Properties of Self-Compacting Concrete Incorporating Waste Foundry Sand

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Abstract

This paper demonstrates the possibilities of using waste foundry sand as partial replacement of sand in self-compacting concrete. Self-compacting concrete, as the name indicates, is a type of concrete that does not require external or internal compaction, because it becomes levelled and consolidated under its self-weight. Foundry sand is high quality silica sand used as a moulding material by ferrous and non-ferrous metal casting industries. It can be reused several times in foundries but, after a certain period, cannot be used further and becomes waste material, referred to as waste, used or spent foundry sand (WFS,UFS or SFS). This experimental investigation was performed to evaluate the strength and durability properties of SCC, in which natural sand was partial replaced with waste foundry sand (WFS). Natural sand was replaced with four percentage (0%, 10%, 15%, 20%) of WFS by weight. Fresh properties of self-compacting concrete were studied. Compression test and splitting tensile strength test were carried out to evaluate the strength properties of concrete at the age of 7, 28, and 56 days. In case of durability properties, sulphate resistance was evaluated at the age of 7, 28 and 56 days and Rapid Chloride Permeability test was conducted at age of 28 days. Test results showed that there is increase in compressive strength, splitting tensile strength of self-compacting concrete by incorporating waste foundry sand (WFS) as partial replacement by sand up to 15%. Resistance of concrete against sulphate attack and rapid chloride permeability were also improved for concrete mixes.

Keywords

Compressive strength; Splitting tensile strength; Self-Compacting Concrete; Fine aggregate; Waste Foundry Sand; Sulphate resistance; Rapid chloride permeability; Fresh properties.

Introduction

Self-compacting concrete, as the name indicates, is a type of concrete that does not require external or internal vibration for placing and compaction but it gets compacted under its self-weight. It is able to flow under its own weight, completely filling formwork and achieving full compaction, even in the presence of congested reinforcement. At the same time it is cohesive enough to fill spaces of almost any size and shape without segregation or bleeding. This makes SCC particularly useful wherever placing is difficult, such as in heavily reinforced concrete members or in complicated formwork. SCC was first developed in Japan to achieve durable concrete structures in 1980's.

For several years beginning in 1983, the problem of the durability of concrete structures was a major topic of interest in Japan. To make durable concrete structures, sufficient compaction by skilled workers is required. However, the gradual reduction in the number of skilled workers in Japan's construction industry has led to a similar reduction in the quality of construction work. One solution for the achievement of durable concrete structures independent of the quality of construction work is the employment of self-compacting concrete, which can be compacted into every corner of a formwork, purely by means of its own weight and without the need for vibrating compaction. The necessity of this type of concrete was proposed by Professor Hajime Okamura in 1986. Studies to develop self-compacting concrete, including a fundamental study on the workability of concrete, were carried out by Ozawa and Maekawa at the University of Tokyo. SCC technology in Japan was based on using conventional super plasticizers to create highly fluid concrete, while also using viscosity-modifying agents (VMA) which increase plastic viscosity thus preventing segregation up to a level of fluidity that would normally cause segregation. The prototype of self-compacting concrete was first completed in 1988 using materials already on the market. The prototype performed satisfactorily with regard to drying and hardening shrinkage, heat of hydration, denseness after hardening, and other properties, Okamura and Ouchi [1].There are many advantages of SCC as there is no vibration necessary during placement of concrete into forms which makes placement of concrete easier and faster, total concreting time is reduced. Energy consumption and required number of workers on construction site is reduced.

High quality of placed concrete is achieved, regardless the skill of the workers. Good bond between concrete and reinforcement is obtained, even in congested reinforcement. The construction speed is increased due to fewer construction tasks and reduced noise generated by vibrators. At the same time there are increased material costs, especially for admixtures and cementitious materials and increased formwork costs due to possibly higher formwork pressures and to prevent leakage. There is delayed setting time in some cases due to the use of admixtures.SCC requires more trial batches at laboratory as well as at plants and require technical expertise to develop control mixtures.

Fresh SCC must possess at required levels the three key properties related to workability. Filling ability is the ability of the SCC to flow, spread and fill into all spaces within the formwork under its own weight. Passing ability is the ability of the SCC to flow through tight openings such as spaces between steel reinforcing bars, under its own weight without blocking them. Resistance to segregation is the property in which SCC must meet the required levels of properties and its composition remains uniform throughout the process of transport and placing that is keeps the sand and aggregate in suspension.

Foundry sand is high quality silica sand used as a moulding material by ferrous and non-ferrous metal casting industries. It can be reused several times in foundries but, after a certain period, cannot be used further and becomes waste material, referred to as used or spent foundry sand (UFS or SFS). The majority of spent moulding sands are classified as nonhazardous waste (that is not corrosive, ignitable, reactive or toxic) Siddique and Noumowe, [2].Foundries use high quality size-specific silica sands for use in their moulding and casting operations. The raw sand is normally of a higher quality than the typical bank run or natural sands used in fill construction sites. In the casting process, moulding sands are recycled and reused multiple times. Eventually, however, the recycled sand degrades to the point that it can no longer be reused in the casting process. When it is not possible to further reuse sand in the foundry, it is removed from the foundry and is termed as spent foundry sand.

The physical and chemical characteristics of foundry sand will depend in great part on the type of casting process and the industry sector from which it originates. In a recent study, Siddique et al. [3] reported that in the United States alone, up to 10 million tons of foundry sand are discarded annually and are available for recycling. Foundries purchase new, virgin sand to make casting moulds and the sand is reused numerous times within the foundry. However, heat and mechanical abrasion eventually render the sand unsuitable for use in casting moulds, and a portion of the sand is continuously removed and replaced with virgin sand. The spent foundry sand, that is, the sand that is removed, is either recycled in a non-foundry application or land filled.

There are about 35,000 foundries in the world with annual production of 90 million tones. In terms of number of foundries China has the highest score (9374), followed by India (6000), Bhimani et al. [4]. Singh and Siddique [5] reported that in India, approximately 2 million tons of waste foundry sand is produced yearly. WFS are major by-products of metal casting industry and successfully used as a land filling material for many years. But use of waste foundry sand (WFS) for land filling is becoming a problem due to rapid increase in disposal cost. In an effort to use the WFS in large volume, research has being carried out for its possible large scale utilization in making concrete as partial replacement of fine aggregate Sahmaran et al. [6] reported that no visible segregation or bleeding was observed in the fresh mixtures. The results for slump flow diameter, slump flow time, V-funnel flow time, and rheological parameters (yield stress and relative viscosity) of the SCC mixtures satisfy the "The European Guidelines for Self Compacting Concrete" [16]. Spread of 50FA-50SFS mixture which was a typical example of the uniform spread of SCC mixtures. Generally, for a given FA content, the super plasticizer requirement increases with SFS content for fresh properties like slump flow diameter. Guney et al. [7] observed that waste foundry sand decreased the fluidity and the slump value of the fresh concrete. In this study fine aggregates were partially replaced with 0, 5, 10 and 15% WFS. This may be probably due to the presence of clayey type fine materials in the waste foundry sand, which are effective in decreasing the fluidity of the fresh concrete. Naik et al. [8] studied the various tests on the use of foundry silica dust in self compacting concrete in which a control mixture was made in which ASTM C 618 Class C fly ash constituted 40% mass of the total cementitious materials. Three more SCC mixtures were made using silica dust obtained from an iron industry. Silica dust was used to replace 10%, 20% and 30% of fly ash at a 1:2 (fly ash and foundry dust) ratio by mass. The extra amount of foundry dust was treated as very fine sand. Use of foundry dust in SCC resulted in very high air content values. At 30% replacement of fly ash with foundry silica dust, the super plasticizer demand for SCC increased considerably. The VMA demand decreased as more fly ash was replaced with silica dust. This could be due to the increase in the amount of fines in SCC at higher replacements level. The slump flow of SCC containing the foundry silica dust was in range of 710-725mm, and H2/H1 in the U-flow test was 99%.SCC containing foundry silica dust did not show noticeably higher bleeding than the reference mixture.

Sahmaran et al. [6] concluded that in all curing ages, the compressive strength of the control mixtures with 0% SFS was higher than the one containing SFS. This holds true even at 100% SFS replacement level. Although SFS and FA reduce the strengths, it is still possible to produce SCC with compressive strengths around 40 MPa at 28 days and 50 MPa at 90 days by using both SFS and FA. Strengths over 40 MPa can be reached even at 100% SFS replacement. Guney et al. [7] examined the influence of inclusion of WFS as partial replacement of fine aggregates on the compressive strength of concrete up to the age of 56 days. Fine aggregates were partially replaced with 0, 5, 10 and 15% WFS. It was observed that the concrete with 10% waste foundry sand replacement exhibited highest compressive strength at the age of 56 days. Compressive strength decreased with an increasing amount of foundry sand. The concrete with 10% waste foundry replacement may indicate the optimum reallocation amount of waste foundry sand. This may indicate that the particle size distribution of the mixture with 10% waste foundry sand has sufficient adherence than the other mixtures with waste foundry sand. Siddique et al. [3] studied the properties of concrete mixtures in which fine aggregate (regular sand) was partially replaced with used-foundry sand (UFS).

In these fine aggregates was replaced with three percentages (10%, 20%, and 30%) of UFS by weight. The splitting-tensile strength of concrete mixtures made with and without UFS was measured at the ages of 7, 28, 56, 91, and 365 days. The variation in the splitting tensile strength with UFS content was similar to that observed in the case of the compressive strength that is splitting tensile strength of concrete mixtures increased with the increase in UFS content. Guney et al. [7] determined the splitting tensile strength of concrete made with WFS as partial replacement of fine aggregates. The splitting tensile strength values of 5 and 15% waste foundry sand replaced specimens are lower than that of the control one; the specimens replaced with 10% waste foundry sand have slightly higher values than control mix (without foundry sand). Bakis et al. [9] explored the possible use of waste foundry sand (WFS) in asphalt concrete. In asphalt Concrete mixtures, fine aggregates were replaced with 0, 4, 7, 10, 14, 17 and 20% WFS. Indirect tensile strength tests were conducted as per AASTHO (1989). As the percentage of WFS was increased, the strength of the asphalt concrete mixtures linearly decreased, yielding values from 1.39 MPa with 0% WFS to 0.94 MPa with 20% WFS. Sahmaran et al. [6] investigated the permeability of self compacting concrete with fly ash and spent foundry sand. The Portland cement in the mixtures was replaced with Fly ash at 0, 30, 50 and 70% by mass. For each FA replacement level, about 0, 25, 50 and 100% of sand by volume was replaced with SFS. The results of RCP tests performed at 28 and 90 days. the use of FA significantly reduced the chloride permeability of the hardened SCC mixtures when compared to the control concretes with 0% FA. The results also showed that the rapid chloride permeability of most concretes containing FA and SFS was below 750 coulomb at 90 days, which indicate relatively high-quality SCC mixtures from rapid chloride permeability standpoint (ASTM C 1202 classifies the chloride ion penetrability of a concrete as ‘‘very low’’ as long as the charge passed is between 100 and 1,000 coulomb). Singh and Siddique [5] concluded that inclusion of WFS decreased the chloride ion penetration in concrete, which indicates that concrete has become denser and impermeable. At 28 days, charges passed were 1368, 1250, 1150, 1060 and 1190 coulombs at 0%, 5%, 10%, 15% and 20% of WFS. Coulomb value decreased with the increase in WFS content up to 15% WFS, which indicate that concrete became more dense. Coulombs charges passed at 91 days are less than those of 28 days, which indicate that concrete microstructure become denser.

The aim of the research was to evaluate the performance of Waste Foundry Sand in Self-Compacting Concrete. WFS are a major by-product of metal casting industry. India, approximately 2 million tons of waste foundry sand is produced yearly.

Material and Method

Materials and mix proportions

Ordinary Portland cement (J.K. Cement, Grade 43) was used conforming as per Indian standard specification BIS-8112:1989 [10]. The sand used for the experimental programme was locally procured and conformed to Indian Standard Specifications IS: 383-1970 [11] and belonged to zone II (Figure 1).

Figure 1. *Used Foundry Sand*

Locally available coarse aggregate having the maximum size of 10 -12 mm was used in the work. Waste Foundry Sand was obtained from a local foundry unit in Mandi Gobindgarh, Punjab, India, having specific gravity 2.43.

Table 1. Physical Properties of Foundry Sand

Properties	**Observed values**
Colour	Grey (Blackish)
Fineness Modulus	1.23
Specific Gravity	2.43
Water Absorption (%)	1.21

Mix proportion of self compacting concrete

Magnesium Sulphate powder form was obtained from Scientific Junction, Patiala.Admixture used was Auramix 400 of FOSROC brand. It is polycarboxylic ether based admixture. Both aggregates met the requirements of Indian Standard Specifications IS: 383 [11]. The specific gravity of fine and coarse aggregate was 2.57 and 2.65, respectively whereas their fineness modulus was 2.65 and 6.85, respectively, and it is detailed in Table 2

Table 2. Test data for materials

Type of Cement	OPC
Specific gravity of cement	3.12
Specific gravity of Coarse Aggregate	2.65
Specific gravity of Fine Aggregate	2.75
Specific gravity of Admixture	1.11

Physical Properties of foundry sand are given in table 1.. The mix proportions of SCC for M30 are given below in Table 3.

Table 3. Mix proportions

Mixture ID	Cement kg/m³	WFS Kg/m³	Sand kg/m³	C.A kg/m³	Water (kg/m³)	w/p	SP (kg/m³)	SP (%)
CM	450	0	1008	697	210.67	0.47	3.6	0.8
10%WFS	450	100.8	907.2	697	210.76	0.47	3.6	0.8
15%WFS	450	151.2	856.8	697	210.67	0.47	3.6	0.8
20%WFS	450	201.6	806.4	697	210.67	0.47	3.6	0.8

Methodolgy

Waste foundry sand was used, to replace fine aggregate by weight in this work. Replacement levels were 0, 10, 15 and 20%. A constant w/p ratio of .47 was used. To evaluate fresh concrete properties Slump flow test, V- funnel, L- Box and U- Box tests were performed. To evaluate hardened concrete properties Compressive strength test, Splitting tensile strength, Sulphate resistance and Rapid chloride permeability tests were performed.

Preparation and casting of specimens

Before casting, the entire test specimen were cleaned and oiled properly. These were securely tightened to correct dimensions before casting. Care was taken that there is no gaps left from where there is any possibility of leakage of slurry. Careful procedure was adopted in the batching, mixing and casting operations. The concrete mixture was prepared in pan mixer. Initially, the coarse and fine aggregates were mixed thoroughly by dry mixing in pan mixer. To this mixture, the cement was added. These were mixed to uniform color. Then water was added carefully so that no water was lost during mixing and admixture was added along with it. After proper mixing concrete is checked for fresh properties, if concrete mix fulfill the workability requirements then only it can be classified as Self-compacting Concrete and the specimens are casted. For each mix 30 samples were prepared, which consists of 9 cubes (150x150x150) for 7 , 28 and 56 days compressive strength , 9 (300x150) cylinders for split tensile strength at 7 , 28 and 56 days and 3 cylinders (200x100) for RCPT and 9 cubes(150x150x150) for 7 ,28 and 56 days for sulphate resistance test.

Testing of Specimens

After required period of curing, the specimens were taken out of the curing tank and their surfaces were wiped off. Besides measuring the fresh properties (U- Box, L-Box-Funnel, Slump flow test), tests performed on hardened concrete was Compressive strength and splitting tensile strength at age of 7, 28 and 56 days as per Indian Standard Specifications (BIS: 516 – 1959) [12] and (BIS: 5816-1999) [13] respectively. Sulphate resistance test was conducted as per (ASTM C 1012) [14]. Tests performed for sulphate resistance in this work are compressive strength test after immersing the cube specimen in 5% magnesium sulphate solution for 7, 28 and 56 days. Before immersing them in sulphate solution, specimens are cured for 28 days in water under normal temperature. Compressive strength test is then conducted on the specimens. Rapid chloride permeability test was conducted at age of 28 days as per (ASTM C 1202) [15].

Results and Discussions

Fresh properties

SCC containing different proportion of waste foundry sand was tested for Slump flow, V-funnel, U-Box, L-box. The results of fresh properties of all Self-compacting concretes with waste foundry sand are included in table 4. In terms of slump flow, all SCCs exhibited satisfactory slump flows in the range of 550–800 mm, which is an indication of a good deformability.

Table 4. Fresh concrete properties

Mixture ID	Slump flow (mm)	V-funnel (seconds)	L-Box (H2/H1)	U-box (H1-H2) (mm)
SCC1 (0% WFS)	605	7	1	5
SCC2 (10% WFS)	625	6.60	0.9	11
SCC3 (15% WFS)	625	6.28	1	17
SCC4 (20% WFS)	590	9.37	0.8	23

As per EFNARC, time ranging from 6 to 12 seconds is considered adequate for a SCC. The V-funnel flow times were in the range of 6–10 seconds. Slump flow is shown in Figure 2. Test results of this investigation indicated that all SCC mixes meet the requirements of allowable flow time. The L-box ratio H2/H1 for the mixes was above 0.8 which is as per EFNARC 16] standards. U-box difference in height of concrete in two compartments was in the range of 5–40 mm. All the fresh properties of concrete values were in good agreement to that of the values given by European guidelines.

Figure 2. *Slump flow test*

Compressive strength

Effect of WFS on compressive strength

Effect of WFS on compressive strength of M30 Grade concrete mixes SCC-1(0% WFS), SCC-2 (10% WFS), SCC-3(15% WFS) and SCC-4 (20% WFS) at the age of 7, 28 and 56days are shown in Figure 3.Mix proportion of control concrete mix SCC-1 (0% WFS) was 450 kg cement, 1021 kg fine aggregate and 702 kg coarse aggregate per cubic meter of concrete with water-cement ratio 0.43. Compressive strength of control concrete mix was 35.06 MPa at the age of 28 days. It was found that, at the age of 7 days, compressive strength of mix SCC-1 (0% WFS) was 27.69 MPa and mixes SCC-2 (10% WFS), SCC-3 (15%WFS) and SCC-4 (20% WFS) were 29.13, 37.42 and 31.10 MPa, respectively. Maximum compressive strength (37.42 MPa) was observed for SCC-3 (15% WFS) concrete mix; it was 35.14 % more than the control mix SCC-1(0% WFS). At the age of 28 days, percentage increase in compressive strength was 14.80, 22.73 and 14.26% for mixes SCC-2, SCC-3 and SCC-4 than control mix SCC-1(35.06 MPa). At 56 days, concrete mixes SCC-2, SCC-3 and SCC-4 exhibited increase in compressive strength12.60, 24.94 and 12.88 % respectively than SCC-1 (39.53 MPa). In investigation, it was observed that compressive strength of concrete increased with the increase in WFS content up to 15% as partial replacement of sand.

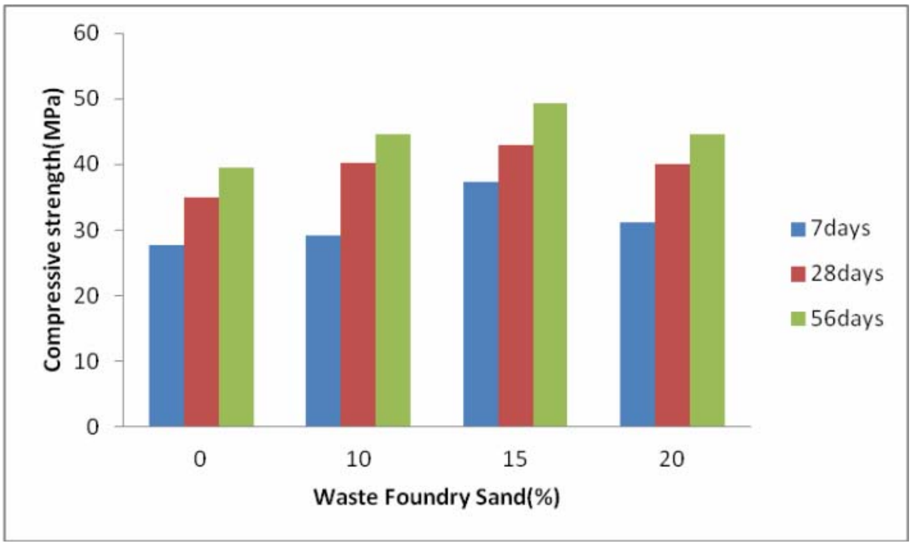

Figure 3. *Compressive strength of waste foundry sand concrete*

Figure 4 shows the variation of percentage increase in compressive strength with replacement percentage of waste foundry sand. The results also indicate that early age strength gain i.e. at 7 and 28 days, is higher when compared to the control mix if 15% of fine aggregate is replaced by waste foundry sand.

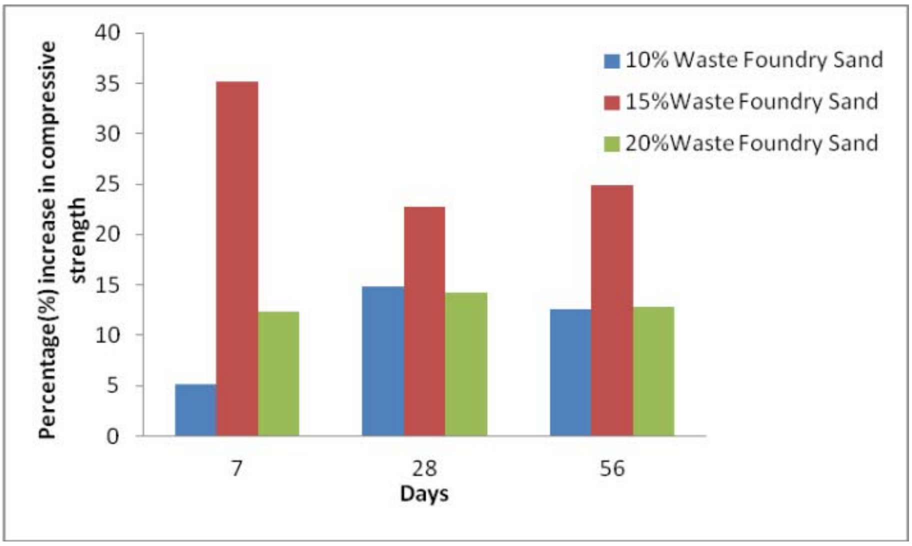

Figure 4. *Percentage (%) increase in compressive strength of waste foundry sand concrete*

Effect of age on compressive strength

Effect of age on compressive strength of M30 Grade (35.06 MPa) concrete mixes are shown in Figure 5. Compressive strength of all concrete mixes increased with age. Concrete mix SCC-1 (0% WFS) achieved an increase of 26.62 and 42.76 % at the age of 28 and 56 days respectively, when compared with 7 days compressive strength (27.69 MPa). For mix

SCC-2 (29.13 MPa), compressive strength was increased by 38.17 and 52.80% at the age of 28 and 56 days respectively, whereas an increase of 15% was observed at 28 days and 31.99% at 56 days for SCC-3 (15% WFS). When SCC-4 (20% WFS) was compared with 7 days compressive strength (31.10 MPa), it was found that it increased by 28.81 and 43.47%.Comparative study of compressive strength between 7 to 28 days indicate that % increase in compressive strength was observed as 26.62,38,17.15 and 28.81% for mix SCC-1, SCC-2, SCC-3 and SCC-4 respectively. Concrete mix SCC-1, SCC-2, SCC-3 and SCC-4 exhibited increase in compressive strength by 12.75, 10.58, 14.78 and 11.38% when comparative study was done between 28 and 56 day.

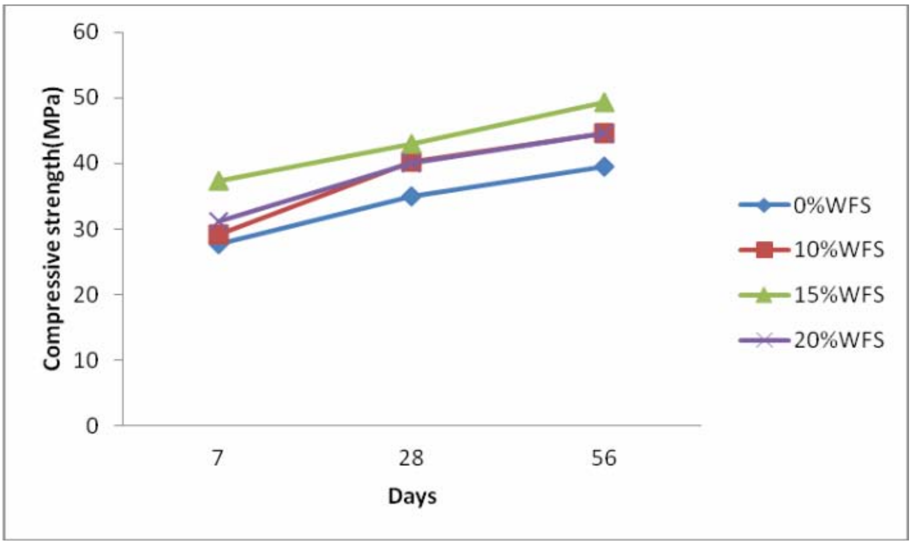

Figure 5. *Compressive strength of Waste Foundry Sand Concrete verses age*

Splitting tensile strength

Effect of WFS on splitting tensile strength

Split tensile strength studies were carried out at the age of 7, 28 and 56 days. The variations in splitting tensile strength with waste foundry sand content were similar to that observed in case of compressive strength. Splitting tensile strength of concrete mixes increased with the increase in WFS content. Splitting tensile strength of control mix SCC-1(0% WFS) was 2.28 MPa at 7 days. It increased by 6.14%, 11.84% and 11.40% for SCC-2 (10% WFS), SCC-3 (15% WFS) and SCC-4 (20% WFS) respectively. Higher value of splitting tensile strength was observed at 15% WFS. At the age of 28 days, increase was 15.14%, 23.94 and 16.55% for SCC-2, SCC-3, and SCC-4 concrete mixes respectively than mix SCC-1 (2.84MPa). At 56 days, splitting tensile strength of mix SCC-1(0% WFS) was

2.92 MPa. Concrete mix SCC-2, SCC-3 and SCC-4 achieved an increase of 12.33, 23.29 and 21.23%. It was observed that up to 15% replacement of natural sand with WFS, concrete mixture SCC-3 (15% WFS) showed higher value of splitting tensile strength among all mixes. Fig. 6 shows the variation of split tensile strength with the percentage of waste foundry sand replaced. Fig. 7 shows the variation of percentage increase in split tensile strength with replacement percentage of waste foundry sand. The strength gain at age of 7, 28 and 56 days is highest for 15% waste foundry sand replacement.

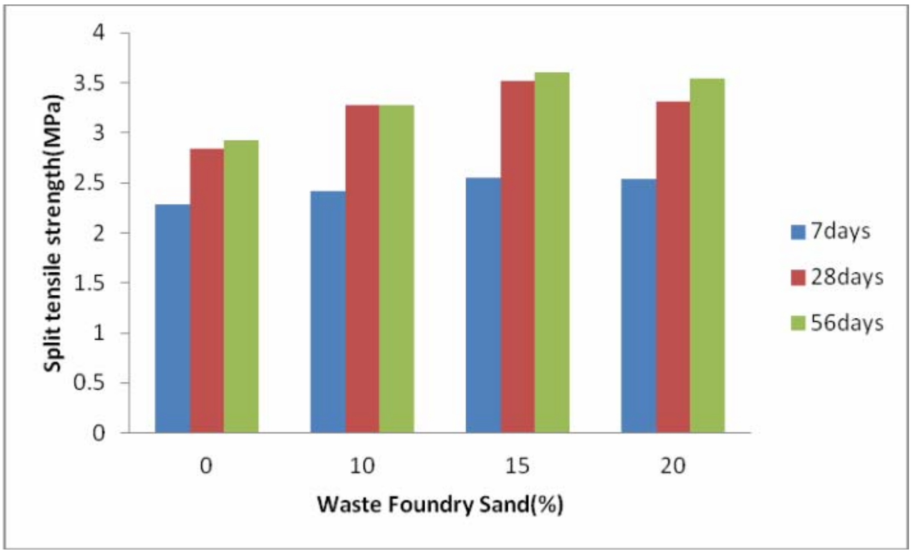

Figure 6. *Splitting tensile strength of Waste Foundry Sand Concrete*

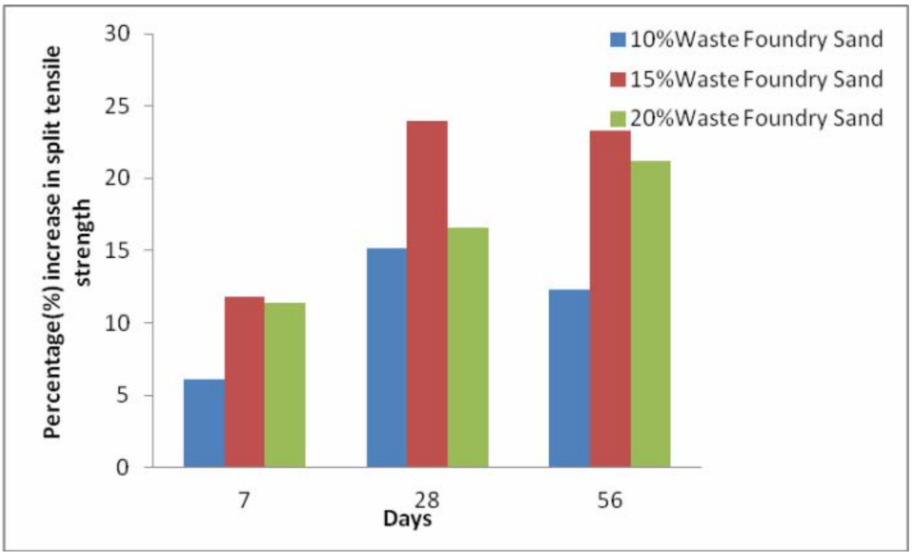

Figure 7. *Percentage (%) increase in split tensile strength of waste foundry sand concrete*

Effect of age on splitting tensile strength

Effect of age on splitting tensile strength on concrete mixes is shown in Fig. 8.

Splitting tensile strength of all concrete mixes increased with age. Concrete mix SCC-1 (0% WFS) achieved an increase of 24.56 and 28.04% at the age of 28 and 56 days respectively, when compared with 7 days splitting tensile strength (2.28 MPa). For mix SCC-2 (2.42 MPa), splitting tensile strength was increased by 35.12 and 35.54% at 28 and 56 days, respectively, whereas an increase of 38.04% was observed at 28 days and 41.18% at 56 days for SCC-3 (15% WFS). When SCC-4 (20% WFS) was compared with 7 days splitting tensile strength (2.54MPa), it was found that it increased by30.31 and 39.37%.The concrete mixes SCC-1, SCC-2, SCC-3 and SCC-4 showed an increase in splitting tensile strength between 28 to 56 days, by 9.4, 7.6, 9.1, 8.1 and 10.8% respectively. Splitting tensile strength of all mixes are continue to increase with increase in age.

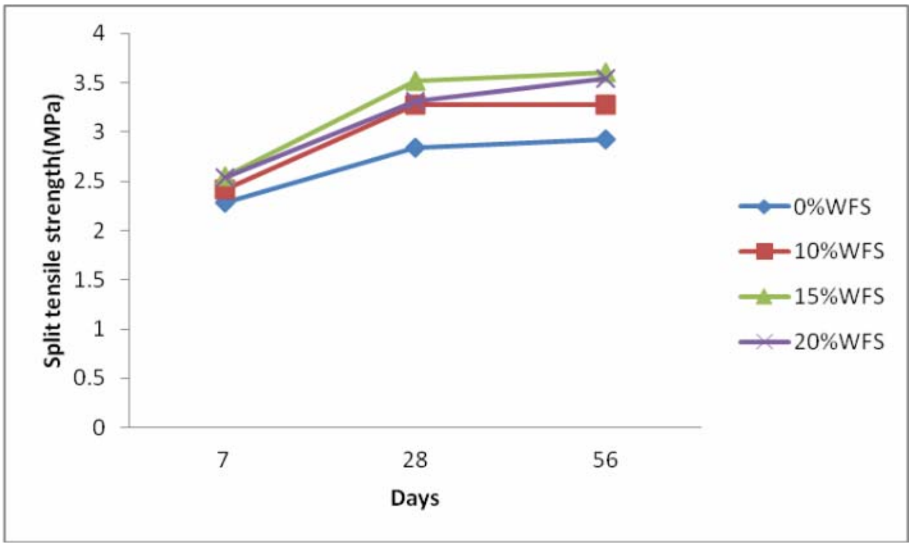

Figure 8. *Split tensile strength verses age*

Resistance to sulphate attack of concrete

This test was conducted on 150 x 150 x 150mm cube specimens. The cubes were casted and cured in water for 28 days. Magnesium sulphate solution of 50g/l is used to evaluate sulphate resistance of concrete. Cubes are immersed in solution after 28 days curing, and are tested for compressive strength after a further period of 7, 28 and 56 days. The cubes are tested for compressive strength and any reduction or change is noted. The compressive strength test results on immersed cube specimens are given in Table 5. Fig. 9 shows the results.

Table 5. Compressive strength of concrete mixes after immersion in 50gm/litre of $MgSo_4$ solution

Mix	7 Days Compressive Strength (MPa)		28 Days Compressive Strength (MPa)		56 Days Compressive Strength (MPa)	
	Control (28 days)	Immersed	Control (28 days)	Immersed	Control (28 days)	Immersed
10%	40.25	46.03	40.25	47.37	40.25	49.62
15%	43.03	39.04	43.03	40.18	43.03	42.44
20%	40.06	37.76	40.06	38.39	40.06	39.69

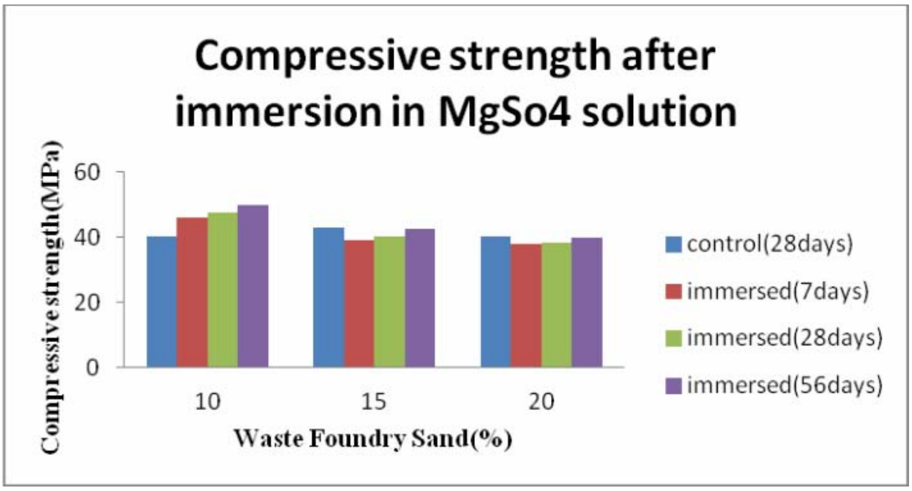

Figure 9. *Compressive strength after immersion in $MgSo_4$ solution (50g/l)*

This compressive strength is compared with the compressive strength of specimen cured in water at same ages. Fig. 10 shows the increased (+) or decreased (-) in percentage of compressive strength after immersion in $MgSo_4$ solution and compared with the compressive strength of specimen of same size 150 × 150 × 150 mm cured in normal water at same ages. It is observed that for the mix containing 10% waste foundry sand an increase in strength is observed at all ages as compared to the control mix even after immersing the cubes in magnesium sulphate solution. However, for both 15% and 20% replacement levels, a decrease in strength is observed when compared to the standard 28 days strength of the related concrete mix, at all ages after immersion in the sulphate solution. This indicates that, one, the strength loss will be much larger if the concrete is immersed in the solution for a larger period of time, the extent needs to be investigated and secondly, 10% waste foundry sand is optimum from the consideration of resistance to sulphate attack as observed from the experimental results.

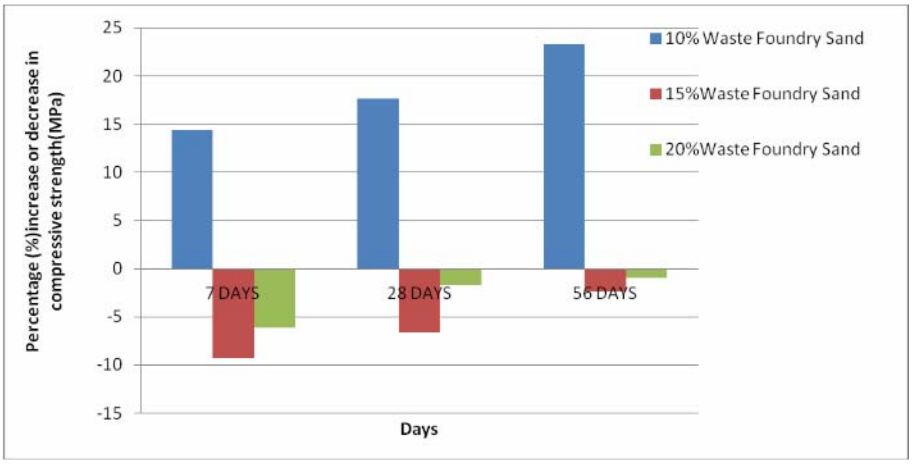

Figure 10. *Percentage(%) increased (+) or decreased (-) in compressive strength after immersion in $MgSo_4$ solution (50g/l) as compared with compressive strength of specimens cured in normal water at same ages.*

Rapid chloride permeability

The measurement concerns the chloride ions that come into concrete and also those flowing through the samples. It was reported that the use of Waste Foundry Sand decreased the rapid chloride penetration Coulomb value of concrete and the presence of Waste Foundry Sand could improve the permeability of concrete.

Effect of WFS on rapid chloride permeability

Influence of WFS on chloride-ion permeability of concrete mixes SCC-1(0%WFS), SCC-2(10%WFS), SCC-3(15%WFS) and SCC-4(20%WFS) are shown in Fig. 11.Chloride-ion permeability of concrete mixes decreased with the increase in WFS content. At 28 days, for mixes SCC-1 (0% WFS), SCC-2 (10% WFS), SCC-3 (15% WFS) and SCC-4 (20% WFS), charges passed were 1200, 910, 720, and 970 coulombs. Coulomb value decreased in mix SCC-3 with the increase in WFS content up to 15% WFS, which indicate that concrete became more dense. This aspect has also been reflected by the compressive strength results of concrete mix made with WFS up to 15% WFS. However, at 20% WFS (SCC-4), there is slight increase in coulomb value with references to 15% WFS. All concrete mixes have Low and very Low Permeability (coulombs between 100 and 2000) as per ASTM C1202. It can be seen that RCPT values decreased with the increase in WFS content (%). Maximum reduction in RCPT value was observed at 15% WFS. It can be concluded that at 15% WFS, concrete mix M-4 exhibited more resistance to chloride-ion penetrability than control mix SCC-1 (0% WFS). According to ASTM C 1202, all concrete mixes have low penetrability to chloride-ion. The 15% replacement of WFS acts as filler material and yields a significant reduction in total charge passed.

These fine particles reduce the voids between ingredient of concrete and makes dense matrix. It also helps to decrease the electrical conductance of concrete. At 15% replacement of natural sand with WFS, WFS gives better effect to internal pore structure of concrete as a filler material. Finer particles of WFS act as a good filler material to make a stronger internal structure of concrete matrix.

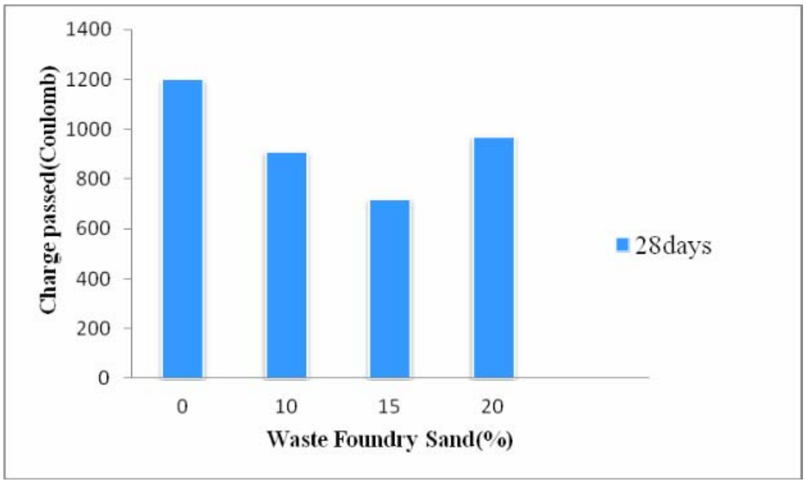

Figure 11. *Chloride penetration for SCC mixes at various Waste Foundry Sand content*

Conclusions

Strength Properties

Compressive Strength

1. Compressive strength of concrete mixes increased due to replacement of fine aggregate with waste foundry sand. However, compressive strength observed was appropriate for structural uses.
2. M30 (37.06MPa) grade concrete mix obtained increase in 28-day compressive strength from 37.06MPa to 43.03MPa on 15% replacement of fine aggregate with WFS. Maximum strength was achieved with 15% replacement of fine aggregate with WFS. Beyond 15% replacement it goes to decrease, but was still higher than control concretes
3. Compressive strength also increased with increase in age of concrete. The rate of compressive development of waste foundry sand concrete mixes were higher compared to no waste foundry sand concrete mixes.

Split Tensile Strength

1. Concrete mixes obtained linear increase in 28-day splitting tensile strength from 2.84 MPa to 3.31MPa for concrete mix on replacement of fine aggregate with waste foundry sand at various percentages of 0% to 20%.
2. Splitting tensile strength of all concrete mixes was found to increase with increase in with varying percentage of waste foundry sand.
3. Maximum increase in splitting tensile strength was observed at 15% replacement of fine aggregate with waste foundry sand at all age for concrete mixes.

Durability Properties

Sulphate Resistance

1. The compressive strength of 10% waste foundry sand specimens when immersed in 50g/l $MgSo_4$ solution gives more strength than standard mix value when immersed in water at 7, 28 and 56 days. But when the percentage of waste foundry sand increase to 15% and 20%, the compressive strength of the mix tends to decrease when compared with the compressive strength of specimen cured in water at same ages.
2. The strength loss will be much larger if the concrete is immersed in the solution for a larger period of time, the extent needs to be investigated.
3. 10% waste foundry sand is optimum from the consideration of resistance to sulphate attack as observed from the experimental results.

Rapid Chloride Permeability Resistance

1. Chloride permeability resistance of concrete mixes increased with the increase in waste foundry sand content.
2. RCPT value (Coulombs) decreased with the increase in WFS content up to 15% WFS, which indicate that concrete has become denser. This aspect has also been reflected by the compressive strength result up to 15% WFS. However, at 20% WFS, there is slight increase in coulomb value with references to 15% WFS but it is less than control one.
3. All concrete mixes with waste foundry sand come under “very low” permeability against chloride at all age as per ASTM standards. Only concrete mix SCC-1(0% WFS) comes under low permeability at 28 days of curing. SCC-3(15%WFS) has the lowest RCPT value among all the mixes.

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