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ACCEPTABILITY OF DEMOLISHED CONCRETE WASTE AGGREGATE IN MAKING HIGH STRENGTH SELF COMPACTING CONCRETE

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ABSTRACT

This paper is an attempt to establish the acceptability of demolished concrete waste aggregate to make self compacting concrete of very high strength and desirable properties. It addresses experiments on two types of self compacting concrete – one with fresh coarse and fine aggregates while the other with 100% replacement of fresh coarse aggregate with recycled one. Results showed that the fresh and hardened properties of both the concretes were comparable. The stigma with recycled aggregates concrete is that they are of inferior quality and can only be used as sub base course and in non structural concrete but the experiments revealed otherwise. A strength up to 85 MPa has been achieved in the SCC made up of 100% recycled coarse aggregate by using a mineral admixture - ground granulated blast furnace slag (GGBS). Also an improving trend in rheological properties and strength was found with the increase in GGBS quantity.

KEYWORDS: Ground Granulated Blast Furnace Slag (GGBS), Recycled Aggregate, Rheological Properties, Self Compacting Concrete, Structural Concrete

INTRODUCTION

Background and Objective

Construction is the backbone of infrastructural development. The momentum of this growth is such that concrete, which forms the indispensable material for construction, can be considered as the second most highly used entity in the world only after water. The basic constituents of concrete are the most widely rampant natural resources i.e., stone aggregate, sand and water, clearly suggesting that this industry has a degrading impact on these environmental assets. In addition, the quarrying and transportation of aggregates further lead to ecological imbalance and pollution. Not only this, the disposal of the debris of the demolished concrete structures has also become a big problem in mega cities due to dearth of landfill sites.

These environmental problems are a driving force in developing an urgent and thoughtful sustainable approach towards our natural resources to which the recycling of the aggregates seems to be a legitimate remedy. The paper presents a comparison of the properties of SCC made with virgin coarse and fine aggregates and with recycled coarse and fresh fine aggregates respectively followed by a study on increase in strength pattren of the recycled aggregate SCC involving a mineral admixture. Concept of use of recycled aggregate in concrete in not new, researches have been carried out on recycled aggregate all over the world. However, use of Recycled Aggregate in high strength concrete production could not become popular perhaps because of the prefix “recycled” with the term aggregates, stigmatizing its application in high strength concrete construction [1], [2], [3], [4], [5]. M C Limbachiya [6], indicating the inferiority of recycled aggregate concrete, reported that often this concrete is used in as road construction, backfill for retaining walls, low grade concrete production, drainage and brick work and block work for low cost housing. Similar views were presented by Vivian [7] confining the use of recycled aggregate to low grade applications such as unbound road base, fill and hard core although, he accepted that recycling rate is high in many countries.

The objectives of this paper are:

- To investigate the suitability of recycled aggregate in self compacting concrete of high strength and desirable properties.
- To transcend the feeling of insecurity among engineers and builders regarding usage of recycled aggregates in structural concrete.

EXPERIMENTAL DETAILS

Materials

Ordinary Portland cement and fly ash were used as fines in SCC mix. The properties of cement are listed in table 1. Class F fly ash with specific gravity of 1.923 was used. The natural coarse aggregates were procured from Kotputli source whereas the recycled coarse aggregates were obtained by crushing demolished concrete waste in a laboratory jaw crusher. The nominal sizes of both the types of coarse aggregates were 20 mm and 10 mm. The fine aggregate used was Kotputli coarse sand. Figure 1 shows the combined grading curves of aggregates used.

A comparison of particle size distribution of fresh and recycled coarse aggregate has been presented in table 2. Mechanical properties of aggregates are given in table 3. The chemical admixture used was super plasticizer of CICO brand which is based on modified sulphonated naphthalene formaldehyde conforming to ASTM C-494. The properties of Ground granulated blast furnace slag of brand “alccofine” which is the mineral admixture employed to improve the strength of SCC are tabulated in table 4. Oxide composition of cement, fly ash and GGBS are given in table 5 and Figure 2.

Table 1

Properties	Vikram Premium Cement		
Specific gravity	2.193		
Initial setting time	200 minutes		
Final setting time	10 hours		
Compressive strength of mortar cubes (conforming to IS:4031 (part – 06)-1988)	**3 day**	**7 day**	**28 day**
	30.24 MPa	39.1MPa	43.8 MPa

Table 2: Comparison of Grading of Fresh and Recycled Coarse Aggregate

Comparison of Grading of Fresh and Recycled 10 mm Aggregate			
IS Sieves (mm)	Limits as Per IS: 383-1970	% Finer	
		Fresh Aggregate	Recycled Aggregate
12.5	100	93.6	100
10	85-100	81	97.8
4.75	0-20	31.6	6.2
2.36	0-5	12.2	0.6
PAN	**0**	**0**	**0**
Comparison of Grading of Fresh and Recycled 20 mm Aggregate			
40	100	100	100
20	85-100	90.4	93.4
10	0-20	2	16.4
4.75	0-5	0.6	6.4
PAN	**0**	**0**	**0**

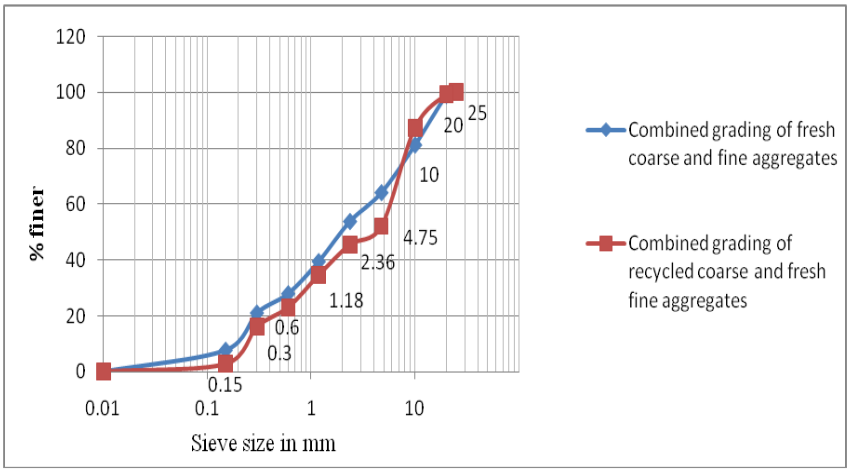


Figure 1: Combined Grading of Aggregates

Table 3: Physical Properties of Aggregates

Aggregate	Nominal Size (mm)	Water Absorption (%) after 24 Hours	Specific Gravity	Bulk Density (kg/m^3)	Crushing Value	Impact Value	Silt Content (%)
Fresh aggregate	20	0.45	2.672		09	27	
	10	0.60	2.69				
	< 4.75	3.58		1.842			7.7
Recycled aggregate	20	4.62	2.55		15	33	
	10	5.74	2.402				

Table 4: Properties of GGBS of Brand "Alccofine"

Property	Test Results		
Initial setting time	2.5 hours		
Final setting time	5 hours		
Fineness	8000 cm^2/ g		
Specific gravity	3.1		
Bulk density	670 kg/m^3		
Particle size distribution	D_{10}	D_{50}	D_{90}
	< 2 μ	< 6μ	< 10μ

Table 5: Oxide Composition of Cement, Fly Ash and GGBS

Test Carried Out (% by Mass)		Test Value		
		Cement	Fly Ash	GGBS
1	Loss on ignition	-	1.7	-
2	Silica (SiO_2)	22.8	58.6	34.3
3	Zinc (ZnO)	-	0.01	-
4	Manganese (MnO)	-	0.02	-
5	Magnesium (MgO)	2.3	1.3	8.9
6	Calcium (CaO)	62.3	1.4	40.8
7	Chromium(Cr_2O_3)	-	0.3	-
8	Iron (Fe_2O_3)	4.7	4.1	1.91
9	Phosphate (P_2O_5)	-	0.4	-
10	Sodium (Na_2O)	0.6	05	-
11	Potassium (K_2O)	-	2.0	-
12	Copper (CuO)	-	< 0.01	-
13	Alumina (Al_2O_3)	4.9	25.7	19.1
14	Titanium (TiO_2)	-	2.6	-
15	Sulphate (SO_3)	2.4	0.1	0.53
16	Lead (PbO)	-	< 0.01	-

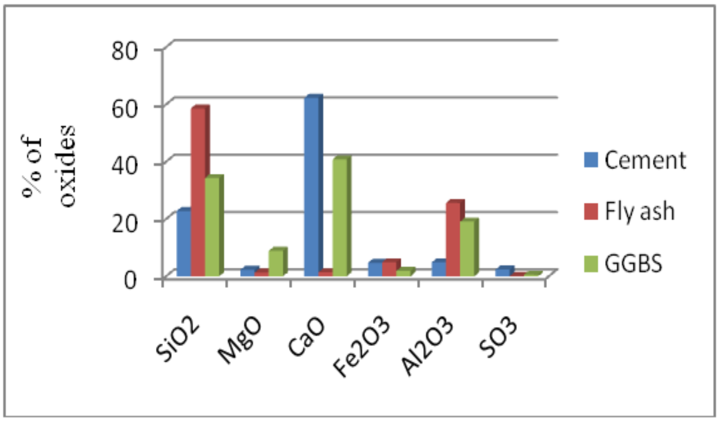


Figure 2: Comparison of Oxide Compositions

Mix Design

Table 6: Description of the Abbreviations Used in the Paper

S. No.	Abbreviation	Description
1	FA	Fine aggregates
2	CA	Coarse aggregate
3	SP	Super plasticizer
4	GGBS	Ground granulated blast furnace slag
5	SCC	Self compacting concrete
6	FAC	Fresh aggregate SCC i.e. SCC with fresh coarse and fine aggregates.
7	RAC	Recycled aggregate SCC i.e. SCC with recycled coarse and fresh fine aggregates.
8	T1	FAC without GGBS
9	T2	RAC without GGBS
10	T3	RAC with 10 % replacement of fly ash with GGBS
11	T4	RAC with 20 % replacement of fly ash with GGBS
12	T5	RAC with 30 % replacement of fly ash with GGBS
13	T6	RAC with 40 % replacement of fly ash with GGBS
14	T7	RAC with 10 % replacement of cement with GGBS
15	T8	RAC with 20 % replacement of cement with GGBS
16	T9	RAC with 30 % replacement of cement with GGBS

The base mix was designed for M35 concrete according to the guidelines given in IS: 10262-2009 (code of practice for mix design of normal concrete) [8] and several changes were made through trials in the mix design to obtain the properties of self compacting concrete. Changes include decrease in the quantity of 20 mm coarse aggregate, increase in the quantity of powder content and optimal dosage of super plasticizer.

Initially two types of SCC were prepared- one completely with fresh coarse and fine aggregates and the other with fresh fine aggregate and 100% replacement of fresh coarse aggregate with recycled one. Thereafter, to further increase the strength of RAC and to obtain a pattern of the increase in strength by addition of different quantities of GGBS, trials were made with 10%, 20%, 30% and 40% replacement of fly ash as well as cement with GGBS.

The percentage of 20 mm coarse aggregates was 35 % while that of 10 mm coarse aggregates was 65 % of the total coarse aggregates in both concretes. The total powder content was kept constant equal to 530 kg/m^3 in all the trials. The dosage of super plasticizer was kept 0.85 % of total powder content for the base mix. The water to cement and water to binder ratio of the base mix was kept as 0.4 and 0.35 respectively.

However, slight modifications in the water and super plasticizer quantity were introduced on the spot to achieve the desired workability, flowability and to account for more water absorption of recycled aggregates than fresh ones. The mix designs of different trials are given in table 7.

Table 7: Mix Proportions of Different Trials

Trial	Cement Kg/m^3	Fly Ash Kg/m^3	FA Kg/m^3	CA (20 mm) Kg/m^3	CA (10 mm) Kg/m^3	Water Kg/m^3	GGBS Kg/m^3	SP Kg/m^3
T1	400	130	866	240	560	160	0	4.77
T2	400	130	820	227	530	170	0	4.77
T3	400	117	822	228	531	170	13	4.65
T4	400	104	823	228	532	170	26	6.05
T5	400	91	825	229	533	170	39	5.89
T6	400	78	828	229	535	170	52	5.74
T7	360	130	818	227	529	170	40	5.88
T8	320	130	819	227	529	170	80	5.4
T9	280	130	819	227	529	170	120	4.92

Specimen Casting and Curing

All concrete trials were mixed for 20 minutes in a laboratory mixer. Before casting, slump flow, J ring, U box, L box and V funnel tests were conducted to determine the fresh properties of the SCC. For each concrete mix, twelve 150×150×150 mm cubes were casted to determine the compressive strength. After casting, the specimens were covered with wet jute bags for 24 hours. They were then demolded and three cubes were immediately tested to determine the 1 day compressive strength of SCC. The rest of the specimens were then kept in water curing tank at 27'C until the time of test.

Test Methods

All the above mentioned tests for fresh SCC were carried out in accordance with the EFNARC standards [9]. Their test results and permissible limits are listed in table 8. The compressive strength of concrete was measured using AIMIL compression machine with a loading capacity of 2000 KN conforming to IS: 14858 (2000). The compressive strength test was carried out on cubes at the ages of 1, 4, 7 and 28 days. Non destructive- rebound hammer and pulse velocity meter tests were also conducted on cubes at the age of 28 days to determine surface hardness and quality of concrete.

ANALYSIS OF TEST RESULTS AND DISCUSSIONS

Fresh Properties: Test Results of All the Tests Carried Out on Fresh SCC are Shown in Table 8

Table 8: Properties of Fresh SCC with Different Quantities of GGBS

Trials		Slump Flow Test		J Ring Test		V Funnel Flow Time (sec)	L Box Test Passing Ratio (H_2/H_1)	U Box Test Filling Height (H_1-H_2) mm
		Time T_{50} (sec)	Slump Flow (mm)	Time T_{50} (sec)	Dia. (mm)			
Permissible Range		2-5 sec.	650-800 mm	4-8 sec.	500-700 mm	8-12 sec	0.8-1.0	<30 mm
T1	0	4.7	650	7.94	520	11.8	0.7945	29.7
T2	0	4.2	670	7.46	548	10.6	0.8344	28.4
Trials with Replacement of Fly Ash with GGBS								
T3	10%	3.9	685	7.12	555	10.3	0.8786	25.37
T4	20%	3.72	692	6.73	574	10	0.8935	20.84
T5	30%	3.55	715	6.35	593	9.8	0.9184	18.42
T6	40%	3.21	734	5.93	615	9.5	0.9327	15.29
Trials with Replacement of Cement with GGBS								
T7	10%	2.95	758	5.52	647	9	0.9598	11.47
T8	20%	2.53	770	4.96	688	8.7	0.9756	9.75
T9	30%	2.24	796	4.29	697	8.2	0.9945	7.39

It is evident from the above table that rheological properties of SCC made up of recycled aggregates are better than that of fresh aggregate SCC. The reason may be attributed towards more rounded particle shape and less specific gravity of recycled aggregate compared to those of virgin coarse aggregates. Round shape of aggregates enhances the flowability and due to less specific gravity the aggregates have a reduced tendency to settle down in the mix thereby forming it more homogeneous. Moreover it has also been found out that the increase in the quantity of GGBS further enhances the properties of fresh SCC which is clear from the figure 3. The presence of GGBS in the mix makes it less viscous without losing its cohesiveness resulting out of better dispersion of the cementitious contents due to surface characteristics of the GGBS particles, which are smooth and absorb less water during mixing [10].

In normal concrete micro structural non-homogeneity causes bleeding/ segregation, GGBS, being finer than cement fills the voids between the cement particles and interfacial zone of aggregate, thus making the mix more homogenous and controls the bleeding/segregation.

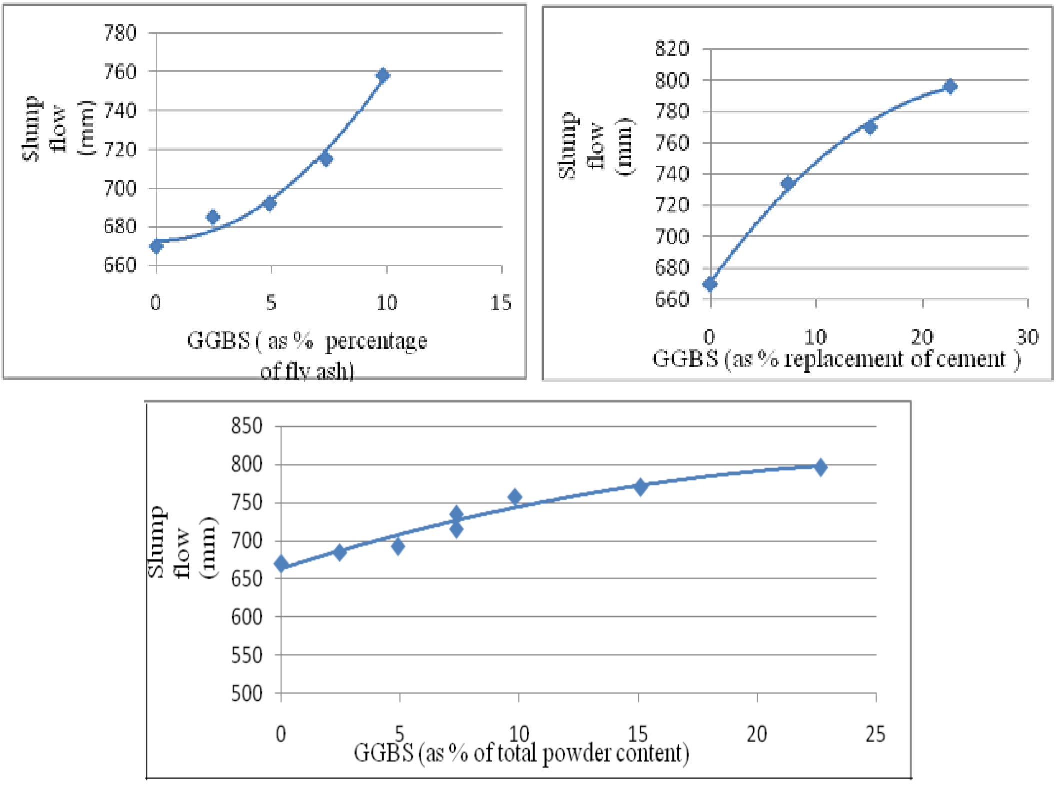


Figure 3: Effect of GGBS on Slump Flow

Hardened Properties

The test results of the compressive strength are summarized in table 9.

Table 9

S. No.	Trial	% of GGBS	Average Compressive Strength (MPa)			
			1-day	4- day	7- day	28- day
1	T1	0	14.5	25.5	30.34	48.14
2	T2	0	14.66	31.41	41.72	53.74
Trials with Replacement of Fly Ash with GGBS						
3	T3	10 %	15.10	33.5	43.98	59.62
4	T4	20 %	15.83	37.93	46.90	64.94
5	T5	30 %	16.41	39.76	48.25	69.45
6	T6	40 %	18.78	42.45	53.10	75.82
Trials with Replacement of Cement with GGBS						
7	T7	10 %	18.86	37.4	49.41	68.65
8	T8	20 %	19.94	41.67	53.80	78.37
9	T9	30 %	21.83	45.87	57.10	85.9

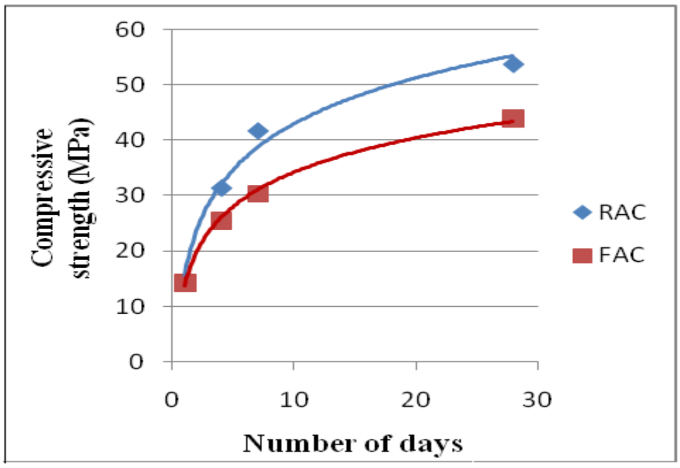
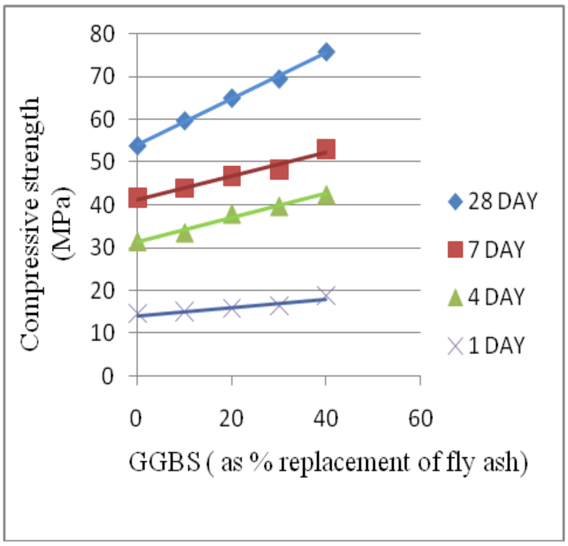


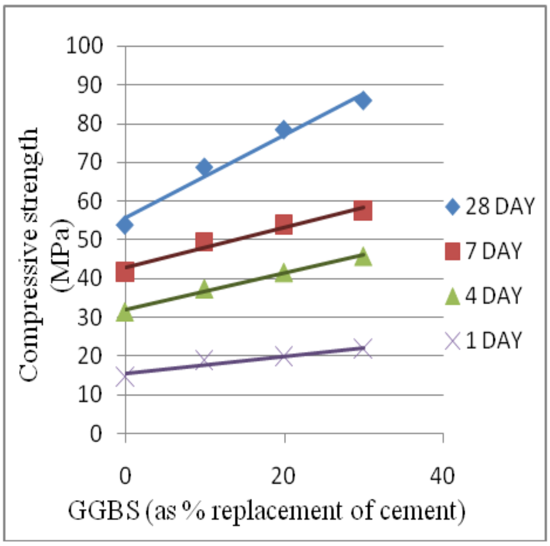
Figure 4: Comparison of Compressive Strengths of FAC and RAC

The test results indicate that the RAC (T1) is stronger than the FAC (T2) as is clear in figure 4, contradicting the general perception about recycled aggregate concrete. The possible reasons are postulated as follows:

(i) excessive flaky and elongated 10 mm fresh aggregate particles that constitute 65 % of the total coarse aggregates, ii) superior grading of the recycled aggregates (Table 2) and, iii) better homogeneity owing to round shape and less specific gravity of recycled coarse aggregate. A significant increase in strength has been recorded with the gradual increase in the quantity of GGBS as is clear from figure 4. The reason lies in the fact that GGBS has more silica and less lime content than cement. Therefore hydration of their mixture produces more C-H-S and less lime than the cement alone, resulting in a dense microstructure of the hydrated cement paste [11]. Figure 5 shows the variation of compressive strength of RAC under two different conditions of introducing GGBS as indicated. Evidently, the strength increases at a higher rate in the trials with more replacement of powder content with GGBS. Since more GGBS is introduced in trials with replacement of cement, their compressive strength trend lines are steeper than the trials having replacement of fly ash with GGBS.

One more noteworthy point is that the slope of trend lines of the compressive strength are increasing with the age of the concrete, i.e., there is a high rate of gain of strength on 28 day as compared to other days. This means that the effect of GGBS on the strength of SCC is less pronounced at early stage but becomes significant in long term. The reason is that the progressive release of the alkalis by GGBS, together with the formation of calcium hydroxide by Portland cement, results in a continuing reaction of the GGBS over a long period of time leading to a long term gain in strength [12].





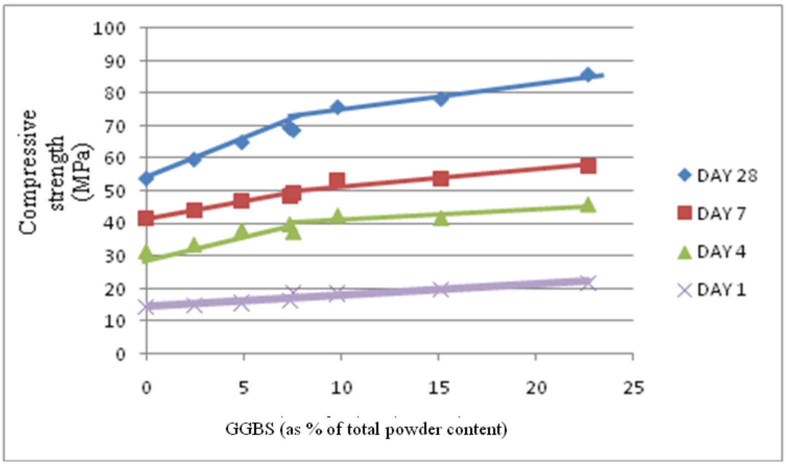


Figure 5: Results of Compressive Strength

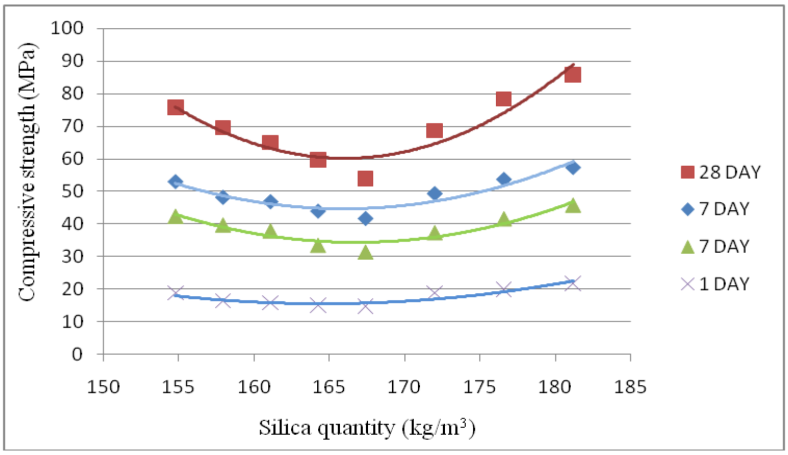


Figure 6: Variation of Compressive Strength with the Quantity of Silica

Figure 6 presents the compressive strength of SCC with variation of total silica content present in the mix. Results show that content of silica present in the mix is not the only parameter which governs the strength of SCC. Figure 7 gives the gradation of alccofine and cement showing that alccofine contains most of the particles in the range of 1.5µ to 7.0 µ while the cement lacks particles of this range, which results in a better particle packing of the two materials. Thus, it is inferred that gradation of cementious materials is a dominating factor for the development of strength (1, 4, 7 and 28 day) of the SCC.

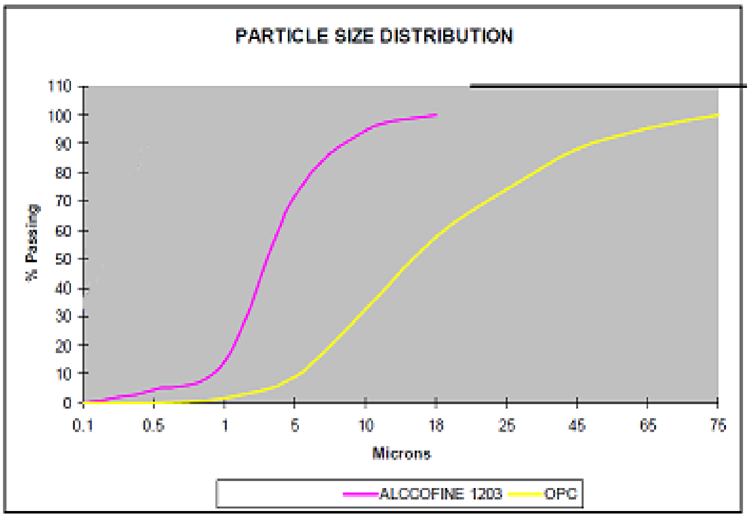


Figure 7

Table 10 shows the value of non destructive tests- rebound hammer and pulse velocity meter for RAC with different quantities of GGBS. Figure 8 clearly shows that with the increase in the quantity of GGBS both the test values are increasing indicating thereby that GGBS also increases the compactness and surface hardness of SCC.

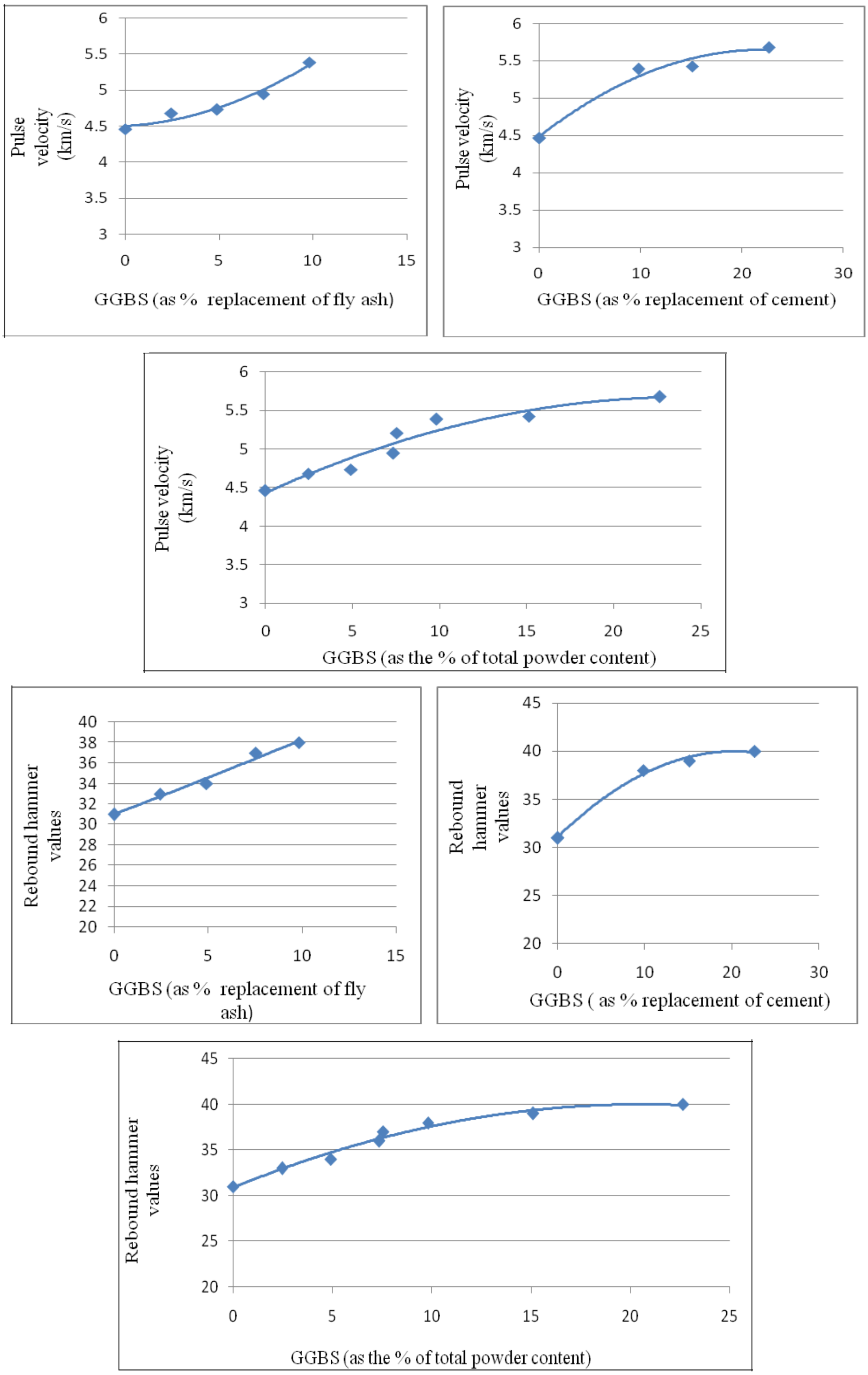


Figure 8: Pulse Velocity and Rebound Hammer Values with Different Percentages of GGBS

Table 10: Values of Rebound Hammer and Pulse Velocity Meter Test for Different Trials

S.No.	Trial		Rebound Hammer Compressive Strength (MPa)	Pulse Velocity (Km/sec)
1	T1		28	4.246
2	T2		31	4.463
Trials with Replacement of Fly Ash with GGBS				
3	T3	10 %	33	4.679
4	T4	20 %	34	4.733
5	T5	30 %	36	4.945
6	T6	40 %	37	5.211
Trials with Replacement of Cement with GGBS				
7	T7	10 %	38	5.389
8	T8	20 %	39	5.425
9	T9	30 %	40	5.677

Apart from improved rheological and hardened properties, the RAC containing fly ash and GGBS is quite economical too, as it saves the price of concrete mix by about 22-24%, whereas RAC without these mineral admixtures saves only 14% compared to the fresh aggregate concrete mix [13].

CONCLUSIONS

The following conclusions can be drawn from this work

- Both rheological and hardened properties of RAC are found to be superior to FAC for the same mix design. The extent of superiority is that the slump flow and 28 day compressive strength of RAC is 3.1% and 11% more than that of FAC respectively.
- Demolished concrete waste aggregates can successfully be used to make high strength SCC (as the 100% replacement of fresh coarse aggregate) with desired workability, flowability, passing and filling ability hereby establishing that it can be confidently employed as structural concrete.
- GGBS enhances the rheological properties of RAC which improve with the increase in the quantity of GGBS. Slump flow of RAC has found to be increased by 18.8% with the introduction of 22.4% of GGBS.
- Silica content is not the sole factor responsible for the strength of SCC, gradation of cementitious materials is also a major parameter for strength development.
- 28 day compressive strength of the RAC is found to be 59.8% more than that of FAC with the increase in proportion of GGBS from zero to 22.6% of total powder content in mix.
- Present work provides the design mix for M 75 grade of SCC using GGBS as mineral admixture.

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