EVALUATION OF COPPER SLAG AS FINE AGGREGATE IN THE DEVELOPMENT OF SELF COMPACTING CONCRETE

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ABSTRACT. In the present century, construction industry endures lack of resources for the development of the infrastructure. Simultaneously, byproducts of industries are increasing leading to hump of waste on the land. One such industrial byproduct obtained in large amount from copper industry is copper slag (CS). In the present investigation, Self Compacting Concrete (SCC) has been developed using CS as substitute to fine aggregates. A total of 12 mixes were prepared which divide into two series i.e. CS based mixes (series 1) and CS based mixes with silica fume (SF) (series 2). Each series consist of six mixes with distinct fractions of CS from 0% to 100% in proportion of 20% with same water/binder ratio of 0.45. The tests conducted for SCC includes fresh properties, compressive strength and ultrasonic pulse velocity. The results revealed that fresh properties escalate with increase in the content of CS for series 1 and series 2. The compressive strength was noticed to have lower early age strength for series 1 with increase in the CS content whereas later age strength improved with respect to reference concrete. For series 2, the early age and later age strength were higher than reference concrete. The ultrasonic pulse velocity also followed similar pattern of compressive results for both series. The results illustrates that CS has the potential to be utilized as fine aggregates in the construction sector.

Keywords: Self compacting concrete, Copper slag, Compressive strength, Ultrasonic pulse velocity

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INTRODUCTION

Self compacting concrete (SCC) is a concrete with unique characteristics of flowability without any need of vibrator even in the congested reinforcement. SCC was developed for the first time in Japan by Okamura in the year 1986 [1]. The composition of SCC is almost similar to the conventional concrete with addition of superplasticizer, viscosity modifying agent if required, small size of coarse aggregates and high content of fine aggregates. In the present scenario of the construction industry, SCC is widely accepted for the various applications such as high rise building, dams, precast members, highways etc. The production of SCC involves huge amount of fine aggregates which involves utilisation of natural resources. This leads to the extinction of natural resources in most of the developing countries. To overcome scarcely available natural fine aggregates, one needs to find an alternative source or innovate material.

Nowadays industrial waste from copper industries is increasing with increase in the utilisation of copper metal for various applications in today's world. About 7% per year is rise in the use of copper metal and waste generated from copper industries during the matte smelting and refining process of copper metal is copper slag (CS). CS can be utilised as an alternative material to the natural fine aggregates. To obtain one ton of copper metal, about 2.2-3 ton of CS is generated [2-3]. Globally, 68.7 million tons of CS was generated from world copper industries and China was country with highest share of one third production followed by Japan 9%, Chile 8%, Russia 5% and India 3.5% [4-5]. Some of the researchers in the past have focussed on the utilisation of CS as fine aggregates as well as replacement to cement. Incorporation of CS as replacement to fine aggregates from 0% to 100% with 11% silica fume as cement substitution in high performance concrete improved compressive and tensile strength up to 50% CS substitution whereas flexural strength decreased. Moreover, water absorption declined up to 40% CS substitution [6]. The inclusion 40% CS in combination with 2% colloidal nano-silica enhanced the mechanical characteristics of the concrete [7]. The dynamic compressive strength of CS reinforced concrete decreased beyond 20% CS substitution [8]. The inclusion of CS from 0% to 100% increased the density nearly by 5% and escalated the workability of concrete. However, signs of bleeding and segregations were observed at higher substitution level of 80% and 100% CS in high performance concrete [7]. CS has also been used in the cold in-place recycling mixtures and asphalt-concrete mix for better resistance to the moisture and satisfactory indirect tensile strength respectively [9-10]. The substitution of 20% copper mine tailing in asphalt mixture can be used for the construction of roads [11].

Most of the researchers have focussed on high strength concrete, high performance concrete and conventional concrete using CS as fine aggregates but less attention has been paid to the SCC. The aim of the present investigation is to develop SCC using industrial by-product CS as fine aggregates by assessing fresh properties and examine for compressive strength and ultrasonic pulse velocity.

MATERIALS

Cement

OPC 43 Grade cement was used throughout the investigation satisfying IS 8112 [12]. The FA of class F and SF were used as SCMs. FA was procured from thermal power plant located in Ropar, Punjab, India. SF conforming ASTM C 1240-15 [13] was obtained from Elkem

Company located in Mumbai, India. The physical properties of OPC, FA and SF are shown in Table 1 and their chemical composition is shown in Table 2.

Locally available sand was utilised in the SCC mixes conforming IS 383[14]. The water absorption of sand was 0.80%, fineness modulus of 2.79 and specific gravity of 2.6. CS was used as a replacement of sand from 0 to 100% at an interval of 20%. CS had fineness modulus of 3.33, water absorption 0.36% and specific gravity of 3.51.

Locally available coarse aggregate of nominal size 12.5 mm and10 mm was used in the proportion of 40% and 60%. The water absorption of coarse aggregate was 0.68%, fineness modulus of 6.93 and specific gravity of 2.64. Master Glenium SKY 8765 was used in different dosages by weight of binder to achieve desirable properties of SCC.

Table 1 Physical properties of OPC, FA and SF

CHARACTERISTIC PROPERTIES	OPC	FA	SF
Standard consistency (%)	32	-	-
Initial Setting time (minutes)	62	-	-
Final setting time (minutes)	270	-	-
Soundness by Le-Chat Expansion (mm)	1.0	-	-
Compressive strength (MPa)		-	-
3 days	24.6		
7-days	34.3		
28-days	45.2		
Specific gravity	3.15	2.1	2.2
Loss on ignition (%)	2.04	3.3	1.25

Note: OPC- Ordinary Portland Cement, FA- Fly Ash, SF- Silica Fume

Table 2 Chemical composition of OPC, FA, SF and CS

COMPONENT (%)	OPC	FA	SF	CS
SiO_2	20.99	57.6	94.63	30.53
Al_2O_3	5.98	30.5	1.20	2.80
Fe_2O_3	4.10	3.72	0.87	57.82
CaO	60.78	1.10	0.42	1.60
MgO	0.96	0.38	0.90	1.48
SO_3	2.86	0.22	0.22	1.59
K_2O	1.18	1.35	0.19	0.71
Na_2O	0.86	0.10	0.32	0.34
TiO_2	0.25	1.72	-	0.26
CuO	-	0.017	-	0.64

Mixtures

A total of twelve concrete mixes were cast which were divided in to two series, CS based mixes (series 1) and CS based mixes with silica fume (SF) (series 2). Each series consist of six mixes with different proportions of CS from 0% to 100% at an interval of 20% with constant w/b ratio of 0.45, total coarse aggregates of 700 kg/m^3 and water content of 247.5 kg/m^3. The control concrete consists of 100% fine aggregates with 330 kg/m^3 of OPC and 220 kg/m^3 of FA which belongs to series 1. Table 3 illustrates the different mixes of the two series. The total cementitious content was kept constant i.e. 550 kg/m^3 in each mix and fine aggregates were replaced by CS through equivalent volume approach. Initially coarse aggregates, fine aggregates, and CS were mixed for 1 minute in hand operated laboratory concrete mixer. Then cementitious materials were added in the mixer and rotated for 2 more minutes to obtain a homogeneous mix. In the next stage, 70 % water was discharge into the mixer and rotated for 3 minutes. At last, 30 % left over water was combined with required dosage of superplasticizer and added into the mixer then rotated for 2 more minutes. SCC was poured into the well-oiled moulds and demoulded after 24 hours. Samples were water cured in temperature controlled curing tank at 27±2^{o}C till the age of testing.

Table 3 Detail of Material Proportions of SCC Mixes in kg/m^3

SERIES	MIX DESCRIPTION	OPC	FA	SF	MK	CS	FINE AGGREGAT-ES	COARSE AGGREGATES		WATER	SP
								10 mm	12.5 mm		
CS based mixes (Series -1)	CF-CS0 (cc)	330	220	-	-	-	1020	420	280	247.5	4.40
	CF-CS20	330	220	-	-	284.4	816	420	280	247.5	4.40
	CF-CS40	330	220	-	-	568	612	420	280	247.5	3.30
	CF-CS60	330	220	-	-	853.2	408	420	280	247.5	2.75
	CF-CS80	330	220	-	-	1137.6	204	420	280	247.5	2.20
	CF-CS100	330	220	-	-	1422	-	420	280	247.5	2.20
CS based mixes with SF (Series -2)	CFS-CS0	330	165	55		-	1020	420	280	247.5	6.60
	CFS-CS20	330	165	55		284.4	816	420	280	247.5	6.60
	CFS-CS40	330	165	55		568	612	420	280	247.5	5.50
	CFS-CS60	330	165	55		853.2	408	420	280	247.5	4.95
	CFS-CS80	330	165	55		1137.6	204	420	280	247.5	3.85
	CFS-CS100	330	165	55		1422	-	420	280	247.5	3.85

Test Methods

Fresh properties

The fresh properties of SCC were evaluated by conducting tests for filling ability, viscosity and passing ability. The filling ability was assessed by using slump flow whereas viscosity and passing ability was examined by T_{500}, V-funnel and L-box test. The fresh properties were conducted as per European Federation of National Association Representing Producers and Applications of Special Building Products of Concrete (EFNARC) [15].

Compressive strength

Compressive strength was carried out on cubic specimens of size 100 mm × 100 mm × 100 mm at 7, 28, 56, 90 and 120 days of curing. The triplicates for compressive were tested as per IS 516 [16] for each curing period on compression testing machine of capacity 2000 ton.

Ultrasonic Pulse Velocity

Ultrasonic pulse velocity was conducted on specimen of size 100 mm x 100 mm x 100 mm as per IS 13311 [17] at 7, 28, 56, 90 and 120 days of curing. The ultrasonic pulse velocity instrument consists of pair of transducers, one as transmitter and other as receiver applied across the cube at frequency of 54 KHz. To facilitate the strong signal such that no air remains trapped, a thin layer of coupling gel was applied between transducers and specimen. In the automatic Pundit Lab Ultrasonic Instrument, path length was fixed and on triggering the pulse, time taken to travel the path and value of velocity were displayed on the instrument.

RESULTS AND DISCUSSIONS

Fresh Properties

CS based mixes (Series 1)

The results of fresh properties i.e. Slump flow, T_{500}, V-funnel, L-box ratio of all SCC mixes are shown in Table 4. The values of slump flow for mixes of series 1 increased with increasein the content of CS in the concrete. The highest slump flow value of 735 mm was obtained for OF-CS100 without any bleeding and segregation whereas lowest value of 705 mm was recorded for control concrete OF-CS0. According to the EFNARC, the slump flow values of whole mixes fall in the category classified as SF2. The results indicate that T_{500} time varied from 2.18 s to 3.8 s and all mixes were in the class VS2 on the basis of viscosity. The V-funnel time for two mixes i.e. OF-CS0 and OF-CS20 with the values of 8.55 s and 8.12 s respectively were in the upper limit of viscosity class VF1. The other four mixes were within the range of class VF1. The blocking ratio of all mixes of series 1 varied from 0.87 to 0.96. As passing ability test conducted include 3 rebars with blocking ratio over 0.8 were classified as PA2.

CS based mixes with SF (Series 2)

The slump flow diameters for mixes of second series were in the range of 690-720 mm for different proportions of CS. The substitution of 10% SF to FA with 0% CS decreased fluidity of concrete in comparison to control concrete. The highest value of slump flow diameter of 720 mm was obtained for 100 % CS substitution whereas the lowest value of 690 mm was achieved for ternary blend containing 0 % CS. The T_{50} time was noticed for all concrete mixes with highest value of 4.61 sec for OFS-CS0 whereas the lowest value of 2.52 sec was observed for OFS-CS100, encouraging in the enhancement of fresh characteristics with an increase in CS content. The control concrete had V-funnel time of 8.55 sec, lowest time was obtained for OFS-CS100 whereas higher time was recorded for mix OFS-CS0. For second series, blocking ratio values exhibited in the range of 0.84-0.95.

Table 4 Fresh Properties of different mixes

SERIES	MIXES	SLUMP FLOW	T_{500}	V-FUNNEL	L-BOX
CS based mixes (Series 1)	OF-CS0	705	3.8	8.55	0.87
	OF-CS20	710	3.27	8.12	0.89
	OF-CS40	710	3.16	7.62	0.9
	OF-CS60	720	2.84	6.83	0.93
	OF-CS80	725	2.41	6.68	0.95
	OF-CS100	735	2.18	6.43	0.96
CS based mixes with SF (Series 2)	OFS-CS0	690	4.61	10.26	0.84
	OFS-CS20	695	4.12	9.84	0.86
	OFS-CS40	705	3.67	9.13	0.87
	OFS-CS60	705	3.05	8.43	0.89
	OFS-CS80	715	2.67	7.59	0.92
	OFS-CS100	720	2.52	7.14	0.93

Compressive Strength

CS based mixes (Series 1)

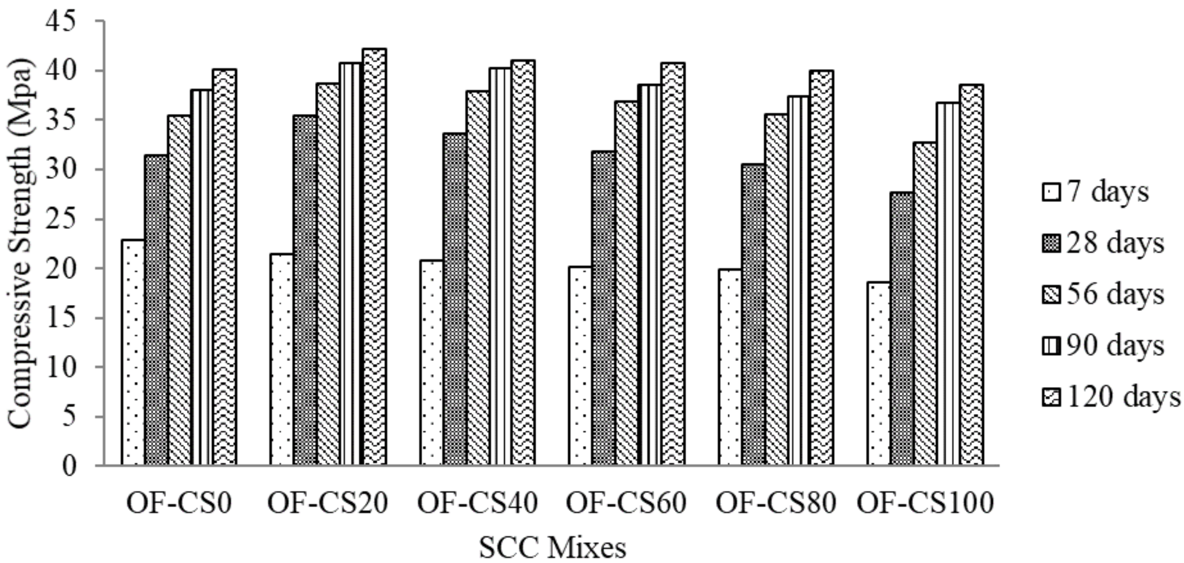

Figure 1 Compressive Strength of series 1 at different curing periods

The development of compressive strength with duration of curing age for different proportion of CS is shown in Fig. 1. The results show decrease in the strength of all SCC mixes containing CS in comparison to the control concrete at an early curing age of 7 days. The compressive strength of control concrete was found to be 22.89, 31.43, 35.47, 38.07 and 40.15 MPa at curing age of 7, 28, 56, 90 and 120 days respectively. The maximum compressive strength was noticed for concrete mix OF-CS20 among mixes of series 1 from

28 to 120 days of curing. An increase of about 12.59 %, 9.02 %, 7% and 5.2 % was noticed for the corresponding curing age of 28, 56, 90 and 120 days. The improvement of 7 %, 6.85 %, 5.56 % and 2.26 % was detected in compressive strength corresponding to curing age of 28, 56, 90 and 120 days for OF-CS40. However, insignificant increase in strength was detected on 60 % CS substitution. The SCC mixes, OF-CS80 and OF-CS100 was observed with decline in the compressive strength. It is evident from Fig. 5 OF-CS100 has lowest compressive strength among all mixes. The decrease in strength for the OF-CS100 was 11.86 %, 7.72 %, 3.46 % and 3.93 % for the ascending curing period of 28, 56, 90 and 120 days respectively.

CS based mixes with SF (Series 2)

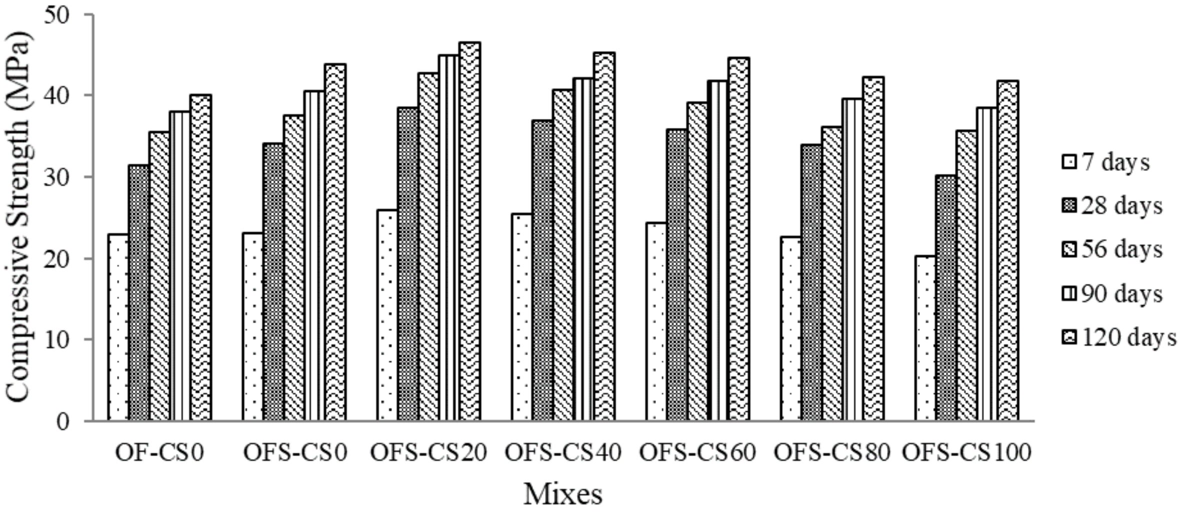

Figure 2 Compressive Strength of series 2 at different curing periods

The results of compressive strength for second series of mixes are shown in Fig. 2. The incorporation of 10% SF as replacement to FA has remarkable improvement in compressive strength for different proportions of CS. It was observed that with an increase in the replacement level of sand by CS, compressive strength increased at all curing ages with respect to control concrete. However, slight decrease in strength was observed for 7 days curing in ternary mixes OFS-CS80 and OFS-CS100. At each curing period, SCC mix OFS-CS20 exhibited the highest strength among all mixes varying from 25.93 to 46.57 MPa, although systematic decrease in strength was observed beyond 20% CS substitution. However, the strength of SCC mixes containing CS beyond 20% has more strength than control concrete. The strength of OF-CS0 varied from 22.89 to 40.15 MPa which was lowest among all mixes at curing periods of 56, 90 and 120 days, though marginal or comparable strength was observed at 7 and 28 days curing relative to OFS-CS100.

Ultrasonic Pulse Velocity

CS based mixes (Series 1)

Ultrasonic pulse velocity (UPV) evaluates inner microstructure of concrete in terms of velocity. Higher the velocity represented by the concrete, more is the dense and homogeneous microstructure. Fig. 3 shows the velocity of concrete mixes for series 1 at different curing ages. It can be noticed from Fig. 3 that at an early curing period of 7 days, concrete mixes exhibited good quality of concrete. Although with progressive curing age, velocity increased for entire SCC mixes. At 28 days of curing, OF-CS80 and OF-CS100 showed good quality of concrete whereas remaining mixes exhibited excellent quality of concrete. The control concrete have UPV values of 4367, 4525, 4630, 4717 and 4739 m/s at 7, 28, 56, 90 and 120 days respectively. The highest value of UPV was observed for OF-CS20 varying from 4405 to 4808 m/s, followed by OF-CS40 within the range of 4365 to 4785 m/s correspondingly for 7 to 120 days. The lowest value of UPV was marked for OF-CS100 with magnitude of 4292, 4464, 4525, 4630 and 4673 m/s for the corresponding curing age 7, 28, 56, 90 and 120.

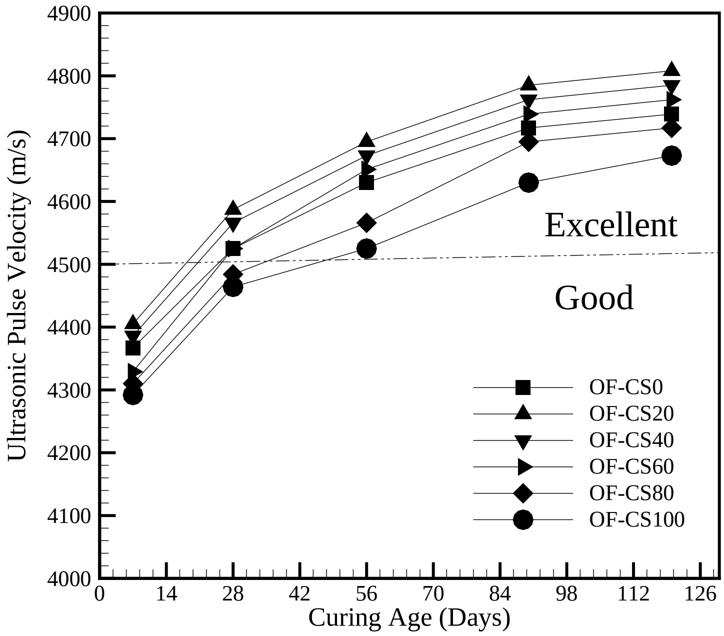

Figure 3 Ultrasonic pulse velocity of SCC mixes for series 1

CS based mixes with SF (Series 2)

The results of ultrasonic pulse velocity for series 2 are shown in Fig. 4. It can be observed from the Fig. 4 that SCC mixes exhibited UPV values varying from 4,425 m/s to 4,367 m/s at 7 days of curing. According to the IS 13311 part 1, all SCC mixes demonstrate good quality of concrete at early curing period. The control mix has lowest UPV value among all mixes at each curing age. The velocity of OF-CS0 was 4,367 m/s, 4,525 m/s, 4,630 m/s, 4,717 m/s and 4,739 m/s for correspondingly progressive curing age of 7, 28, 56, 90 and 120 days. The substitution of SF as replacement of 10 % FA resulted in the increased UPV values which may be attributed to the filling effect of SF. The SCC mixes OFS-CS20 and OFS-CS40 revealed maximum velocity within the range of 4,425 to 4,975 m/s and 4,425 to 4,950 m/s respectively, followed by OFS-CS60, OFS-CS80, OFS-CS100 and OF-CS0. All SCC mixes showed excellent quality of concrete after the curing age of 28 days and difference between the velocity values among mixes becomes small with prolonged curing age.

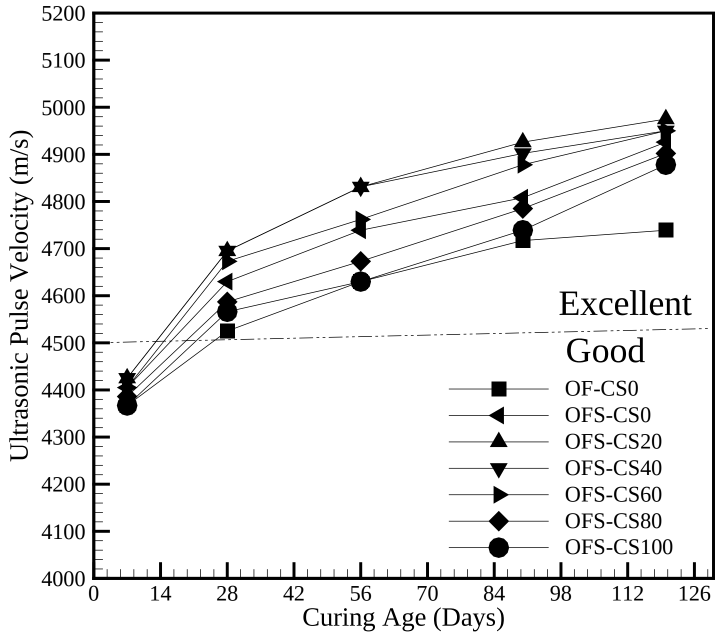

Figure 4 Ultrasonic pulse velocity of SCC mixes for series 2

The fresh properties enhanced with increase in the CS content in both the series. Though, inclusion of SF as substitution to 10% FA in series 2 reduced the flowability of the mixes in comparison to series 1. Moreover beyond 60% CS substitution in series 2, fresh properties were better than control concrete.

The compressive strength decreased for series 1 with inclusion of CS at initial curing age of 7 days in comparison to control concrete. With progress in curing age, compressive strength improved up to 60% CS and comparable at higher substitution level. For series 2, compressive strength increased for initial curing age of 7 days expect 80% and 100% CS content whereas later age strength for series 2 is higher than control concrete as well as series 1.

The ultrasonic pulse velocity of concrete mixes of series 1 and series 2 demonstrate good quality of concrete at 7 days of curing age but at 28 days of curing, mix containing 80% and 100% also exhibit same quality of concrete for series 1. For series 2, beyond 7 days of curing period, all mixes have excellent quality of concrete. The ultrasonic pulse velocity of concrete mixes of series 2 has higher velocities than series 1.

This investigation shows that CS can be utilised as substitute to fine aggregates for the development of SCC.

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