of OC and SFRCFA

Fiber amount	Concrete type			
	OC (1)	SFRCFA15 (2)	SFRCFA30 (3)	SFRCFA45 (4)
0%	640	-	-	-
1%	-	640	--	
2%	-	-	586-	
3%	-	-	-	560

Figure 13shows the comparison of MoR, of OC, SFRC, SFRCW, and SFRCFA. In comparison to that of OC, an increase of 25.47%, 6.41%, 7.03%, 12.66% and 16.25% is observed in MoR of SFRC1, SFRC2, SFRC3, SFRCW1, SFRCW2 and SFRCW3 respectively.While a decrease of 8.44% and 12.50% is observed in MoR of SFRCFA2 and SFRCFA3 respectively. As per the results of flexural strength tests for the SFRC, SFRCW and SFRCFA, the SFRC1 showedbetter result in terms of enhanced MoR as compared to OC, SFRCW and SFRCFA. Due to the improved flexural properties of SFRC and SFRCW, It is possible to conclude that SFRC will likely perform magnificently in preventing concrete cracking.

Figure 13: Shows the Comparison of Flexural strength (MoR) of OC, SFRC, SFRCW and SFRCFA



4. CONCLUSION

Based on the results of our investigation, the following findings and conclusions can be drawn on SFRC:

1. For the same W/C ratio, the slumps of SFRC1, SFRC2, and SFRC3 are reduced by

52%, 68%, and 92%, respectively, as compared to OC. The required slump was achieved, when WRA of 1 lit/100 kg cement, 1.8 lit/100kg cement and 2.5 lit/100kg cement are added to SFRCW1, SFRCW2 and SFRCW3 respectively The densities of SFRC1, SFRC2 and SFRC3 are also decreased by 14%, 16.7% and 18.5%, respectively, in comparison to that of OC.

2. In comparison to OC, compressive strength of SFRC was same as OC, while by adding of WRA, the CS was increased, in which the maximum amount of 18.25% increase was observed for SFRCW1, as a result for compressive strength 1% is the optimum amount for sisal fiber with WRA.
3. As compared to OC splitting-tensile and flexural strengths of SFRC, SFRCW and SFRCFA was increased, in which the percentage of increase for STS was observed 5.87%, 2.35% and 7.33% for SFRC2, SFRCW2 and SFRCFA2, respectively. As well the maximum percentage of increase for flexural strength was observed 25.47% for SFRC1. This indicates that 2% is the optimum amount of sisal fiber for splitting tensile strength, and 1% is the optimum amount for flexural strength (FS).
4. While by adding 3% of sisal fiber, a decrease in the STS was also observed, which may be because of the high amount of fiber and WRA. As well a decrease was also seen for SFRCFA, which may be due to the reduced strength at early stage of the flyash concrete, which could be increased by testing the specimens at an age of 56 to 180 days.

5. RECOMMENDATION

Following are the recommendations:

- Further investigation is needed on sisal fibers reinforce concrete with different fiber lengths.
- Investigation is also needed on SFRC with flyash (SFRCFA) to be tested at an age of 56 to 180 days.
- Further investigation is also needed on durability properties of R-310 Type D, Water reducer agent.

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