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Industrial Wastes as Alternative Materials to Fine Aggregates in Triple Blend Self Compacting Concrete – a Sustainable Technological Solution

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Abstract: Self-compacting concrete is a most revolutionary development in concrete constructions for several decades and presently has become a common feature of day to day constructions. The powder content of SCC consists of cement as major binding material. It is a well-known factor that cement production is the major contributor of emission of CO₂, One of the methods adopted to reduce the consumption of cement and hence to reduce greenhouse effect is to use the mineral admixtures such as Fly Ash, GGBS, Metakaolin etc., as cementitious materials, replacing cement partially. It is a solution for the management of Industrial by-products as solid waste, reducing the burden on environment. The consumption of depleting natural resources as FA can also be reduced. Encouraging the use of alternative materials in concrete contributing to green and clean environment. The quality and strength criteria of end product, concrete and SCC are maintained as expected.

The paper presents the experimental study on use of cementitious materials alternate to cement/powder content replacing cement equally named as Triple Blend and also to replace Natural River sand (FA) with Manufactured Sand and Pond Ash.

The literatures report the studies on rheology and strength parameters of concretes with Supplementary Cementitious Materials (SCM). Few studies on the application of cement, fly ash and GGBS in equal proportion by weight (Triple Blend SCC-TSC) is available. The literature on properties of TSC replacing both cementitious materials and FA are scanty.

This paper is an effort to develop a sustainable concrete (TSC) with alternative materials for Cement and Natural River sand and to assess the suitability in terms of required properties of TSC.

The SCC mixes are designed for a powder content of 400 kg/m³ using Absolute Volume method. The Rheology of mixes namely Slump Flow, Slump T₅₀, V Funnel and L-Box are assessed with 180lts of water and varying the dosage of admixtures as per EFNARC 2005. Specimens are cast and cured (for 28 days) as per standard codal procedure. The properties in fresh state of TSC and strength are assessed and analysed in comparison with that of Normal SCC – SCC with 70% cement, 30% Fly ash as powder content and with 100% Natural River Sand as FA.

Properties in fresh state confirms to the requirement of EFNARC 2005. However, the study showed that the presence of Pond ash as FA makes the SCC mix is sticky due to more inter particle friction. Slight bleeding of



mixes can be attributed to the that higher water absorption of Pond Ash in comparison with Natural River Sand and lesser water retentivity of Pond Ash.

The rheological properties of TSC mixes is comparable with that of Normal SCC mixes recommending the use of industrial waste from the point of view of properties of fresh SCC.

The strength reduction of TSC mixes is ranging from 5-10% for the mix in which replacement of M-Sand and Pond ash is carried out in equal proportion by weight. This may be due to the presence of porous, irregular particles of Pond ash which may affect packing density of the mix. Other important observation in the study is that reduction in strength of TSC mix may be attributed to higher water absorption of Pond Ash and lesser water retentivity of Pond Ash.

Hence, the present study recommends the use of alternative materials to both power content of TSC and FA content to produce a sustainable SCC mix contributing to lesser release of CO₂ to atmosphere, avoiding the dependency on depleting natural resources (using alternatives as M-Sand and Pond ash) contributing to Green Design Mix of TSC. This may be one of the most appropriate solution for management of huge solid waste from the industry.

Keywords: *Alternative Materials, Supplementary Cementitious Materials(SCM), Fine Aggregates(FA), Sustainable SCC, Rheology, Strength*

1. Introduction

Self-Compacting Concrete has been developed in late 1980's (Okamura, 1994) and by the year 2000, SCC had become popular in Japan. Till today investigations on SCC are being carried out to study and understand the dual characteristic properties of SCC in fresh state (Nagataki, 1995) as well as in the hardened state. It is very essential to evaluate strength and durability of SCC in its hardened state for the appropriate design and quality control of SCC (Bharathi2009).

Fundamental obstacle to the wider use of SCC and its rapid spread all over the world is the influence of material properties on the behaviour of SCC. This seriously hinders the increased use of SCC in the construction process, since it is difficult to predict the performance of SCC. Due to the vast demand of infrastructure development worldwide, there is huge demand for concrete and SCC making materials, especially FA, Sand which has resulted in this natural resource to get depleted.

The worldwide consumption of sand as FA in concrete production is very high. The supply of natural sand in order to meet the increasing needs of infrastructural development in recent years has led to the use of substandard materials in the name of Filtered Sand and such materials that are damaging the reputation of the profession and Civil Engineering fraternity. The other direct effect is on the increase in the price of sand/FA, and hence the cost of concrete.

The efforts of researchers and practitioners from construction industry in various ways to address the issue through the use of various alternative materials namely Quarry Dust, Manufactured Sand, Slag, Limestone, Sea Sand, Pond Ash, Copper Slag etc. to natural river sand is in progress.

This paper is on the study on the use of pond ash as an alternative material to FA in Triple Blend SCC. Pond ash is a dry bottom ash, a dark grey, granular, porous, and coarser waste material generated from Thermal Power Plants at the end of the process of burning of pulverized coal at very high temperature. Nearly 20 percent of the ash is collected in a water-filled hopper at the bottom of the furnace to form slurry and is pumped to the Ash Pond. This paper is on the study conducted experimentally on the effect of use of alternative materials to FA in Triple Blend Self-Compacting Concrete on Strength Criteria.

2. Literature Review

The literatures report the studies on rheology, strength and durability of concretes with SCM. The studies on the application of cement, fly ash and GGBS in equal proportion by weight (Triple blend SCC-TSC) were carried out extensively by authors in their literature. The literature on structural behaviour of TSC with both Fly Ash and GGBS as supplementary cementitious materials, replacing cement in equal proportion are scanty. Hence an effort to evaluate the strength behaviour of TSC

containing M-Sand and Pond Ash as FA replacing to natural river sand is taken in the present study and presented in this paper.

3. Materials and Methods

The following are the details of various properties assessed as per relevant codes of practices of materials used for SCC, mix design procedure adopted, assessment of properties in fresh and hardened state of TSC.

OPC-Ordinary Portland Cement 53 grade conforming to IS12269:1987 (testing), Pulverized Fuel Ash (from RTPS) conforming to specification IS3812:2003, Part 1 & 2 and testing requirements conforming to IS1727:1967 and GGBS (JSW, Bellary) conforming to IS: 12089-1987 were used as fines which contribute to the powder content of SCC. Natural River Sand conforming to specification IS383:1970 (Zone II) having specific gravity of 2.68 and fineness modulus of 2.65, Pond Ash and Manufacturing sand (M-Sand) conforming to IS383:1970 (Zone III and Zone II) were used as FA. Coarse aggregate of size 12.5mm passing conforming to specification IS383:1970 and also to testing requirements conforming to IS 2386 Part I, III and IV was used for the investigation. The particle size distribution was assessed using sieve analysis on the samples as per IS 2386 (Part I) 1963(Table 2).

Table 1 Properties of Materials

Sl. No.	Properties	Coarse Agg 12.5mm	Natural River Sand	M- Sand	Pond Ash
1	Loose Bulk Density (LBD) (kg/m ³)	1429	1450	1533	1029
2	Rodded Bulk Density (RBD) kg/m ³	1535	1520	1700	1295
3	Specific Gravity	2.643	2.68	2.42	2.02
4	Fineness Modulus (%)	7.0	2.65	2.69	7.09

The specific gravity and bulk density (both LBD and RBD) are measured in accordance with IS2386 (Part III) 1963 (Table 2). Clean potable water available in the laboratory was used for manufacturing TSC.

3.1 Mix Proportion for SCC

Few guidelines for mix design procedure are published in various publications, yet there is no definitive or standard mix design method till date. Mixes were designed as per Absolute Volume Method, design mixes were arrived after extensive trials and are as presented in table 2.

TSC mix contains cement, fly ash and GGBS in equal proportions: M-sand and Pond ash as FA at proportion of 50:50 and CSC mix is with cement and fly ash at 70:30 proportions of cementitious materials and M-sand and Pond ash at 50:50 as FA. CNCS mix is a control mix with Cement and Fly Ash as cementitious content (70:30) and natural river sand as FA (100%).

Table 2 Mix Design by Weight in kg/m³ of SCC

Trial Mix Details	TSC	CSC	CNSC
OPC	133.33	280	280
PFA	133.33	120	120
GGBS	133.33	0	0
Water in litres	180	180	180
w/b ratio	0.45	0.45	0.45
N-Sand	0	0	943.57
M-Sand	432.46	436.27	0
Pond Ash	360.98	362.65	0
Coarse Aggregates	772.84	779.68	779.68
PC Admixture	0.3%	0.3%	0.3%

4. Assessment of Properties of SCC

The rheology of SCC and Strength criteria of different SCC mixes assessed as per the relevant codes of practice are presented as follows.

4.1 Workability of SCC

The main three properties of SCC namely fillability, flowability and segregation resistance of SCC mixes were evaluated as per the EFNARC 2005. The properties of fresh SCC are very much sensitive to variations to the quality of constituents of the mix and the consistency. Rheology of SCC, a challenging task is of great importance to its flow performance, placement and consolidation. The Rheology of mixes was evaluated and test results are tabulated in Table 3.

Table 3 Rheology of SCC Mixes

Rheology and Units	TSC	CSC	CNSC	EFNARC-2005 Requirements
Slump Dia. in mm	715	686	697	600 - 800
V Funnel Time in Sec.	7.48	4.00	3.92	8 - 12
L Box (Blocking Ratio)	0.82	0.90	0.98	0.8 - 1.0

It is observed that the mixes of TSC and CSC showed the better workability when compared to that of Conventional SCC mixes of CNSC. This behaviour may be attributed to the presence of finer particles of Fly Ash and GGBS as cementitious content in the mixes enhancing flow properties of SCC mixes.

4.2 Strength Criteria of SCC Mixes

The Compressive strength, flexural strength(f_b) and split tensile strength(f_t) are assessed as per the codal procedure of relevant codes, the results and discussions are presented as follows.

4.2.1. Compressive Strength

The compressive strength (f_{ck}) of mixes is assessed as per the procedures of IS516:1959 (reaff. in 2004). The results of the test on compressive strength of SCC mixes TSC, CSC and CNSC were assessed for three curing periods of 3, 7 and 28days and are presented in Table 4.

Table 4 Compressive Strength of SCC Mixes

Mix Designation	f_{ck} in N/mm ² at Curing Period of			Normalised Values in terms of CNSC Mix at Curing Period of			Normalised Values in terms of 28 days Strength of respective mixes at Curing Period of		
	3	7	28	3	7	28	3 days	7 days	28 days
	days	days	days	days	days	days			
TSC	9.84	15.37	23.85	0.51	0.69	0.79	0.41	0.64	1
CSC	11.72	17.1	26.89	0.61	0.77	0.89	0.44	0.64	1
CNSC	19.37	22.16	30.38	1	1	1	0.64	0.73	1

4.2.2. Flexural Strength

The f_b test is carried out as per the standard procedure of IS 516:1959 (Reaff. in 2004 at a curing period of 28 days for Prism specimens of 100 x 100 x 500 mm and are presented in Table 5.

The results are discussed in comparison with that of control SCC mix – CNSC, the mix with 70% cement and 30% Fly Ash as cementitious content and Natural River Sand as FA.

Table 5 f_b and f_t of SCC Mixes at 28 days Curing Period

Mix Designation	f_b in N/mm ²	Normalised values in terms of that of CNSC Mix	f_t in N/mm ²	Normalized values in terms of that of CNSC Mix
TSC	3.88	0.89	2.57	0.82
CSC	4.05	0.93	3.01	0.96
CNSC	4.37	1.00	3.12	1.00

4.2.3. Split Tensile Strength

The f_t is an important property of concrete, since cracking in concrete is also due to the tensile stresses under the load, or due to environmental changes.

The split tensile test is conducted as per the standard procedures of IS 5816:1999 (reaff.2004). The cylindrical specimens of TSC, CSC and CNSC of 150mm dia. and 300 mm height are tested at 28 days curing period and are tabulated in Table 5.

4.2.4 Discussions

From the results of test on various strengths of TSC mix and CSC mix in comparison with that of CNSC mix, the following observations are made.

1. The gain of strength at early curing periods of 3 and 7 days is in line with the expectations of strength gain of normal concrete of around 2/3rd of 28 days strength.
2. The strength of TSC mix 32% less at early curing and is reduced to 21% at 28 days curing. The presence of fly ash and GGBS may improve the strength at extended curing period and there is a scope for assessing strength due to accelerated curing.
3. CSC mix showed better strength exhibiting 25%, 19% and 11% at 3, 7 and 28 days curing period respectively. The enhanced strength of CSC mix may be due to the presence of Cement by an amount of nearly 17% in comparison with that of TSC mix where 33.33% powdered content used was GGBS.
4. Presence of irregular shaped, porous Pond ash particles may also have played the role in reduction in strength.

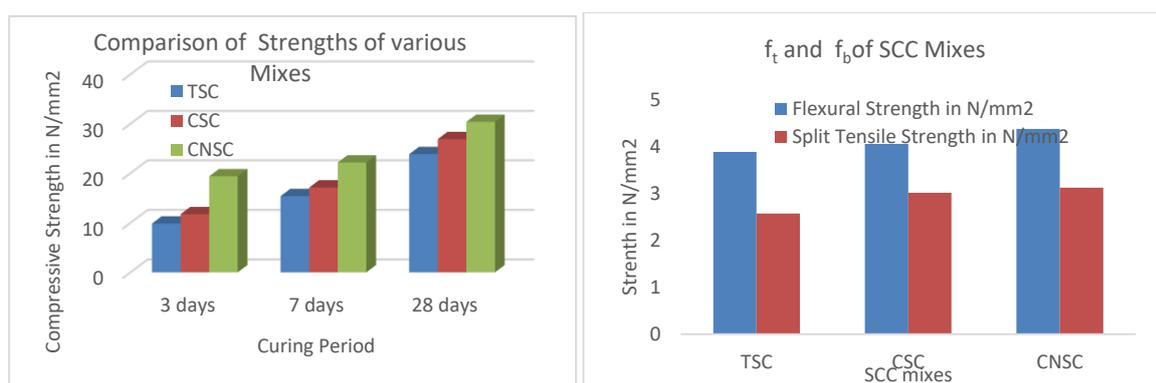


Fig. 1. f_{ck} for Different SCC Mixes and f_b and f_t of Different SCC Mixes

It is observed that the load applied on the cylindrical specimen induced tensile and shear stresses on the aggregate particles and mortar of the specimen, generating the bond failure between the aggregate particles and the cement paste. Specimen failure indicated the failure in transition zone indicating the weaker mortar due to the presence of pond ash particles. However, flexural strength requirement as per IS456:2000 and tensile strength requirement as per the field requirement are satisfied.

5 Conclusions

From the discussions on the test results of various tests, the following conclusions may be made.

- a. Triple blend SCC improves the flowability properties of SCC, with increased rheology in terms of Slump Flow, V Funnel and L Box. Therefore, better rheological properties of SCC can be achieved with Fly ash as secondary cementitious material and GGBS as ternary cementitious material in SCC.
- b. The f_{ck} , f_b and f_t of TSC mix and CSC mix in comparison with that of CNCS mix showed that the strength of CSC mix are better than that of TSC mix, however lesser than that of CNCS mix. Higher reduction of TSC mix may be attributed to the presence of porous pond ash and lesser content of cement in TSC mix. The reduction in strength of TSC and CSC mixes may attribute to the presence of pond ash as FAs and slightly higher strength of CSC mixes in comparison with that of TSC may be due to the higher content of pozzolanic materials. The effect of pozzolanic should be studied at longer curing period. The effect of presence of GGBS has to be studied varying the content of GGBS in SCC mixes.
- c. Enhanced curing period study may provide the effect of higher quantity of pozzolanic materials as continued pozzolanicity may increase the strength at enhanced curing period.

The investigations on the use of alternative materials to both cement and FAs in SCC mixes encourage the use of alternative materials in SCC. It is an effort towards sustainable construction practices and hence encourage the large scale utilization of industrial waste, facilitating human habitation, replacing fast depleting natural resource, and also helps in conserving the precious top soil required for growing food contributing to environmental and ecological benefits (Bharathi ganesh 2015).

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