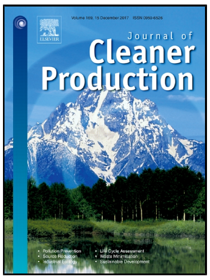

Recycle option for metallurgical by-product (spent foundry sand) in green concrete for sustainable construction

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Highlights

- Paper presents economic and environmental benefits of green concrete made with SFS
- Compared to control concrete, SFS green concrete exhibited higher compressive strength (26%), splitting tensile strength (12.87%) and improvement in durability properties.
- Green concrete made with SFS is economical and reduces negative impact on environment by reducing CO_2 emissions.

Recycle option for metallurgical by-product (spent foundry sand) in green concrete for sustainable construction

By

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Abstract

Reuse of waste materials as construction material is very much essential to achieve sustainable construction. Utilization of waste materials as construction material not only help in protection of environment but also result in monetary savings. Spent Foundry Sand (SFS) is the waste material generated by metal casting industry. This paper presents study on economic and environmental benefits of recycling of SFS in concrete as sand replacement. Strength and durability properties of green concrete made with SFS as sand replacement are also presented. Natural sand in concrete was replaced with SFS at 0, 5, 10, 15 and 20% replacement levels by weight. To assess the performance of green concrete made with SFS, compressive strength, splitting tensile strength, deicing salt resistance and chloride permeability tests were performed. At age of 28 days, green concrete mixtures containing SFS as sand replacement displayed up to 26% and 12.87% improvement in compressive strength and splitting tensile strength over that of control concrete, respectively. Similarly, concrete mixtures made with SFS exhibited 7.2 to 17.7% lower chloride ion penetration and 6.6 to 26.42% improvement in salt scaling resistance on use of SFS. The green concrete mixtures showed very slight scaling after 50 cycles of freezing and thawing in the presence of deicing salt compared to slight to moderate scaling shown by control concrete. The incorporation of up to 20% SFS as sand replacement results improvement in strength and durability properties of green concrete over those of control concrete. Green concrete made with SFS is economical and reduces negative impact on environment by reducing CO_2 emissions.

Keywords: Green concrete; spent foundry sand; compressive strength; permeability

1.0 Introduction

Sustainable construction can be achieved with the help of green concrete by implementing the tools and strategies reported by Berry et al., (2009) and Stanley (2010). For this purpose they suggested to use 1) recycled material to reduce dependence on natural materials; 2) supplementary cementing materials to reduce consumption of cement thereby reducing CO_2 emissions; and 3) wash water in manufacturing concrete with improved properties. Green concrete is the durable concrete produced with the aim to have the least impact on the environment by substituting 1) cement with waste materials such as fly ash, blast furnace slag and silica fumes; and 2) natural aggregates with recycled / waste materials or industrial by-products.

The manufacturing of cement, the main constituent of concrete contribute about 95% of the total greenhouse gas released per cubic yard of concrete produced (Obla, 2009). Worldwide, the cement manufacturing industry contributes nearly 7% of global greenhouse gas emissions. The emission of greenhouse gases to the atmosphere is responsible for global warming (www.ucsusa.org). As per Carbon Dioxide Information Analysis Center (CDIAC) statistical data, CO_2 emissions in India increased from 0.268 to 1.59 metric tons per capita in a period between year 1960 and 2013. CO_2 emissions are expected to increase in future with increase in construction activities, increase in living standards, etc. However, CDIAC data (2013) reveals that in India, per capita CO_2 emission is much lower compared to 16.39 metric tons per capita in USA.

Till date, research has been focused on the use of supplementary cementing materials to enhance the concrete properties and reduce CO_2 emissions. Though mining of natural aggregates contributes nearly 1% of the total CO_2 emissions, the mining of natural materials on large scale for use in the manufacturing of concrete every year leaves a significant negative effect on the environment. The best way to protect the environment is to utilize the waste materials in civil engineering applications to replace the natural materials and minimize their mining. This will help in protecting the environment apart from saving in disposal cost of waste materials and saving in CO_2 emissions related to the mining of natural aggregates. Waste materials such as Spent Foundry Sand, Coal Bottom Ash, Recycled Aggregate, etc. can be used as replacement of natural aggregates in production of concrete and other civil engineering applications. According to American Foundrymens Society (AFS report, 1991) up to 33% Spent Foundry Sand can be used as replacement of natural sand in asphalt paving mixes, ready mix concrete, precast concrete blocks, concrete pavers etc..

Spent or waste foundry sand is generated by metal casting industries. Metal casting industry use high quality silica sand having specific size particles for molding and casting process. Foundry sand is recycled and reused number of times in metallurgical industry in the casting process. When foundry sand loses its quality and becomes unfit for further use for the molding purpose, it is removed from the foundry industry and is treated as waste material. This unusable material is called Spent Foundry Sand (SFS). The main factors which effect the properties of SFS are poured metal type, casting process, technology used, and finishing process. Generally 85% of clay bonded foundry is used in metallurgical industry in the casting process. Clay bonded foundry sand consists of 80-95% silica sand, 4-10% bentonite clay, 2-10% carbonaceous additive and 2-5% water. In USA, nearly 10-15 million tons of SFS is generated annually (American Foundrymen's Society) and in India, this figure is 1.71 million tons annually (Metal World, 2006)

1.1 Literature Review

Literature review reveals use of SFS in many civil engineering applications. Naik et al. (2003) observed that SFS along with fly ash can be used in making of blocks for construction of building walls. Naik et al. (2004) reported that F type fly ash as a partial replacement of Ordinary Portland cement and coal bottom ash combined with SFS as a partial replacement of natural sand could be suitably used in concrete production. Haggar and Hatow (2009) reported use of SFS in the production of manhole covers. Periraa et al. (2004) have reported the use of SFS for making refractory mortars. Santurde et al. (2011) examined the potential use of SFS in manufacturing of clay brick.

Siddique et al. (2007 and 2009) reported that the use of SFS up to 30% as partial replacement of sand resulted in slight increase in compressive strength, splitting tensile strength, and modulus of elasticity of concrete. However, Guney et al. (2010) illustrated that the strength properties including modulus of elasticity of concrete made with SFS decreased with increase in the replacement level of standard fine sand. They also reported that concrete specimen with 10% SFS displayed similar compressive strength, tensile strength and modulus of elasticity results to that of control concrete. They observed that by carefully arranging the particle size distribution of SFS, it can successfully be used in manufacturing of high strength concrete.

Though mechanical properties of concrete made with SFS have been extensively evaluated, the published literature lacks in studies on concrete microstructure, economic and environmental benefits of using SFS as partial replacement of sand in concrete. The recycling of SFS has an important bearing on maintaining the ecological balance and economy of a country in general and construction industry in particular. Therefore this research work was carried out to evaluate the feasibility of recycling SFS in concrete to achieve technical, environmental and monetary benefits. In this study, microstructure, compressive strength, splitting tensile strength, deicing salt resistance and chloride permeability of concrete containing SFS as partial replacement of sand have been evaluated. The monetary and environmental benefits of green concrete made with recycled SFS have also been deliberated.

The present manuscript is structured in four sections i.e. Introduction section; Experimental program section comprises material characterization, concrete mix design and casting of concrete specimens; Result and discussion section demonstrates the evaluation of properties of concrete made with SFS and economic study; and Conclusion section contains the concluding remarks of the present research work.

2. Experimental Program

2.1 Material

The present study used Portland pozzolanic cement incorporating 30% Fly ash conforming to Indian standard specification BIS: 1489-1991, locally available natural sand and crushed coarse aggregate. SFS was received from the metal casting industry at Mandi Gobindgarh, Punjab (India). Compressive strength, setting times, soundness, specific gravity and shrinkage test results of Portland pozzolanic cement are presented in Table 1. Physical properties of natural sand, spent foundry sand and coarse aggregate (crushed) with maximum particle size of 12.5 mm are given in Table 2. Characterization of materials such as natural sand, SFS and coarse aggregate was done according to Indian standard specification BIS: 383-1970. Particle size distribution curves of natural sand and SFS are presented in Fig. 1. According to this curve, nearly 95% SFS material is finer than 600 µm compared to 52% of natural sand. Chemical composition of SFS is given in Table 3. SFS has low fineness modulus and specific gravity. Polycarboxylate with relative density of 1080 gm/L at 30°C and brown in color was used as superplasticizer for obtaining good workability of concrete made with or without spent foundry sand.

2.2 Concrete mix proportions

Control concrete (CC) mix was made according to Indian specification BIS: 10262-1982 to achieve 30 MPa compressive strength at the age of 28 days. Natural sand in concrete was replaced with 5, 10, 15, and 20% SFS and the concrete mixtures were accordingly designated as SFS5C, SFS10C, SFS15C and SFS20C. The detail of mix proportions and properties such as slump, and temperature of fresh concrete determined as per Indian standard specification BIS: 1199-1959 are given in Table 4.

2.3 Preparation of specimen

Concrete specimens of size 150 x 150 x 150 mm were cast for evaluating the compressive strength and ultrasonic pulse velocity of concrete mixes made with and without SFS as substitute of natural sand. Cylindrical concrete specimens of size 150 x 300 mm and 100 x 200 mm were cast for determining the splitting tensile strength and the chloride permeability of concrete mixes, respectively. For assessing the deicing salt resistance, 75 mm thick concrete tile specimens of size 225 × 225 mm were cast for all concrete mixtures. The specimens were covered with plastic sheet to reduce the moisture loss. The concrete specimens were de-mouled after 24 hours of mixing of water. The specimens were then water cured at room temperature (27 - 28°C) up to the age of test.

2.4 Testing procedures

Slump values and temperature of fresh concrete were measured according to Indian standard specification BIS: 1199-1959. Compressive strength and ultrasonic pulse velocity through concrete were determined up to the age of 365 days according to Indian standard specification BIS: 516-1959 and ASTM C597, respectively. Splitting tensile strength and chloride ion penetration through concrete specimens up to the age of 365 days were determined as per BIS: 5816-1999 and ASTM 1202 C- 97, respectively. Deicing salt resistance of concrete mixes was assessed according to ASTM C672-98. The average of three specimen test values has been taken as value for each property of concrete mix at the specified age.

3. Result and Discussion

3.1 Workability

The slump test results of control concrete and SFS concrete are given in Table 4. The slump values of concrete decreased marginally from 90 mm to 80 mm on inclusion of 20% SFS as replacement of sand. SFS used in this research contained 95% particles finer than 600 µm compared to 52.3% particles of sand. The presence of more quantity of finer particles in SFS possibly decreased the fluidity of fresh concrete. It can be concluded that incorporation of SFS (up to 20%) as replacement of sand does not significantly reduce slump values of fresh concrete. The results of present work are covenant with those observed by Gunney et al., 2010 and Etxeberria et al., 2010).

3.2 Compressive Strength

Influence of SFS on compressive strength of concrete at the age of 7, 28, 91 and 365 days is shown in Fig. 2. It was found that, at the age of 7 days, compressive strength of control concrete (0% SFS), SFS5C (5% SFS), SFS10C (10%SFS), SFS15C (15% SFS) and SFS20C (20% SFS) were 19.7, 22.4, 23.3, 25.3 and 24.8 MPa, respectively. At the age of 7 days, concrete mixture containing 15% SFS (SFS15C) exhibited maximum compressive strength of 25.3 MPa i.e. 28.42 % higher than that of control concrete. At the age of 7 days, concrete mixtures SFS5C, SFS10C, SFS15C and SFS20C achieved 74.67, 81.0, 84.3 and 82.67% compressive strength of control concrete at the age of 28 days. At the age of 28 days, these SFS concrete mixtures achieved 14.6, 22.6, 26 and 23.3%, higher compressive strength than that of control concrete (30MPa). At the age of 91 days, improvement in compressive strength of concrete mixtures SFS5C, SFS10C, SFS15C and SFS20C over that of control concrete (34.5 MPa) was 11.69, 18.8, 20.8 and 18.2%, respectively.

Similarly, at the age of 365 days, there was 9.45, 17.82, 21.6 and 18.9% increase in compressive strength for concrete mixtures SFS5C, SFS10C, SFS15C and SFS20C over that of control concrete (37.0 MPa). It was observed that concrete mixtures containing SFS as partial replacement of sand exhibited compressive strength higher than that of control concrete at all the ages. This may be due to presence of more quantity of fine particles in SFS which acted as good packing material and ultimately resulted in denser concrete matrix. It was also observed that compressive strength development pattern of concrete mixtures containing SFS as partial replacement of sand with age was identical to that of control concrete.

3.3 Splitting Tensile Strength

Splitting tensile strength test results of control and SFS concrete mixtures are shown in Fig. 3. The splitting tensile strength test results of concrete made with SFS were covenant with those for compressive strength. Increase in splitting tensile strength of concrete made with SFS was observed with increase in SFS content. Splitting tensile strength of control concrete mixture (0% SFS) was 2.15 MPa at the age of 7 days. It increased by 5.1%, 10.7%, 16.3% and 11.6% for concrete mixtures SFS5C, SFS10C, SFS15C and SFS20C, respectively. Optimal splitting tensile strength value was observed for concrete mixture containing 15% SFS. At the age of 28 days, splitting tensile strength was higher by 8.2%, 12.5%, 12.8% and 8.2% for concrete mixtures SFS5C, SFS10C, SFS15C and SFS20C, respectively, than that of control concrete (4.23MPa). At the age of 91 days, concrete mixtures SFS5C, SFS10C, SFS15C and SFS20C achieved an increase of 6.4, 11.48, 12.3 and 9.6% over splitting tensile strength of control concrete. At the age of 365 days, increase of 3.5, 8.6, 10.1 and 8.3% in splitting tensile for concrete mixtures SFS5C, SFS10C, SFS15C and SFS20C, respectively, than that of control concrete was observed. It was observed that similar to compressive strength test results, concrete mixture containing 15% SFS as replacement of natural sand (SFS15C), displayed optimal value of splitting tensile strength amongst all the SFS concrete mixtures. As anticipated, splitting tensile strength of SFS concrete mixtures increased with age. Also splitting tensile strength development pattern of SFS concrete mixtures was similar to that of control concrete. The results of present study are in good agreement with the findings of Etxeberria et al. (2010), Siddique et al. (2009) and Guney et al. (2010).

3.4 Rapid Chloride Permeability Test

Chloride-ion permeability test results of SFS concrete mixtures and control concrete are presented in Fig. 4. Lower chloride-ion permeability of concrete mixtures made with SFS as partial substitute of natural sand was observed when SFS content was increased. At the age of 28 days, total charge passed through concrete mixtures SFS5C, SFS10C, SFS15C and SFS20C, was 1410, 1320, 1250 and 1280 coulombs (C), respectively, compared to 1519 C passed through control concrete. At the age of 91 days, total charge passed through these SFS concrete mixtures was 1290, 1200, 1110 and 1150 C in comparison to 1399 C passed through control concrete. It was observed that total charge passed values decreased with the increase in SFS content up to 15% SFS replacement level. This shows concrete mixture made with up to 15% SFS are denser than control concrete. This characteristic was also reflected by the compressive strength test results of similar SFS concrete mixture. However, at 20% SFS replacement level, there was trivial increase in total charge passed value with reference to corresponding value for concrete mixture made with 15% SFS. It can be concluded that at 15% SFS replacement level, concrete mixture SFS15C exhibited more resistance to chloride-ion penetrability than control concrete. According to ASTM C 1202, all concrete mixtures have low penetrability to chloride-ion. At age the age of 365 days, SFS concrete mixture SFS15C (15% SFS) falls under the category of very low chloride-ion penetrability. At the age of 91 days, SFS concrete mixtures SFS5C, SFS10C, SFS15C and SFS20C showed 9.2, 9.1, 12.61 and 10.15%, respectively, decrease in total charge passed values compared to 7.9% decrease for control concrete. Similarly at the age of 365 days, total charge passed values decreased by 17.77% for control concrete (0% SFS), 20.57% for mixture SFS5C (5% SFS), 23.48% for mixture SFS10C (10% SFS), 24.0% for mixture SFS15C (15% SFS) and 23.44% for mixture SFS20C (20% SFS). This shows the reduction in total charge passed values of concrete mixtures containing SFS as partial replacement of natural sand is more prominent than in normal concrete. This can be attributed to the filler effect of fine particles of SFS which resulted in denser concrete matrix. Lower chloride ion penetration in concrete made with SFS as replacement of sand indicates better protection against corrosion of reinforcement steel in saline environment.

3.5 Deicing Salt Resistance

Deicing salt scaling resistance test results of concrete mixtures are presented in Table 5. At the age of 28 days, control concrete and concrete mixture containing 5% SFS as replacement of natural sand (SFS5C) exhibited slight to moderate scaling (rating of 2 according to ASTM C 672 – 98). However, SFS concrete mixtures SFS10C, SFS15C and SFS20C showed better resistance to deicing salt scaling and showed very slight scaling (rating of 1). At the age of 91 days, control concrete and concrete mixtures SFS5C and SFS10C exhibited very slight scaling (rating of 1) after 50 cycles of freezing and thawing in the presence of deicing salt. Whereas, SFS concrete mixtures SFS15C and SFS20C showed “no scaling”. At the age of 365 days, all SFS concrete mixtures SFS5C, SFS10C, SFS15C and SFS20C exhibited “no scaling” compared very slight scaling (rating 1) shown by control concrete.

Deicing salt scaling resistance of concrete mixtures measured as mass loss (scaled off residue) is illustrated in Fig. 5. It was observed that mass loss decreased with increase in SFS content in concrete mixtures. At the age of 28 days, weight loss of SFS concrete mixtures SFS5C, SFS10C, SFS15C and SFS20C ranged from 0.99% to 0.78% compared to 1.06% weight loss of control concrete. Concrete mixture containing 15% SFS as replacement of natural sand showed minimum weight loss of 0.78%. At the age of 91 days, the mass loss of scaling residue was 0.96% for control concrete, 0.85% for mixture SFS5C, 0.70% for mixture SFS10C, 0.56% for mixture SFS15C and 0.65% for mixture SFS20C. Similarly, at the age of 365 days, control concrete, SFS concrete mixtures SFS5C, SFS10C, SFS15C and SFS20C exhibited 0.79, 0.70, 0.57, 0.50 and 0.55% mass loss, respectively. The above results show that, at 15% replacement of sand with SFS, concrete mixture SFS15C exhibited maximum scaling resistance against deicing chemical. Scaling resistance of SFS concrete mixtures as well as control concrete increased with age. XRD and SEM analysis of concrete specimens did not reveal formation of any additional phase on use of SFS as sand replacement. Fig 1, shows nearly 95% SFS material finer than 600 µm compared to 52% (approximately) that of natural sand. The more quantity of finer particles of SFS acted as a packing material and resulted in denser concrete matrix. This may be the possible reason for higher scaling resistance of concrete incorporating SFS as partial replacement of sand.

3.6 Ultrasonic Pulse Velocity

Effect of SFS on ultrasonic pulse velocity of concrete mixtures is shown in Fig.6. On use of SFS as sand replacement, no significant change in ultrasonic pulse velocity of concrete mixtures was observed at all the ages. At the age of 28 days, ultrasonic pulse velocity ((USPV) was 4010 m/s for control concrete (0%SFS), 4025 m/s for mixture SFS5C (5%SFS), 4039 m/s for mixture SFS10C (10%SFS), 4050 m/s for mixture SFS15C (15%SFS) and 4048 m/s for mixture SFS20C (20%SFS). The USPV results are in good agreement with compressive strength and rapid chloride permeability test results. USPV values for concrete mixture containing SFS as replacement of natural sand were found more than that for control concrete. Maximum value of USPV was observed for concrete mixture SFS15C (15%SFS). Slight increase in USPV values of all concrete mixtures were observed with an increase of age of curing. The increase in USPV values ranged from 0.89% to 1.35%. According to BIS 13311 (part 1): 1992, the values of USPV of concrete mixtures incorporating SFS as sand replacement fall under the good quality of concrete zone.

3.7 Microstructure

Microstructure of control concrete and SFS concrete specimens were analyzed using scanning electron microscope (SEM) images and XRD spectrum. SEM images of concrete specimens obtained using secondary electron (SE) image mode are presented in Figs 7 through 10. The morphologies of various phases such as portlandite (CH), calcite (C), ettringite (E) and calcium silicate hydrate (CSH) present in the concrete are marked on the SEM images with higher magnification (Figs 8 through 10). The needle type morphology of ettringite in the voids and plated morphology of calcium hydroxide are clearly visible in SEM image shown in Fig 9. The formation of dog tooth type morphology of calcite is visible in Figs 8 and 10. The voids (V) in the concrete specimens are also marked on these SEM images. As shown in Fig. 8, the proportion of voids in SEM image of control concrete specimens is more compared to that of SEM images of concrete made with SFS (Figs 9 and 10). Also the CSH gel is seen more evenly spread on SEM images of concrete specimens containing SFS as partial replacement of sand compared to that for control concrete (Fig. 7).

The XRD spectrum of powered cement pastes separated from concrete specimens was obtained for diffraction angle 2θ ranged between 5° and 70° in steps of 2θ = 0.017°. XRD spectrums of powered concrete specimens showing various phases are presented in Figs 11 through 14. The main phases present in concrete are quartz, portlandite, calcite, calcium silicate hydrate, ettringites and calcium aluminum silicate hydrate. Crystalline phases such as Quartz, portlandite and calcite forms clear peaks. Amorphous or poorly crystallined phases such as calcium silicate hydrate, calcium aluminum silicate hydrate, calcium monosulphoaluminate and calcium hemi- or monocarboaluminate do not produce visible reflexes in the XRD spectrum, but increase the background. XRD spectrums of powdered concrete specimens show a hump-like peak between 25°-38° 2θ due to presence of amorphous C-S-H gel. The XRD diffraction diagrams of concrete specimens containing SFS and control concrete are qualitatively similar and no extra phase is formed on addition of SFS as sand replacement. Quantitative analysis of concrete specimens done using X'Pert HighScorePlus software (Rietveld method) show increase in composition of portlandite from 2.5 to 5.7% (except SFS20C) and decrease in calcite composition from 11.4 to 8.4% on inclusion of SFS as sand replacement. The composition of portlandite in SFS20C was lower than that for control concrete. Since no additional phase was detected in XRD analysis of powdered SFS concrete samples, therefore particle packing effect dominated in increasing the compressive strength and decrease in RCPT values of concrete on addition of SFS as sand replacement.

3.8 Economic of recycling of SFS and environmental benefits of green concrete

According to Ibn Taymiyyah, if desire for good increases while its availability decreases, its price rises. On the other hand, if availability of the good increases and the desire for it decreases, the price comes down. Therefore, the price of material or product or service is a function of gap between demand and supply. This holds well in the present free market also where in if any commodity falls short of supply, then its price rises. Similar is the case with the price of natural sand in Punjab (India) these days. The increased public awareness towards protection of environment has forced the governmental environment protection agencies to impose restrictions on mining of natural sand in the large part of the state. As a result, the supply of natural sand for construction industry has been affected badly and its price has increased substantially. The present price of natural sand is Indian Rs. 600.00 (US $ 9.35) per ton compared to Indian Rs. 155.00 (US $ 2.42) per ton in year 2008. The price of natural sand has increased 3.87 times since last 10 years. Whereas SFS from the metal casting industry is treated as a waste material and disposed on open land. The metal casting industry is spending substantial amount on safe disposal of SFS. The safe disposal cost of SFS includes capital cost (land cost), recurring cost (transportation cost, labour cost) and social cost. The social cost comprises of loss of fertile soil and negative effect to human being. In spite of spending substantial amount on safe disposal of SFS, there is no benefit to the industry. Metal casting industry in India generate nearly 1.71 million tons of SFS annually (Metal World, 2006). It is not used in any form and is dumped on an open land which poses hazard to environment. In USA, the production of SFS is 9 to 10 million tons annually (Winker and Bol'shakov, 2000). The cost of safe disposal of SFS in USA is $15-75 per ton (Winkler et al., 1999). It includes storage, transportation and labor costs. Total cost of safe disposal of SFS in USA was estimated as $ 135-657 million.

Though the natural materials have quality control advantages over the waste materials, the economic viability of using of waste materials will increase early enough, as the sources of natural materials are depleting gradually and disposal cost of waste material is increasing progressively. The use of SFS in any form has multiple advantages, such as saving in disposal cost and preservation of environment from the negative effects of landfilling with SFS. It has been established from this and previous published studies that SFS can safely be used as partial replacement of natural sand in concrete without affecting strength and durability aspects. Utilization of SFS will help in three ways 1) by reducing the cost of concrete production; 2) saving in CO_2 emissions to the atmosphere though it may be small and 3) protection of environment from bad effect of spent foundry disposed on open land.

Worldwide, nearly 25 billion tons of concrete is produced annually (World Business Council for Sustainable Development 2009). The mass resources used for production of concrete are natural aggregate, cement and water. The production of one ton of conventional concrete releases 0.05 to 0.13 tons carbon dioxide to the atmosphere (Obla, 2009). Consequently, worldwide, 1.25 to 3.25 billion tons of CO_2 is released to the atmosphere annually. To date, all the efforts have been made on partial replacement of cement with supplementary cementing material in concrete but the impact of natural aggregate in terms of CO_2 emissions from concrete has not been considered significant. The use of virgin aggregate contributes only 1% of all greenhouse gas emissions from concrete (Obla, 2009). As such, the use of waste materials in place of natural aggregate did not attract the attentions of researchers. Till now, least effort has been made in this direction. The use of waste materials such as coal bottom ash, SFS, etc. as replacement of fine aggregate in concrete not only prevents landfilling, but also provide environmental preservation, saving in concrete cost and disposal cost of these waste materials. Though it is deliberated that contribution of natural aggregate in concrete towards CO_2 emissions is small, but if quantity of concrete produced worldwide is considered, the total CO_2 emissions to the atmosphere annually vary from 12.5 to 32.5 million tons. Considering 33:67 ratio of fine and coarse aggregate in concrete, CO_2 emissions to the atmosphere range from 4.1 to 10.8 million tons, annually from use of natural fine aggregate. In India, about 1500 million tons of concrete is produced annually. Thereby 75 to 195 million tons of CO_2 is released to the atmosphere annually. These emissions can be reduced by using SFS as partial replacement of sand in concrete. As shown in Table 6, on use of 20% SFS as replacement of sand, the cost of concrete can be reduced by Indian Rs. 68.00 (US $ 1.06) per cubic meter in addition to reduction in CO_2 emissions, saving in disposal cost of SFS and benefit gained due to improvement in properties of concrete. In case 100% SFS generated in the country is used by substituting 20% natural sand in concrete, direct saving of nearly Indian Rs 1000 (US $ 15.60) million can be affected in addition to reduction in the range of 74250 to 193050 tons of CO_2 emissions to the atmosphere.

4.0 Conclusions

Most of the published studies are based the concept of reducing CO_2 emissions by using supplementary cementitious materials as cement replacement in concrete but the published literature lacks in studies on CO_2 emissions and monetary benefits due to replacement of natural materials with SFS in concrete. In this study, the significance of use of SFS in concrete in terms of improvement in properties and microstructure of green concrete, monetary and environment benefits was examined. From the present study following conclusions can be drawn.

1. Strength and durability properties of concrete improved on use of up to 20% SFS as partial replacement of sand. The use of finer SFS material resulted in denser concrete matrix. At the age of 28 days, SFS concrete mixtures exhibited up to 26% and 12.87% higher compressive strength and splitting tensile strength compared to that of control concrete, respectively. Similarly, SFS concrete mixtures displayed 7.2 to 17.7% lower chloride ion penetration and 6.6 to 26.42% improvement in salt scaling resistance on use of SFS.
2. Concrete mixture containing 15% SFS as sand replacement displayed optimum percentage improvement in strength and durability properties. On further increase in replacement level up to 20%, percentage improvement in strength and durability properties of SFS concrete with reference to that of control concrete started decreasing.

3. SFS is a potential material to be used as partial replacement of natural sand in concrete for achieving the sustainable construction. On recycling of SFS in concrete, reduction in CO_2 emissions as well as saving in disposal cost can be achieved.
4. Green concrete made with fly ash based cement and SFS lessens negative impact on environment by reducing CO_2 emissions. Green concrete made with SFS as sand replacement consumes less energy and is more economical compared to conventional concrete.

References

American Foundry men's Society, 1991. Alternative utilization of foundry spent sand. Final Report (Phase I) prepared by American Foundry men's Society Inc. for Illinois Department of Commerce and Community Affairs, Des Plaines, Illinois, USA

ASTM C 672/C 672M,-98, 1998. Standard test method for scaling resistance of concrete surface exposed to deicing chemical, American Society for Testing and Materials International, West Conshohocken, USA

ASTM C 597-93, 1993. Standard Test Method for Pulse Velocity through Concrete, American Society for Testing and Materials International, West Conshohocken, USA

ASTM 1202 C – 97, 1997. Standard test method for electrical induction of concrete, s ability to resist chloride ion penetration, American Society for Testing and Materials International, West Conshohocken, USA

BIS: 1489(Part 1), 1991. Portland pozzolana Cement Specification, Fly Ash Based, Bureau of Indian Standards, New Delhi, India

BIS: 383, 1970. Specifications for coarse and fine aggregates from natural sources for concrete. Bureau of Indian Standards, New Delhi, India

BIS: 10262, 1982. Recommended guidelines for concrete mix design. Bureau of Indian Standards, New Delhi, India

BIS: 1199, 1959. Indian standard methods of sampling and analysis of concrete. Bureau of Indian Standards, New Delhi, India

BIS: 516, 1959. Indian standard code of practice- methods of test for strength of concrete, Bureau of Indian Standards, New Delhi, India

BIS: 5816, 1999. Splitting tensile strength of concrete-Test method, Bureau of Indian standards, New Delhi, India

BIS: 13311 (part 1), 1992. Non- Destructive testing of concrete methods of test (Ultrasonic Pulse Velocity), Bureau of Indian standards, New Delhi, India

Braham A., 2002. The use of blended recycled foundry sand in hot mix asphalt. Interim Report, University of Wisconsin – Madison, Asphalt Research Group.

Christopher Stanley, 2010. The green concrete revolution 35th conference on world in concrete & structure. Singapore, 25-27 August.

Christian Meyer, Concrete as a green building material. Columbia University, New York, USA

Carbon Dioxide Information Analysis Center, Environmental Sciences Division, Oak Ridge National Laboratory, Tennessee, USA.

Dungan SR, Kukier U, Lee B., 2006. Blending foundry sands with soil: Effect on dehydrogenase activity. Science of the Total Environment, 357(1-3): 221-230.

Deng A. N., Tikalsky J. P., 2008. Geotechnical and leaching properties of flowable fill incorporating spent foundry sand, 28 (11): 2161-2170.

Etxeberria M, Pacheco C, Meneses J M, Beerridi I., 2010. Properties of concrete using metallurgical industrial by-product as aggregate. Construction and Building Materials, 24: 1594-1600.

Guney Y, Aydilek A, Demirken M., 2006. Geoenviromental behavior of foundry sand amended mixes for highway sub base. Spent Management; 26: 932-945.

Guney Y, Sari Y D, Yalcin M, Tuncan A, Donmez S., 2010. Re-usage of spent foundry sand in high strength concrete. Spent Management, 30: 1705-1713.

Haggar, S. El., Hatow L. El.., 2009. Reinforcement of thermoplastic rejects in the production of manhole covers. Journal of Cleaner Production, 17: 440–446.

Javed S, Lovell CW, 1994. Use of foundry sand in highway construction. Joint Highway Report No. C-36-50N, Department of Civil Engineering, Purdue University, Indiana, USA

Kirk, P.B, 1998. Highway Construction Application Using Spent Foundry Sand, Thesis Doctoral, Purdue University, West Lafayette, USA, 202.

Khatib JM, Ellis DJ, 2001. Mechanical properties of concrete containing foundry sand. ACI Special Publication, (SP-200):733-748

Mast, D.G., Fox, P.J., 1998. Geotechnical performance of highway construction using spent foundry sand. Geotechnical Special Publication, 79, 66-85.

Michael Berry, 2009. Changing the environment. An alternative “Green” concrete produced without Portland cement. World of coal ash Conference, May 4-7, pp 2-6

Naik TR, Kraus RN, Chun YM, Ramme WB, Singh S. S., 2003. Properties of field manufactured cast-concrete products utilizing recycled materials. Journal of Materials in Civil Engineering 15(4), 400–7.

Naik TR, Kraus RN, Chun YM, Ramme WB, 2004. Siddique R. Precast concrete products using industrial by-products. ACI Materials Journal, 101(3):199–206.

Naga S.M, El-Maghraby A., 2003. Industrial spent as raw materials for tile making. Silicates Industrials 2003; 68: 89–92.

Obla K.H., 2009. What is green concrete? The Indian Concrete Journal, April, 26-28

Quaranta N, Caligaris M, López H, Unsen M, Pasquini J, Lalla N, Boccaccini A.R., 2004. Recycling of foundry sand residuals as aggregates in ceramic formulations for construction materials. Key Engineering Materials, 264–268: 1743–1746.

Pereiraa F R, Nunes F A, Segadães A M, Labrincha J A., 2004. Refractory mortars made of different spents and natural sub-products. Key Engineering Materials, 264-268: 1743-47.

Pereiraa F R, Hotzab D, Segadãesa A M, Labrincha, J A., 2006. Ceramic formulations prepared with industrial spent and natural sub-products. Ceramics International 32 (2): 173–9.

Siddique, R., Noumowe, A., 2008. Utilization of spent foundry sand in controlled low-strength materials and concrete. Resources, Conservation and Recycling, 53: 27–35.

Siddique R., Gupta R, Kaur I., 2007. Effect of spent foundry sand as partial replacement of fine aggregate on the properties of concrete. In: 22nd International Conference on Solid Spent Technology and Management Widener University, Philadelphia, USA.

Siddique R, Schutter G, Noumowe A., 2009. Effect of used-foundry sand on the mechanical properties of concrete. Construction Building Materials, 23: 976–980.

Seung-Whee R., Woo-Keun, L., 2006. Characteristics of spent foundry sand–loess mixture as ceramic support materials. Materials Science Forum, 510-11: 378–381.

Santurde R S, Andrés A, Viguri J R, Raimondo M, Guarini G, Zanelli C, Dond M., 2011. Technological behaviour and recycling potential of spent foundry sands in clay bricks. Environmental Management, 92 (3): 994-1002.

Tikalsky PJ, Smith E, Regan R., 1998. Proportioning spent casting sand in controlled low-strength materials. ACI Material Journal, 95 (6): 740-746.

World Business Council for Sustainable Development, 2009, Cement Industry Energy and CO2 Performance: Getting the Numbers Right, 43 pp., http://www.wbcsd.org/ DocRoot/02fH0Bj3tZNV1RvmG2mb/CSIGNRReportfinal. pdf.

Winkler ES, Bol'shakov, AA, 2000. Characterization of foundry sand waste. Chelsea Centre for Recycling and Economic Development University of Massachusetts, USA

Winkler ES, Kosanovic B., Genovese T., Roth I., (1999). A survey of foundry participation in Massachusetts beneficial use determination process. Chelsea Centre for Recycling and Economic Development University of Massachusetts, USA

http://www.ucsusa.org/global_warming/science_and_impacts/science/CO2-and-global-warming

Table 1 Physical properties of Portland pozzolana cement (Fly ash based).

Physical Properties	Permissible limits as per BIS-1489:1991 [41]	Test Result values
Soundness Le-chat expansion	10.0 Max	2.1
Setting time (mm)		
Initial	30 Min.	70
Final	600 Max	230
Compressive Strength (MPa)		
3 day	16	19
7 day	22	37
28 day	33	48.5
Specific gravity	--------	3.08

Standard Consistency (%)	------	33%
Drying shrinkage (%)	Max 0.15	0.03

Table 2 Physical properties of coarse aggregate, natural sand and spent foundry sand (SFS)

Properties	Coarse aggregate	Natural Sand	SFS
Specific Gravity	2.65	2.65	2.10
Fineness Modulus	6.48	2.59	1.91
Water absorption (%)	1.11	1.4	0.53
Moisture content (%)	-	0.12	0.13

Table 3 Chemical composition of SFS

Constituent	SiO_2	Al_2O_3	TiO_2	CaO	MgO	Fe_2O_3	Na_2O	K_2O	SO_3	Mn_3O_4
Value (%)	81.5	0.95	0.24	1.82	0.91	5.45	0.82	1.24	0.27	0.035

Table 4 Concrete mix proportions

Mix	Cement (kg/m^3)	Natural sand (kg/m^3)	SFS (kg/m^3)	Coarse aggregate (kg/m^3)	Water (L/m^3)	Super plasticizer (L/m^3)	Slump (mm)	Air temperature (°C)
Control Concrete (CC)	390	569	0	1165	195	0.59	90	27
SFS5C	390	541	28	1165	195	0.59	85	27

SFS10C	390	513	56	1165	195	0.59	85	28
SFS15C	390	484	85	1165	195	0.59	80	27
SFS20C	390	456	113	1165	195	0.59	80	27

Table 5 Visual Rating for Concrete

Mix	Visual rating (50 cycle)		
	28 d	90 d	365 d
Control Concrete	2	1	1
SFS5C	2	1	0
SFS10C	1	1	0
SFS15C	1	0	0
SFS20C	1	0	0

Table 6 Cost benefits of using 20% SFS as sand replacement in green concrete

Constituent material	Rate (Rs per 50 kg)	Control Concrete		SFS concrete	
		Quantity (kg)	Amount (Rs.)	Quantity (kg)	Amount (Rs.)
Cement	300.00	390	2340.00	390	2340.00
Sand	30.00	569	341.40	456	273.60
SFS	0	-	-	113	0
Coarse Aggregate	35.00	1165	815.50	1165	815.50
Total			3496.90	Total	3429.10

1 US $ = Rs. 64.0 (Indian)

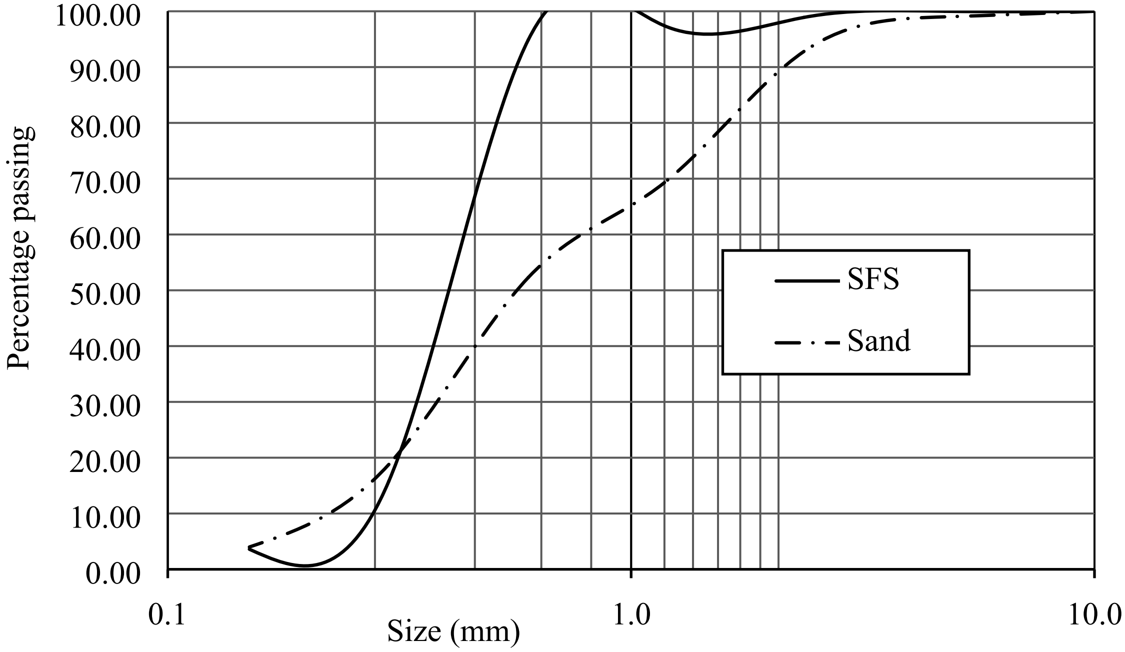


Fig. 1 Particle size distribution of SFS and Sand

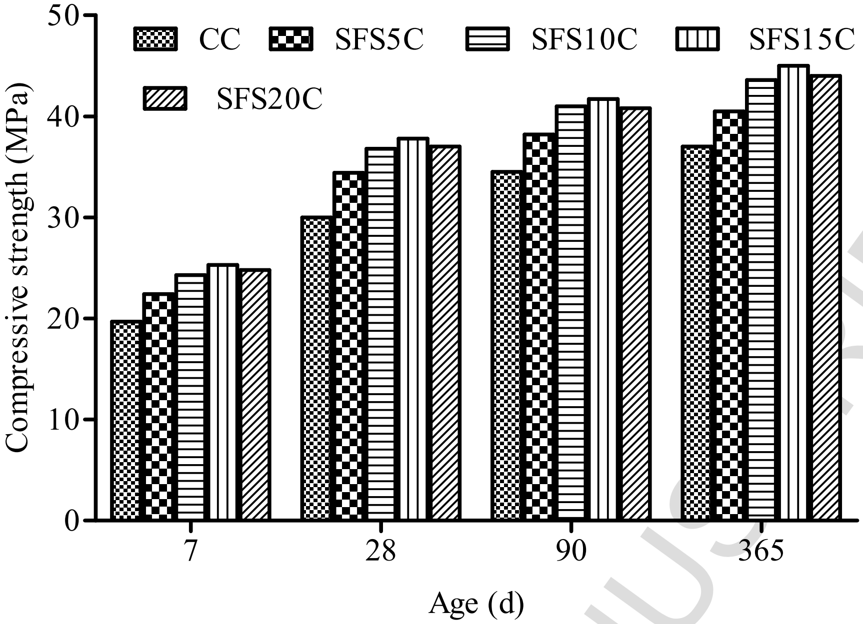


Fig. 2 Effect of SFS on compressive strength of concrete

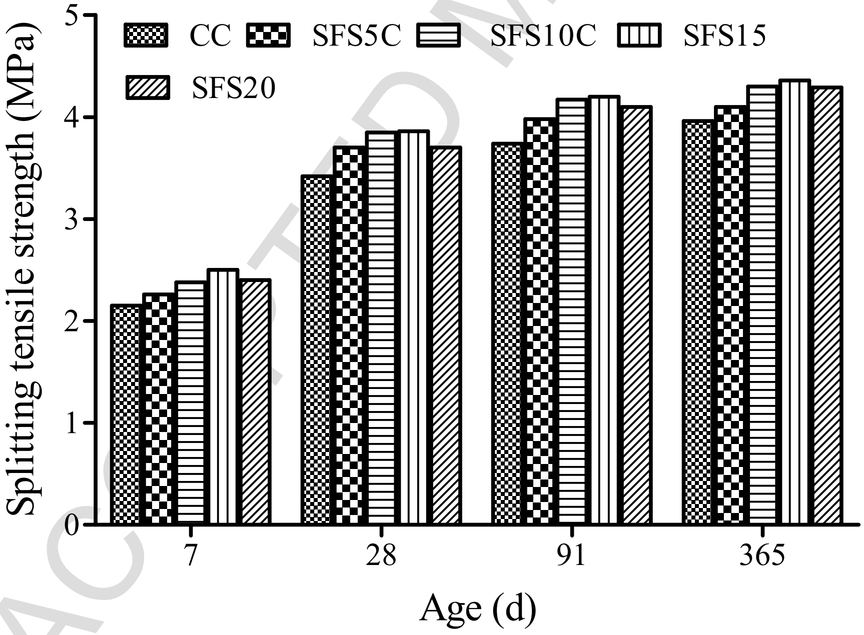


Fig. 3 Effect of SFS on splitting tensile strength of concrete

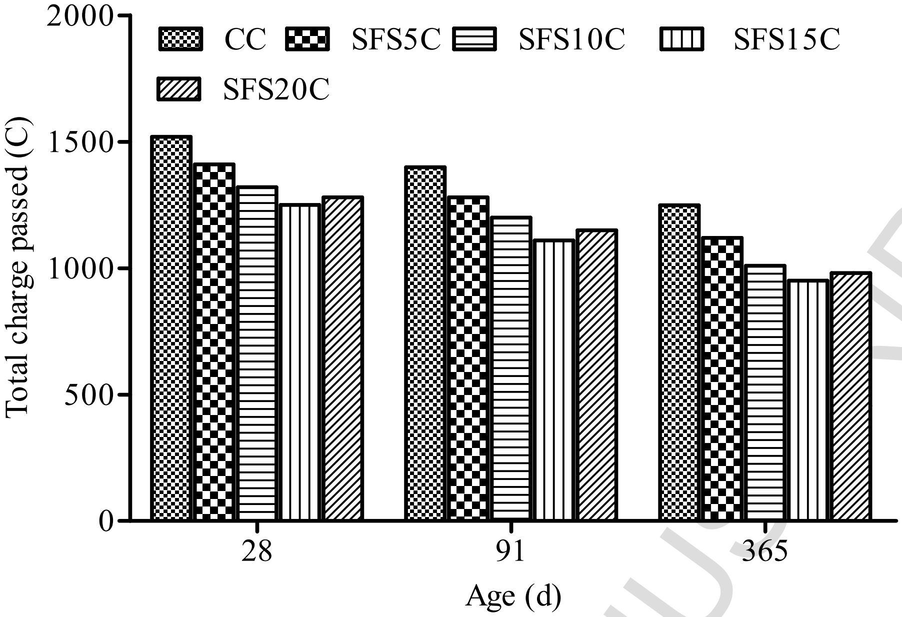


Fig. 4 Effect of SFS on resistance to chloride ion penetration of concrete

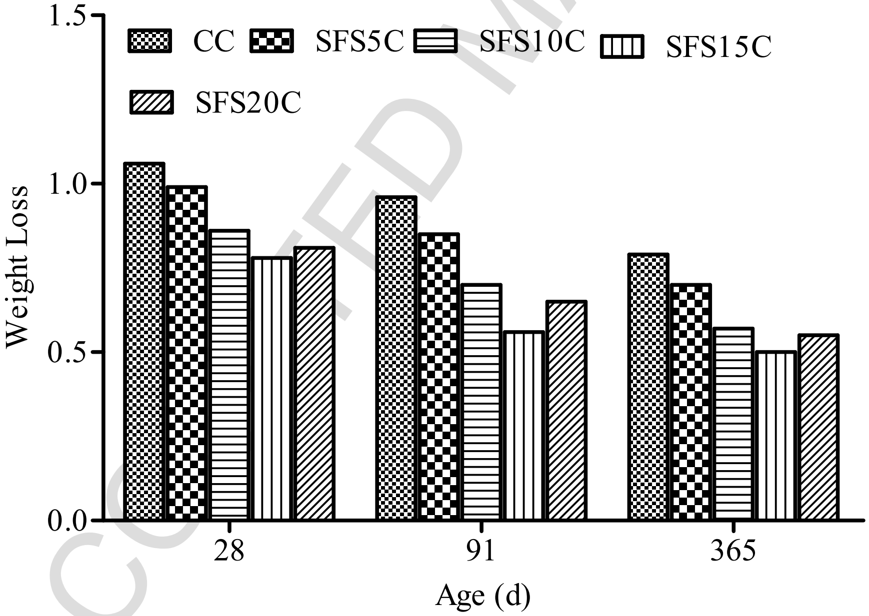


Fig. 5 Effect of SFS on deicing salt scaling resistance of concrete

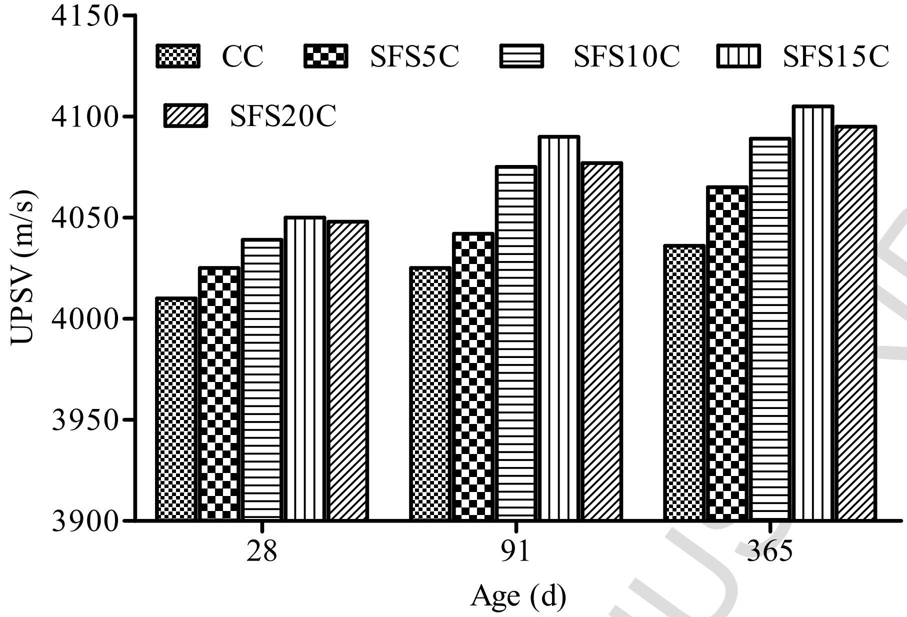
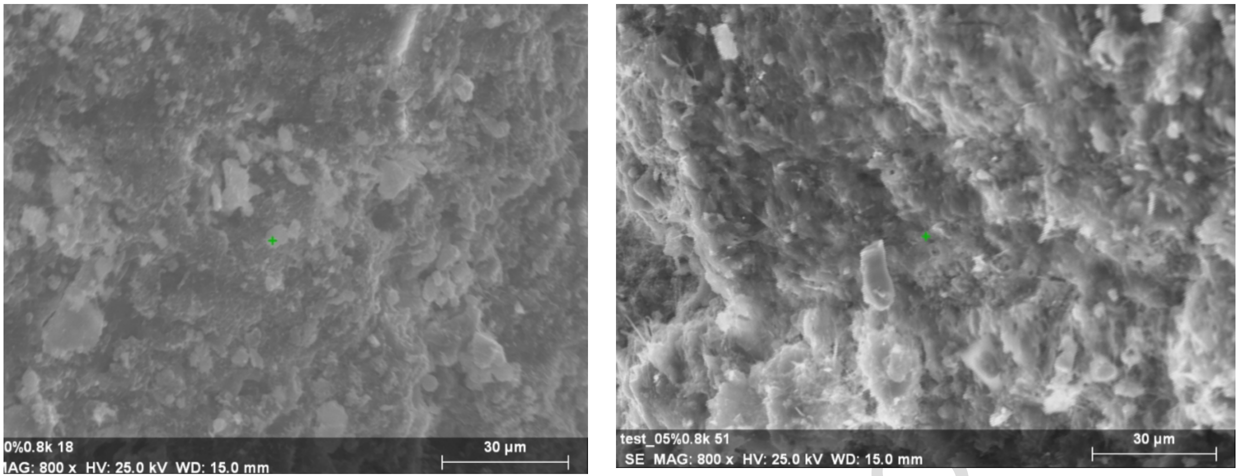
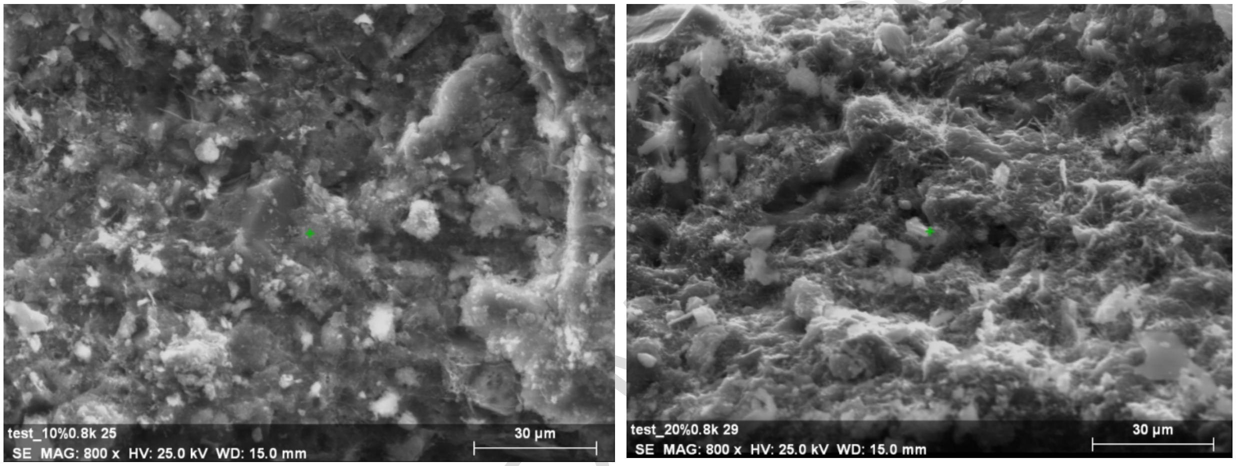


Fig 6 Effect of SFS on ultrasonic pulse velocity through concrete



Control concrete

SFS5C



SFS10C

SFS20C

Fig 7 SEM images of control concrete and SFS concretes at 28 d age

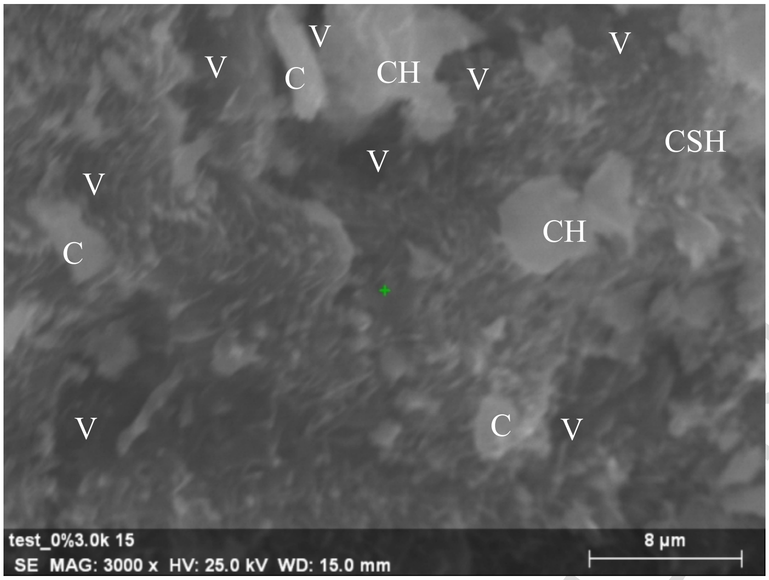


Fig. 8 SEM image of control concrete at 28 d

(V = Voids, C = Calcite, CSH = Calcium Silicate Hydrate, CH = Calcium Hydroxide)

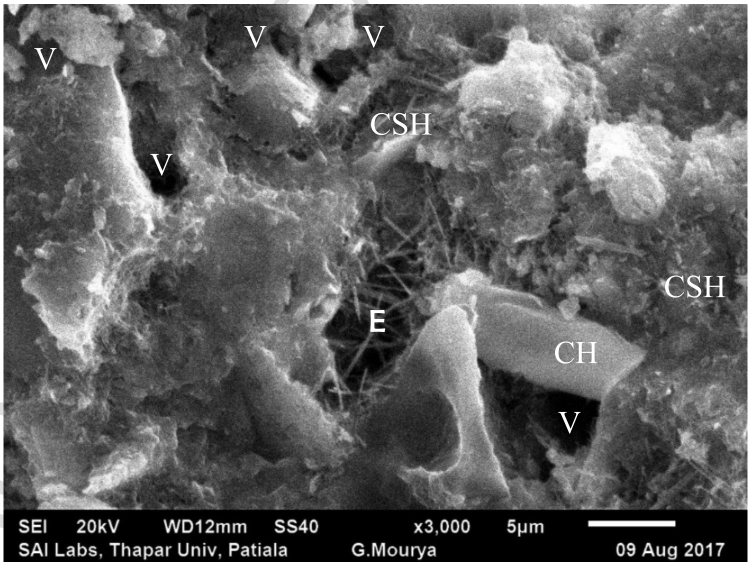


Fig. 9 SEM image of concrete containing 15% SFS as sand replacement at 28 d (V = Voids, CSH = Calcium Silicate Hydrate, E = Ettringite, CH = Calcium Hydroxide)

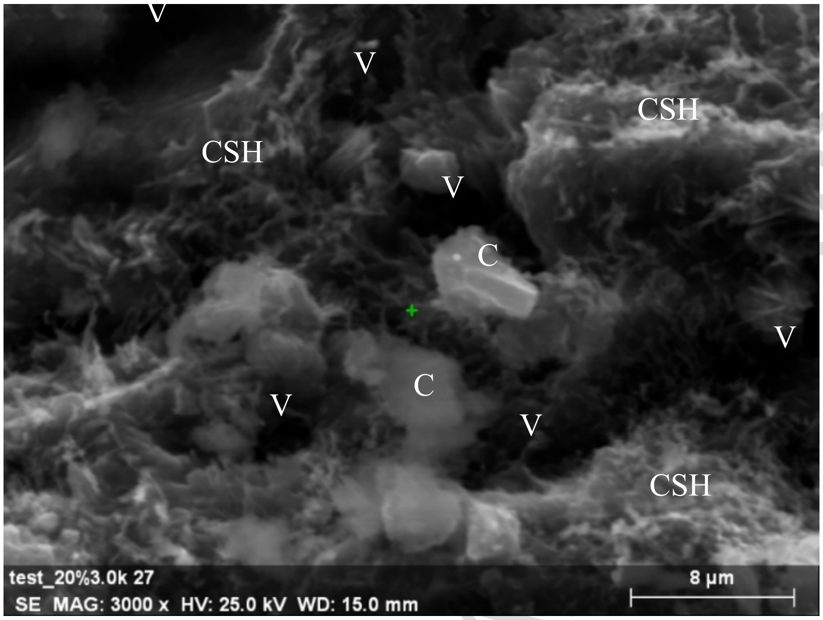


Fig. 10 SEM image of concrete incorporating 20% SFS as sand replacement at 28 d
(V = Voids, C = Calcite, CSH = Calcium Silicate Hydrate)

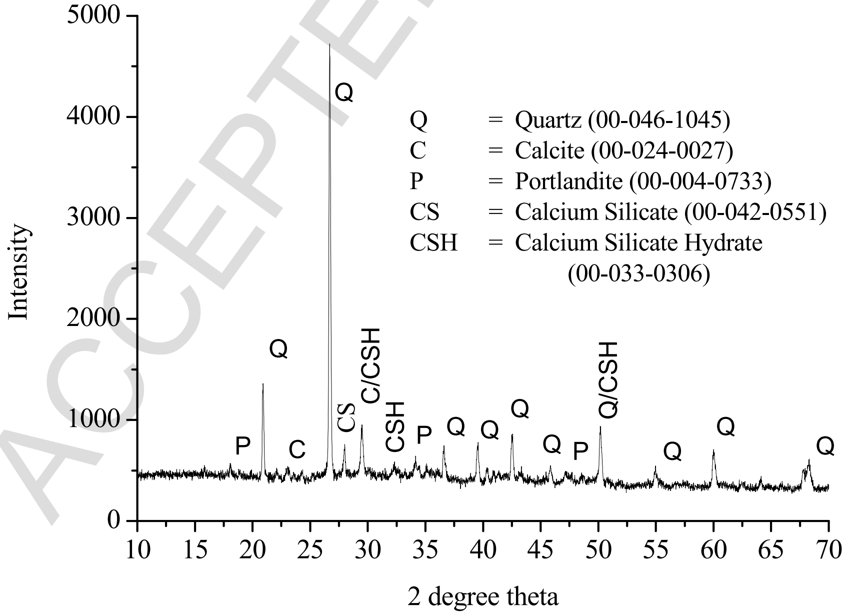


Fig. 11 XRD diffraction of powdered control concrete at 28 d

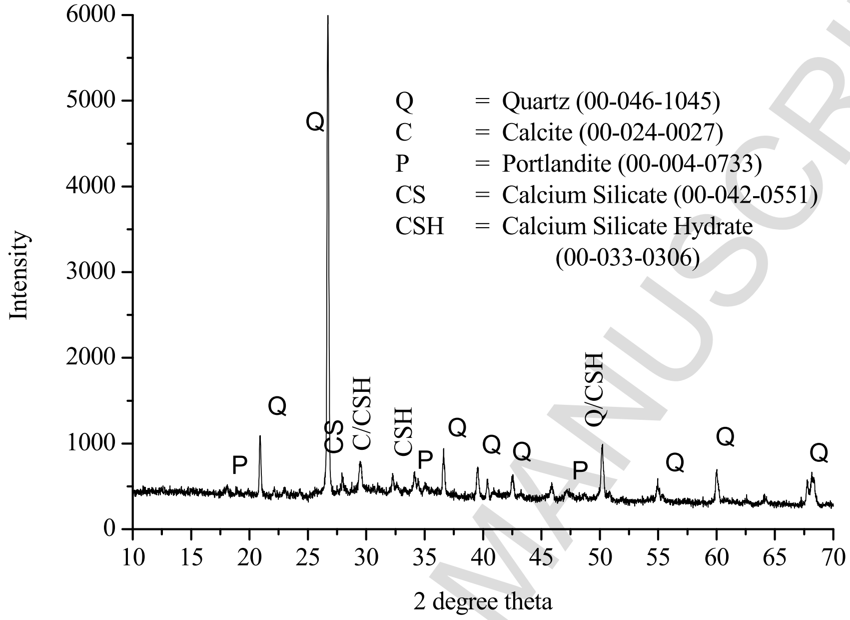


Fig. 12 XRD diffraction of powdered concrete containing 5% SFS as sand replacement at 28 d

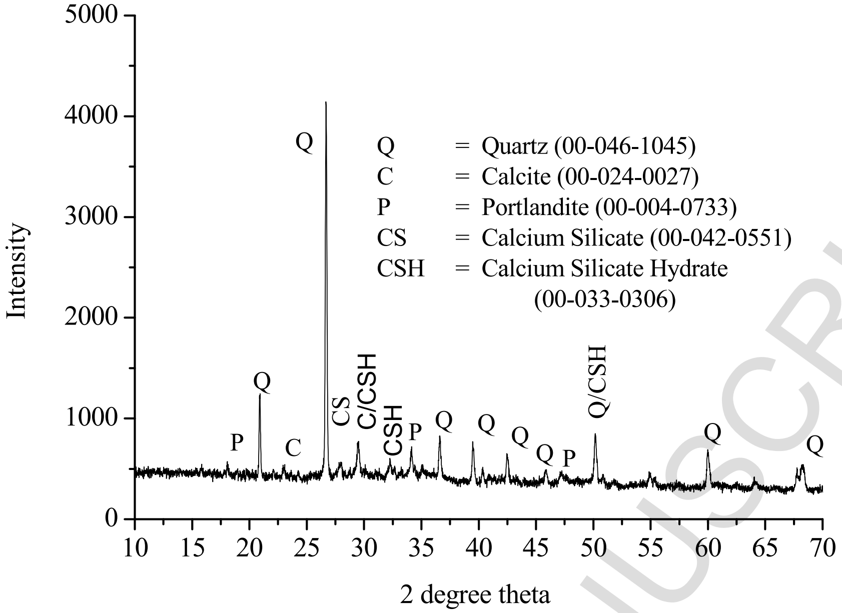


Fig.13 XRD diffraction of powdered concrete containing 10% SFS at 28 d

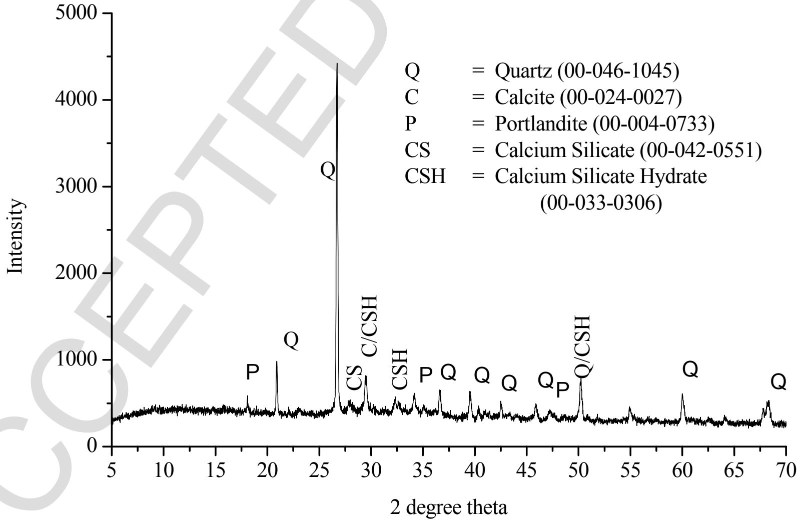


Fig.14 XRD diffraction of powdered concrete containing 15% SFS at 28 d