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Strength Properties of Fibre-Reinforced Self-Consolidating Concrete with Foundry Waste Sand

R. Elangovan

Abstract*— This study presents a comprehensive overview of replacing natural river sand (FA) with foundry waste sand (FWS) in fibre-reinforced high strength self-consolidating concrete (SCC). Fine aggregate (FA) was replaced with FWS, proportions varying from 0% to 70%. To maintain workability in the SCC mix, chemical admixtures were added. During fresh state, properties of SCC like filling and passing ability, segregation resistance were studied. Assessment results indicated a moderate reduction in workability, slump flow decreased by 4% over control mix, for 70% replacement of FA with FWS. SCC mixes were prepared with different FWS contents and evaluated for density, modulus of elasticity, compressive, flexural and split tensile strengths. The compressive strength increased by 6% to 8%, flexural strength by 2% to 4% and split tensile strength by 2% to 3% when the FA was partially replaced by 20% with FWS. Density of SCC increased by 6.5% and modulus of elasticity decreased by 10% for 70% replacement of FA with FWS. From the assessment outcome, it can be resolved that FWS could form a dependable alternative source for natural river sand replacement in high strength SCC.

Index Terms*— Self-consolidating concrete, waste foundry sand, slump, strength, segregation, filling ability, passing ability.

I. INTRODUCTION

Self-consolidating concrete is a breakthrough in concrete technology as a result of improved performance and working environment. Its success is due to reasons like versatility, adoptability, formability and economy. However, sustainability of concrete construction is a cause for concern. In spite of the recent advancements in concrete technology, sustainability of concrete construction is still questioned for a number of reasons (Metha, 2004) [13]. Considering the volume of materials consumed for producing concrete, greenhouse gas emissions contributing significantly to the global warming and the durability failure of concrete structures are the reasons. Sustainability is an issue that affects us all.

Today's world is witnessing a major increase in the construction activities. Growth in construction activities requires the availability of cement and natural aggregates. But non-availability of natural aggregates in sufficient quantities slows down construction. Hence it is time to look for alternate materials for sustainability in construction.

Industrial and commercial activities generate various types of waste materials. These materials must be safely disposed or economically recycled. Some of these waste materials may be used in construction activities. The use of commercial, industrial wastes in construction limits the utilization of natural reserves, formulates an economical disposal method for the wastes as well.

Foundry Waste sand is a good quality silica sand with homogeneous properties. FWS is basically fine aggregate. It gets generated during the manufacture of metal castings. FWS may be either moulding sand or polymer bonded sand. The colour of moulding sand is black to grey, polymer bonded sand is off-white. Moulding sand consists of silicon dioxide 80-95%, clay 0-15%, additives 0-10% and water 0-5%. Polymer bonded sand may contain silicon dioxide 93-99% and polymer binder 1-3%. FWS has similar properties of natural sand, can be used in construction as a replacement to natural or manufactured sand. Even though many research works carried out in other countries on using FWS for producing cement mortar and concrete, less research work has been accomplished in India to utilise FWS as FA to manufacture SCC in Indian environment.

II. LITERATURE REVIEW

Serious research is taking place at several locations in the world for potential large scale adoption of FWS as an alternate material for FA to manufacture high performance concrete. Results disclosed by several researchers have demonstrated the use of FWS in construction works such as road constructions and asphalt concrete [1, 17, 21], concrete, precast concrete, bricks, blocks and paving stones [11, 12, 14, 16, 18-20].

Mustafa Sahmaran, Mohamed Lachemi, Tahir K Erdem and Hasan Erhan Yucel [12] examined the usage of FWS in SCC, concluded that neither bleeding nor segregation was present in fresh concrete. The test results fulfilled the requirements of EFNARC guidelines. Y Guney, YD Sari, M Yalcin, A Toucan and S Donmez [22] demonstrated that FWS reduced the workability of concrete. Tarun R Naik, Rudolph N Kraus, Yoon-Moon Chun, Bruce W Ramme and Shiw S Singh [20] conducted various tests using FWS dust in self-consolidating concrete. Recep Bakis, Hakan Koyuncu and Ayhan Demirbas [15] tested the possible utilization of FWS in road construction. JM Khatib and DJ Ellis [11] investigated the mechanical properties of concrete manufactured with different FWS as a replacement of FA.

III. RESEARCH SIGNIFICANCE

Even though construction of buildings and other structures lead to economic development of a nation,

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R. Elangovan, Civil Engineering Department, Sri Krishna College of Engineering and Technology, Coimbatore, T.N, India. (E-mail: elangovanr@skcet.ac.in)

positively impacting the quality of life, higher production of cement, continuous large scale mining of aggregates for construction destroys the environment. This exploitation changes the climatic conditions, decrease in ground water table, flooding and non-uniform rain fall pattern.

Every day, large volumes of waste materials are produced due to commercial and industrial activities. These wastes must be safely disposed or economically recycled. Waste materials may also be reused in construction related works. It is necessary to identify the area where the waste materials can be effectively used and suitable technology to use them. India produces 15 million metric tons of FWS annually. 80-90% of this material is disposed off in land fillings. Instead this may be used in construction to make SCC. Cost saving, performance enhancement and the quest to introduce an alternate material to natural river sand or manufactured sand are the forces behind this investigation.

IV. RESEARCH OBJECTIVES

This investigation examines the influence of FWS on the strength properties of SCC when used as a replacement to natural river sand or manufactured sand, reducing the consumption of river sand in construction. This would minimize the environmental impact due rapid exploitation of the environment for natural aggregates. This investigation concentrates on the following three crucial aspects.

1. To test whether FA can be replaced partially or fully with FWS to make SCC.
2. If yes, determine the correct replacement percentage of FWS.
3. To design a SCC mix containing FWS, verify its characters at fresh and hardened state.

V. EXPERIMENTAL PROGRAM & RESULTS

A SCC mix was designed with a characteristic compressive strength of 50 MPa. Ordinary Portland Cement (OPC), grade 53 was used to prepare the SCC mix. Aggregates used were river sand as FA and crushed granite as CA. The FA used in the mix was replaced gradually by 10% up to a maximum of 70% with FWS. Potable water was used to cast and cure SCC specimens. Superplasticizer (SP) - Glenium B233, Viscosity Modifying Admixture (VMA) - Glenium Stream II had been added to improve concrete properties at fresh state. After mixing, the SCC mixes were tested to verify flowability, filling ability and segregation resistance, the SCC mixes were then casted. After necessary curing, the specimens were allowed to dry and tested to determine density and the mechanical properties of SCC. The research methodology adopted is listed in figure 1.

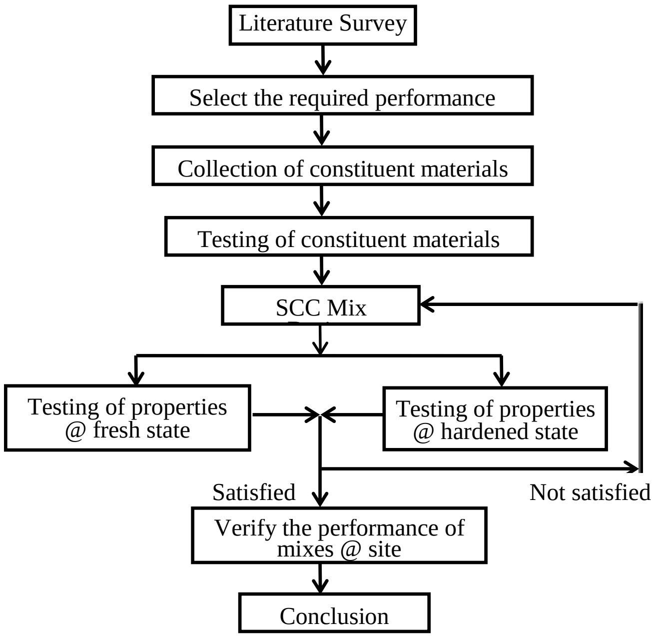

Figure 1 Research Approach

A. Materials

Cement

OPC grade 53, as per IS 1489-1991[9] was utilized for producing the SCC specimen. The properties of cement are fineness (based on the weight of residual cement) 7%, Specific Gravity of cement 3.12, Initial setting time of cement 40 min, 240 min final setting time, Soundness (Le-chatelier – mm) 1.0 mm. The cement sample developed compressive strength was 30.5 MPa on day 3, 45.5 MPa on day 7 and 57 MPa on day 28.

Fine Aggregate

Natural river sand available locally as per ASTM C33 / C33M – 13[2] was used as FA with size varying from 0.075 mm to 4.75 mm. The properties of FA belonging to zone II with fineness modulus 2.67, absorption of water 1.09%, free from clay / organic matter, Bulk Density (dry rodded) was 1615 kg/m^3 and Bulk Density (loose) 1415 kg/m^3, specific gravity 2.76.

Coarse Aggregate

Coarse aggregate was crushed angular granite aggregates, 8 mm to 12.5 mm size, as per ASTM C33 / C33M – 13 [2]. The properties of CA are specific Gravity 2.62, Fineness modulus 5.89, bulk density (loose) of CA 1285 kg/m^3 and bulk density (dry rodded) of CA 1482 kg/m^3.

Steel Fibres

Glued steel fibres conforming to ASTM 820 & EN-14889 standards, dosage of steel fibres is 0.5%, aspect ratio 65 and the tensile strength is 1100 MPa.

Fly Ash

Fly ash with light grey color, specific gravity 2.20, passing freely in IS Sieve 75 micron sieve, fineness of fly ash 290 m^2/kg, Silicon dioxide SiO_2 69.13%, Sodium oxide Na_2O 0.36%, Calcium oxide CaO 0.91%, Ferric oxide Fe_2O_3

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3.72 %, Aluminium oxide Al_2O_3 21.29%, Potasium oxide K_2O 0.19%, Sulfur trioxide SO_3 0.08%, Magnesium oxide MgO 3.82%

Foundry Waste Sand

Property	Detail
Physical properties	
*Bulk density	2.51 gm/cm^3
*Specific gravity(G)	2.43
*Fineness modulus(FA)	3.17
*Absorption of water	0.38%
*Colour	Black
Chemical properties	
*SiO_2 (Silicon dioxide)	84.40
*Al_2O_3 (Aluminum oxide)	6.32
*Fe_2O_3 (Ferric oxide)	1.02
*CaO (Calcium oxide)	0.16
*MgO (Magnesium oxide)	0.28
*SO_3 (Sulfur trioxide)	0.07
*K_2O (Potassium oxide)	0.21
*Na_2O (Sodium oxide)	0.22
*TiO_2 (Titanium oxide)	0.11
*Mn_2O_3(Manganese III oxide)	0.03
Loss on ignition	6.12

Table 1 Physical and Chemical properties of foundry waste sand

Figure 2 Foundry Waste Sand

Water

Potable water used for drinking purposes as per ASTM C1602 / C1602M – 12[6], was used for concrete casting and curing purposes.

Superplasticizer (SP)

The properties of Superplasticizer are listed in Table 2.

Property	Detail
Colour	Light brown, free flowing liquid
*Specific gravity(G)	1.20
*Relative density at 25ºC	1.08 to 1.10
*Chloride content	Lesser than 0.2%
*Value of pH	Greater than 6.0

Table 2 Features of Superplasticizer (SP)

Viscosity Modifying Admixture (VMA)

The features of viscosity modifying admixture are given in Table 3.

Property	Detail
Colour	Colourless, free flowing liquid
*Specific gravity(G)	1.20
*Relative density at 25ºC	1.00 to 1.02
*Chloride content	Lesser than 0.2%
Value of pH	Greater than 6.0

Table 3 Properties of Viscosity Modifying Admixture (VMA)

Particle size analysis was performed to understand the gradation of FA and FWS. Both FA and FWS fulfilled the requirements of grading limits of zone 1.

B. Mix Proportioning

A SCC mix was formulated to obtain a characteristic strength of 50 MPa. For the current investigation, Nan Su method and European method was followed. This suggests that it is advisable to follow a regular mix proportioning method for SCC from M20 to M50 grade with some modifications. So as per IS 10262:1982, a mix was designed. The modifications carried out were 12.5 mm of 40% and 10 mm of 60% of the total coarse aggregate proportion calculated in mix design procedure, percentage of CA may be 50% of the total volume of concrete, their grading needs to be uniform and use of admixtures. The total powder content has been kept in the range between 450-600 kg/m^3. Maximum water content not to exceed 200 lt/m^3. The mix proportion adheres to EFNARC guidelines. The SCC mix proportion is listed in Table 4

Mixture Proportion of SCC							
Binder	Fly ash	FA	CA		Water	SP	VMA
			8 to 10mm	12.5 mm			
(kg / m^3)	(kg / m^3)	(kg / m^3)	(kg / m^3)	(kg / m^3)	(kg / m^3)	(kg / m^3)	(kg / m^3)
316	240	851	521	348	176	1.89	0.56

Table 4 SCC Mixture Proportion (per m^3 of concrete)

C. Casting the specimen

First CA was first placed in the concrete mixer and then FA was placed. Afterwards 20~25% of the total amount of water was poured into the concrete mixer. After rotating the mixer for 1 to 2 minutes, cement and fly ash were added to the mix. Then 40% of the remaining water was added. The concrete mixer rotated for another 1 to 1.5 minutes. Chemical admixtures were mixed to the balance water, added to the mix. The materials in the concrete mixer were blended for another 2 minutes.

D. Tests on Concrete at Fresh State

After perfect mixing, the characters of SCC at fresh state were determined. Filling, passing ability and resistance for segregation were evaluated by Slump test, V funnel, U – Box, L – Box test. The assessment results are listed in Table 6.

E. Curing the Specimen

After casting the specimen, the top surface of the specimens were smoothly finished. The specimens were kept safely for one day in room temperature. After the specimens hardened, they were taken out from the moulds, kept inside potable water for curing. Once the curing period completed, the specimens were allowed to dry in room temperature for one day.

F. Tests on Concrete at Hardened State

To evaluate the strength at hardened state, the dried specimens were investigated according to Table 5.

S. No	Detail	Specimen	As per
1	Compressive strength (on day 3, 7, 14, 28, 56 and 90)	150 x 150 x 150 mm Cube	IS:516-1959 (Reaffirmed 2004) [8], BS 1881: Part 116 [7]
2	Splitting tensile strength (on day 3, 7, 14, 28, 56 and 90)	Dia 150 mm length 300 mm Cylinder	IS5816-1999 (Reaffirmed 2004) [10], ASTM C496-96 [5]
3	Flexural strength (on day 3, 7, 14, 28, 56 and 90)	100x 100 x 500 mm Prism	IS:516-1959 (Reaffirmed 2004) [8], ASTM C78-94 [3]
4	Modulus of elasticity – on 28th day	Dia 150 mm length 300 mm Cylinder	IS:516-1959 (Reaffirmed 2004) [8], ASTM C469-14 [4]
5	Variation in density – on 28th day	150 x 150 x 150 mm Cube	-

Table 5 Tests on hardened concrete

VI. TEST RESULTS AND DISCUSSIONS

A. Concrete at Fresh State

Any concrete mixture may be accepted as a SCC mix when three workability properties are fulfilled (EFNARC, 2002). They are filling, passing ability and segregation for resistance. Filling ability was investigated by Slump flow, T50 Slump flow and V funnel Tests. Passing ability was evaluated by U-Box and L-Box Tests. Segregation resistance was examined by V funnel at T5 minutes. The evaluation details are listed in Table 6.

S. No	Detail	**M0** Sand 100% + FWS 0%	**M01** Sand 90% + FWS 10%	**M02** Sand 80% + FWS 20%	**M03** Sand 70% + FWS 30%	**M04** Sand 60% + FWS 40%	**M05** Sand 50% + FWS 50%	**M06** Sand 40% + FWS 60%	**M07** Sand 30% + FWS 70%	Limit
1	Slump flow (mm)	682	678	677	674	670	666	661	659	650 ~ 800 mm
2	T_{50}cm Slump flow (Seconds)	3	3	4	4	4	5	5	6	2 to 5 Sec
3	V funnel Test (Seconds)	8	10	10	10	1	11	12	13	8 to 12 Sec
4	V funnel at T5 minutes (Seconds)	10	13	13	12	14	14	16	17	0 to +3 Sec
5	L Box Test	0.94	0.92	0.91	0.88	0.88	0.86	0.85	0.81	h_2/h_1 = 0.8 to 1.0
6	U Box Test	20	22	23	24	25	25	27	28	h_2-h_1 = 0 to 30 mm

M0 = Control Mix (Sand 100% + FWS 0%), FWS = Foundry Waste Sand

Table 6 Concrete properties at fresh state

The workability of SCC mixes vs with FWS proportions is shown in figure 3. The slump flow by Abrams cone for the conventional SCC mix M0 (100 % sand, 0 % FWS) was 682 mm. The workability decreased by 3.5% (659 mm) for SCC mix M07 (30 % sand, 70 % FWS). The workability of SCC is inversely proposed with the FWS content.

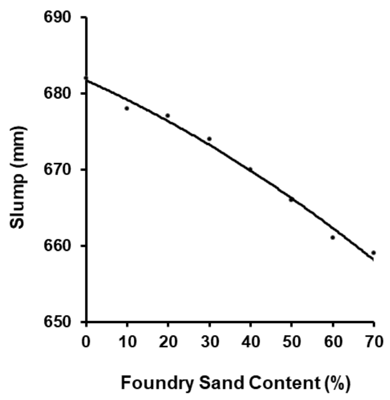

Figure 3 Workability vs FWS content

Density

Figure 4 and Table 7 shows the variation of density of SCC with FWS proportions. The density was 24.11 kN/m^3 for the SCC mix CM having 100 % sand and 0 % FWS. The density increased to 25.67 kN/m^3 (6.5% increase) for SCC mix M07 with 30 % sand and 70 % FWS. The density of SCC increases with the FWS content.

B. Hardened Concrete

S. No	Detail	M0 Sand 100% + FWS 0%	M01 Sand 90% + FWS 10%	M02 Sand 80% + FWS 20%	M03 Sand 70% + FWS 30%	M04 Sand 60% + FWS 40%	M05 Sand 50% + FWS 50%	M06 Sand 40% + FWS 60%	M07 Sand 30% + FWS 70%
1	Density on 28th day (kN/m^3)	24.11	24.32	24.57	24.81	25.02	25.27	25.52	25.67

M0 = Control Mix (Sand 100% + FWS 0%), FWS = Foundry Waste Sand

Table 7 Concrete properties at hardened state

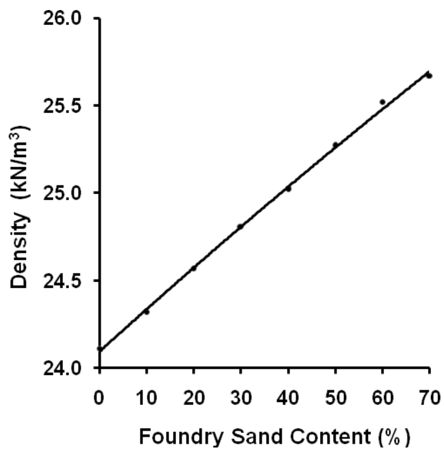

Figure 4 Density vs FWS content

Compressive Strength

Three SCC cubes, the dimensions of each cube being 150 x 150 x 150 mm, were evaluated on 3, 7, 14, 28, 56 and 90 days to obtain the compressive strength. SCC mix M0 (100 % sand, 0 % FWS), the compressive strength on 28th day was 50.60 MPa. The compressive strength increased to 53.90 MPa for Mix M02 (80% sand and 20% FWS) when FA was replaced with FWS. Compressive strength increased by 6.5%. If FA was further supplemented with FWS, compressive strength reduced further. Mix M07 (30 % sand and 70 % WFS) developed a compressive strength of 38.50 MPa on the 28th day. The compressive strength decreased by 24%. Table 8 and Figure 5 details the assessment results.

S. No	Detail	M0 Sand 100% + FWS 0%	M01 Sand 90% + FWS 10%	M02 Sand 80% + FWS 20%	M03 Sand 70% + FWS 30%	M04 Sand 60% + FWS 40%	M05 Sand 50% + FWS 50%	M06 Sand 40% + FWS 60%	M07 Sand 30% + FWS 70%
1	Compressive Strength @ 28 days (N/mm^2)	50.6	51.4	53.9	48.3	44.7	41.4	39.6	38.5

M0 = Control Mix (Sand 100% + FWS 0%), FWS = Foundry Waste Sand

Table 8 Concrete properties at hardened state

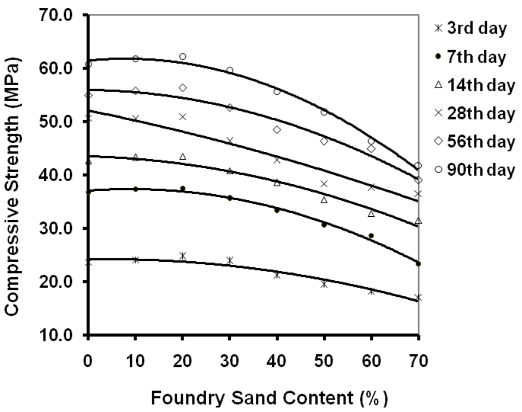

Figure 5 Compressive Strength vs FWS content

Three SCC prism specimens, the size of each specimen being 100mmx100mm x500mm, were evaluated on 3, 7, 14, 28, 56 and 90 days to obtain the flexural strength. SCC mix M0 (100 % sand, 0 % FWS), the flexural strength on 28th day was 4.26 MPa. The flexural strength increased to 4.32 MPa for Mix M02 (80% sand and 20% FWS) when FA was replaced with FWS. The increase in flexural strength was roughly 1.5%. On further replacement of FA with FWS, the flexural strength decreased. For the SCC mix M07 (30 % sand and 70 % FWS), the flexural strength on 28th day was 3.65 MPa. The flexural strength decreased by 14.3%. Table 9 and Figure 6 details the assessment results.

Flexural Strength

S. No	Detail	M0 Sand 100% + FWS 0%	M01 Sand 90% + FWS 10%	M02 Sand 80% + FWS 20%	M03 Sand 70% + FWS 30%	M04 Sand 60% + FWS 40%	M05 Sand 50% + FWS 50%	M06 Sand 40% + FWS 60%	M07 Sand 30% + FWS 70%
1	Flexural Strength @ 28 days (N/mm^2)	4.26	4.31	4.32	4.15	3.99	3.84	3.72	3.65

M0 = Control Mix (Sand 100% + FWS 0%), FWS = Foundry Waste Sand

Table 9 Concrete properties at hardened state

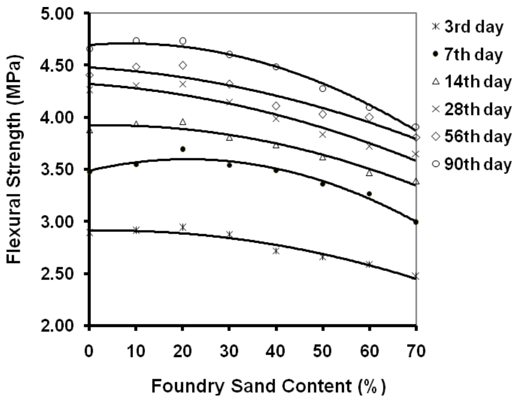

Figure 6 Flexural Strength vs FWS content

Three SCC cylinder specimen, diameter 150mm, height 300mm were evaluated on 3, 7, 14, 28, 56 and 90 days to obtain the splitting tensile strength. SCC mix M0 (100 % sand, 0 % FWS), the split tensile strength on 28th day was 2.97 MPa. Mix M02 (80% sand and 20% FWS), the split tensile strength improved to 3.03 MPa when FA was replaced with FWS. Split tensile strength increased by 2%. If FA was further supplemented with FWS, splitting tensile strength decreased again. Mix M07 (30 % sand and 70 % FWS), showed the splitting tensile strength on 28th day as 2.58 MPa. This decreased by 13.1%. Table 10 and Figure 7 details the assessment results.

Split Tensile Strength

. No	Detail	M0 Sand 100% + FWS 0%	M01 Sand 90% + FWS 10%	M02 Sand 80% + FWS 20%	M03 Sand 70% + FWS 30%	M04 Sand 60% + FWS 40%	M05 Sand 50% + FWS 50%	M06 Sand 40% + FWS 60%	M07 Sand 30% + FWS 70%
1	Split Tensile Strength @ 28 days (N/mm^2)	2.97	3.02	3.03	2.89	2.80	2.69	2.61	2.58

M0 = Control Mix (Sand 100% + FWS 0%), FWS = Foundry Waste Sand

Table 10 Concrete properties at hardened state

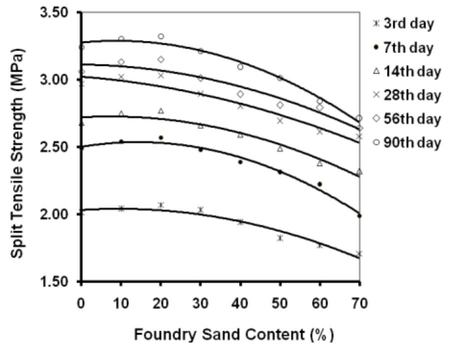

Figure 7 Split Tensile Strength vs FWS content

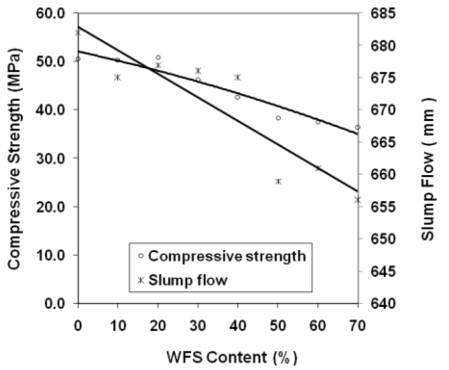

Figure 8 – Workability and Compressive Strength

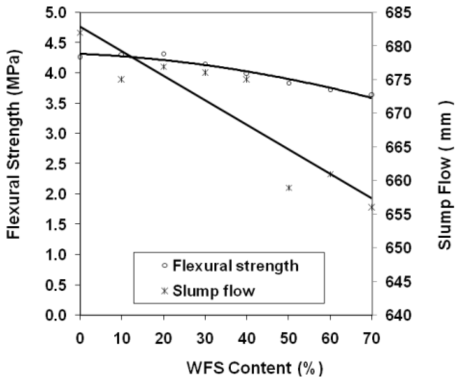

Fig 9 – Workability and Flex ural Strength

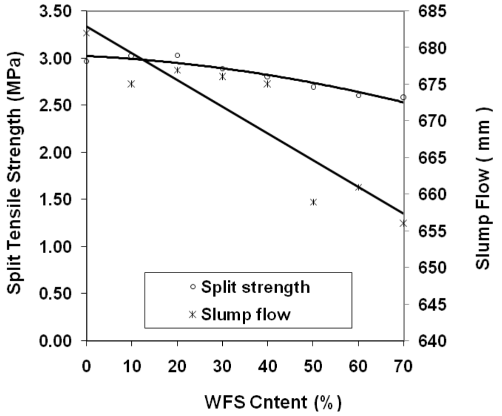

Fig 10 – Workability and Split Tensile Strength

Modulus of Elasticity

Three SCC cylinder specimens, the size of each specimen being diameter 150mm, height 300mm were evaluated for each mix on 3, 7, 14, 28, 56 and 90 days to calculate the elastic modulus. On the 28th day, the modulus of elasticity for mix M0 (100 % sand, 0 % FWS) was evaluated as 32,064 MPa. When FA was replaced with FWS, the modulus of elasticity improved to 34,022 MPa for Mix M02 (80% sand and 20% FWS). The increase in modulus of elasticity increased by 6.1%. If FA was further supplemented with FWS, modulus of elasticity decreased. Mix M07 (30 % sand and 70 % FWS), developed the modulus of elasticity on 28th day as 28,850 MPa. The modulus of elasticity went down by 10%. Table 10 and Figure 7 details the assessment results.

S. No	Detail	**M0** Sand 100% + FWS 0%	**M01** Sand 90% + FWS 10%	**M02** Sand 80% + FWS 20%	**M03** Sand 70% + FWS 30%	**M04** Sand 60% + FWS 40%	**M05** Sand 50% + FWS 50%	**M06** Sand 40% + FWS 60%	**M07** Sand 30% + FWS 70%
1	Modulus of Elasticity @ 28 days (N/mm^2)	32,064	33,447	34,022	33,948	33,267	32,728	29,450	28,850

M0 = Control Mix (Sand 100% + FWS 0%), FWS = Foundry Waste Sand

Table 11 Modulus of Elasticity of concrete at hardened state

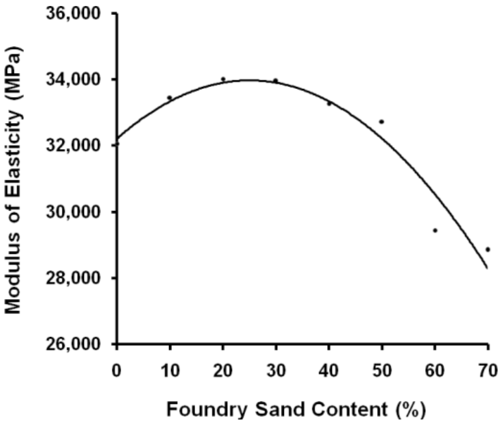

Fig 11– Modulus of Elasticity vs FWS content

VII. CONCLUSION

The conclusions arrived at, as per the experimental study are

WORKABILITY

- The test results indicate that the fresh concrete properties for all the mixes are within the allowable limits as per EFNARC guidelines, i.e., passing ability, flowability and resistance for segregation.
- The workability of SCC decreases substantially as the FWS content increases. This may be attributed to the presence of fine particles in FWS. The fine particles absorb water present in the mix, resulting in lesser workability.

HARDENED PROPERTIES

- The density of SCC increases when FWS content increases. The specific gravity of FWS is 2.43, higher than the specific gravity of FA 2.36. Replacement of FA with FWS makes SCC denser.
- The mechanical properties of SCC with FWS are comparable with conventional SCC. If 20% of FA are replaced partially with FWS, the SCC mixes showed an increase of 6–8% in compressive strength, 2-4% in flexural strength and 2–3% in splitting tensile strength 2–3%.
- Further additions of FWS indicated decrease in the above strengths. When FWS content increases, the fine particles in FWS absorb the free water available in SCC mixes, causing reduction in strength of the mixes.
- From 28 to 90 days, compressive strength increased by 20% to 35%, flexural strength by 10% to 15% and splitting tensile strength by 10% to 22 %.
- Replacement of FA with FWS was evaluated as optimum at 20% to make high strength SCC.
- Test results indicate that FWS has potential to be used as replacement FA to produce high strength SCC.

VIII. LIMITATIONS AND FUTURE RESEARCH

The study has concentrated on the strength properties of SCC. The durability aspects need to be investigated in the future research.

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Elangovan is currently working as associate professor at Sri Krishna College of Engineering and Technology, Coimbatore. His area of interest being waste management technics and modern construction materials. He is currently working for optimum utilization of foundry waste sand. He is a member in the Institution of Engineers (India) and Indian Society for Technical Education.