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PROPERTIES OF SELF COMPACTED RECYCLED AGGREGATE CONCRETE (SCRAC) WITH DIFFERENT TWO STAGE MIXING APPROACHES

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ABSTRACT

This article addresses the methods of improvement of mechanical properties of self compacting concrete (SCC) with the use of coarse recycled concrete aggregate (RCA) obtained from construction and demolition (C&D) waste. Two stage mixing approach$_{(silica\ fume,\ fly\ ash\ and\ cement)}$ *($TSMA_{sfc}$) is employed, in which 6% silica fume and proportional amount of cement is added to the recycled aggregate in the premix stage. All the other quantities of ingredients are added subsequently as per recommended procedure of mix design of SCC in the literature. In $TSMA_{sfc}$, addition of silica fume and cement in the premix stage fills up the weak areas in the RCA and thus stronger interfacial transition zone (ITZ) is developed around the aggregate, resulting improved strength in the concrete. Experimental results show that 100% replacement of RCA marginally affects the mechanical properties in two stage mixing approach (TSMA). However, $TSMA_{sfc}$ significantly improves all the mechanical properties as compared to normal mixing approach (NMA) and TSMA.*

Keywords: C&D waste, Fly ash, RAC, Self compacting concrete, Silica fume, TSMA.

I. INTRODUCTION

In recent years, the reuse of waste concrete as recycled concrete aggregate (RCA) to replace natural aggregate for new concrete has developed. It is commercially sustainable and technically good for recycling waste concrete. Recycling of concrete waste is beneficial and necessary from the view point of environmental preservation and effective utilization of resources. The construction and demolition (C&D) waste is one of the main and important resources for a sustainable construction. C&D waste causes various environmental problems such as the use of landfill space, illegal deposits, etc. Therefore, recycling of these C&D waste for the production of new aggregates is a solution to a number of problems. RCA is manufactured by crushing and screening the coarse aggregate and the concrete manufactured with these aggregates is normally known as RAC. Many literature paper shows that RAC can be used as self compacting concrete (SCC). SCC fills formwork in the presence of congested reinforcement under its own weight. Flowability, filling ability and segregation resistance affects the mechanical and durability properties of SCC. Flowability is achieved by using admixtures such as fly ash, silica fume, ground granulated blast furnace slag, superplasticizer (SP). This paper presents the fresh and mechanical properties of self compacted recycled aggregate concrete (SCRAC) with two stage mixing approach and two stage mixing approach$_{\text{(silica fume and cement)}}$ with suitable presence of admixtures like fly ash, silica fume and superplasticizer.

Otsuki *et al.*[1] have done 100% substitution of RCA and followed double mixing method. They observed that, the compressive strength and tensile strength enhanced by 4.18% and 5.25%, respectively, after 28 days of curing. TSMA was first developed by Tam *et al.* [2] in which the mixing process is divided into two parts and the required water is proportionally split into two, which is added at different stages. Here, the improvement of compressive strength was achieved by 21.19% for 20% of replacement of RCA in 28 days curing period. Tam *et al.* [3] proposed another two different mixing methods i.e. $TSMA_{p1}$ and $TSMA_{p2}$. $TSMA_{p1}$ gave 11.47% improvement in compressive strength than NMA for RAC for 25% replacement of RCA. However, $TSMA_{p2}$ observed 19.75% improvement in compressive strength for 20% replacement of RCA. Tam and Tam [4] also developed two other mixing approaches and compared the result with NMA. For TSMAs, after 28 days of curing, the compressive strength, flexural strength, tensile strength, and static modulus of elasticity were enhanced by 19.50% for 25% RCA substitution, 20.04% for 20% RCA substitution, 16.16% for 10% RCA substitution and 16.28% for 30% RCA substitution respectively for $TSMA_s$. However, for $TSMA_{sc}$ after 28 days of curing, the compressive strength, flexural strength tensile strength and static modulus of elasticity were enhanced by 19.73% for 25% RCA substitution, 4.44% for 25% RCA substitution, 24.22% for 5% RCA substitution and 11.92% for 30% RCA substitution, respectively.

II. MATERIALS AND METHODS

2.1 Materials used

Ordinary Portland cement, silica fume and fly ash were used as the cementitious material in SCC mixtures. Ordinary Portland cement of 43 grade with specific gravity 3.15 confirming to IS 8112-1989 [5] was used. Class-F fly ash produced from Bokaro Thermal power plant, Bakaro, India was used. The physical properties of cement, class-F fly ash and silica fume are given in Table 1, Table 2 and Table 3, respectively.

2.2 Aggregates

Locally available river sand and the crushed stone (20 mm maximum size) were used as fine aggregate and VCA, respectively. RCA were obtained from a concrete waste of 35 years old building in Dhanbad, India. The fineness modulus of fine aggregate was 2.45 and confirming to zone II as per IS 383-1970 [6]. The physical and mechanical properties of VCA, RCA and fine aggregates are presented in Table 4.

2.3 Water and Admixture

Potable drinking water available within the Indian School of Mines, Dhanbad, India, campus was used for making all mixes. SP is generally added to increase the flowability of SCC with reduced water content. Modified poly carboxylic ether based admixture GLENIUM B233 was used in present study.

Table 1.Physical Properties of Cement

Sl.no	Characteristics	IS:8112-1989 specifications	Value obtained
1.	Normal consistency (%)	-	29
2.	Initial setting time(min)	30 (min)	76
3.	Final setting time(min)	600 (max)	216
4.	Fineness(Retained on 90µm)	10 mm	7.00
5.	Specific gravity	-	3.15
6.	Soundness(mm)	10 (max)	2.50
7.	Compressive strength (N/mm²)		
	3 days	23.00	25.00
	7 days	33.00	35.97
	28 days	43.00	45.08

Table 2. Physical Properties of Fly Ash

Sl.no	Test property	Value obtained
1.	Specific gravity	2.15
2.	Fines passing 150 µ sieve (%)	99.2
3.	Fines passing 90 µ sieve (%)	97
4.	Blaine's fineness (cm^2/gm)	3890

Table 3. Physical Properties of Silica Fume.

Sl.no	Test property	Value obtained
1.	Specific gravity	2.2
2.	Specific Surface Area	20000 m^2/kg
3.	Particle size	0.1 *micron*
4.	Bulk loose density	230-300 kg/m^3

Table 4. Properties of Aggregates

SL.no	Test property	VCA	RCA	Fine aggregates
1.	Specific gravity	2.66	2.62	2.62
2.	Water absorption (%)	0.6	4.78	0.85
3.	Bulk density (kg/m^3)	1,520	1,420	1,680
4.	Crushing value (%)	28	33	-
5.	Impact value (%)	23	28	-

2.4 Mix proportions

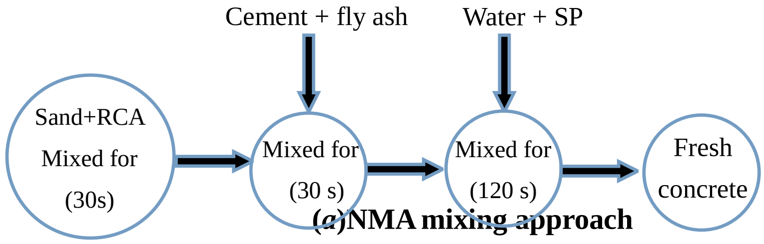
The mix composition was chosen to satisfy all specifications given by EFNARC [7] for both the fresh and hardened states of SCC. Mix design of SCC using Nan Su method [8] was followed for preparing SCC mix of M30 grade of concrete. The experimental study included one reference mix which contains 100% VCA and designated as SCVAC. Two other mixes were made with RCA to replace natural aggregate by 50% and 100% levels and designated as SCRAC50 and SCRAC100, respectively. The results are presented in Table 5.

Table 5. Mix Proportioning for Compressive Strength $(fck = 30MPa)$ of Various SCC Mixes by Nan Su Method [12].

% of RA	Mix designation	Cement (kg/m^3)	Fine aggregates (kg/m^3)	Coarse aggregate (kg/m^3) NA	Coarse aggregate (kg/m^3) RA	Fly ash (kg/m^3)	Water (kg/m^3)	SP (kg/m^3)
0	SCVAC	315	990	805	-	135	191	4.0
20	SCRAC-20	315	990	644	133	135	191	4.2
40	SCRAC-40	315	990	483	266	135	191	4.2
60	SCRAC-60	315	990	322	399	135	191	4.3
100	SCRAC-100	315	990	-	666	135	194	4.3

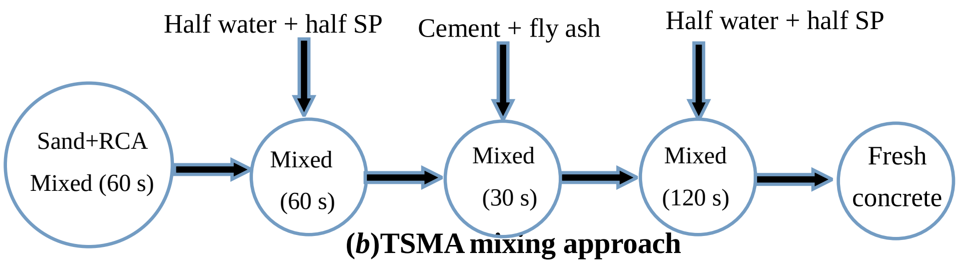
2.5 Mixing approaches

2.5.1 Normal mixing approach (NMA)



(*a*)NMA mixing approach

2.5.2 Two stage mixing approach (TSMA)



(*b*)TSMA mixing approach

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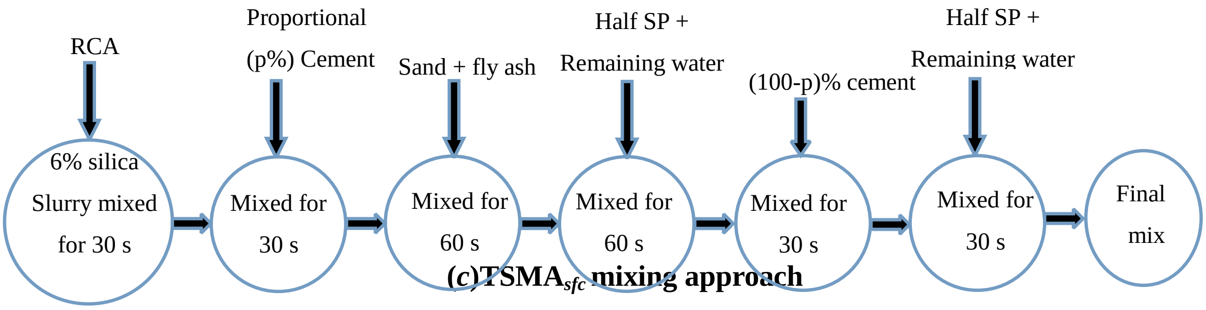
2.5.3 Two stage mixing approach (silica fume, fly ash and cement) (TSMA$_{sfc}$)



(*c*)TSMA$_{sfc}$ mixing approach

Fig.1. Flow Diagrams of Different Mixing Approaches Followed in Present Investigation.

III. RESULTS AND DISCUSSION

The test results of slump flow, J-ring and V-funnel test of SCRAC with NMA, TSMA and TSMA$_{sfc}$ are shown in Table 6. T_{50} is the time taken by fresh concrete for reaching a distance of 50 *cm* radially and was measured during the time of slump flow test. The T_{50} value for NMA, TSMA and TSMA$_{sfc}$ with and without recycled aggregate found between 3-5 *sec*. As per EFNARC guidelines [7]**Error! Reference source not found.**, the recommended value for engineering application is between 2-5 *sec* and recommended value for slump flow is 650 *mm.* From Table 6, it is observed that the T_{50} value and slump flow value follows the guideline for all the mixing approaches (NMA, TSMA and TSMA$_{sfc}$). Passing ability of SCRAC was measured by J-ring. It is the difference in height between the concrete inside and that just outside of the J-ring. It is concluded from Table 6, that J-ring varies from 7.5-9.3 *mm* for all cases of mixes with NMA, TSMA and TSMA$_{sfc}$. It is noted that the J-ring value follows the guideline for both the mixing approaches (NMA, TSMA and TSMA$_{sfc}$). Filling ability and flow ability of SCC were measured in terms of V- funnel apparatus, which ranges from 7.8-9.6 *sec*. The fresh properties of SCC with TSMA gives better results in comparison with NMA because in TSMA the pores and cracks present on the surface of RCA are filled up or eliminated during the first stage of mixing. These values satisfy the EFNARC guidelines as the permissible value is from 6-12 *sec*. The fresh properties of SCC with TSMA gave better results in comparison with NMA because in TSMA the pores and cracks present on the surface of RCA were filled up or eliminated during the first stage of mixing. However, for TSMA$_{sfc}$ it is observed that with 6% replacement of fly ash by silica fume, the fresh properties meet the requirement as per EFNARC codal provision. Fresh properties of the concrete mix may be affected because of the presence of excess silica fume due to the larger surface area and very fine particle size, silica fume increases the water requirement of concrete and makes

Table 6. Fresh Properties of Self Compacted Concrete in Different Proportion of RCA Using NMA, TSMA, TSMA$_{sfc}$ of Having Compressive Strength ($fck = 30$ MPa)

Mixing methods	% of replacements	Mix designation	Fresh properties of Self compacted concrete			
			T_{50}, (sec)	Slump flow (mm)	J-ring (mm)	V funnel time (s)
NMA	0%	SCVAC	3	750	7.8	7.5
	60%	SCRAC-60	5	700	9.1	8.5
	100%	SCRAC-100	5	700	9.3	10.6
	0%	SCVAC	3	760	7.5	7.3
TSMA	60%	SCRAC-60	4	709	8.8	8.4
	100%	SCRAC-100	5	700	9.2	9.6
TSMA$_{sfc}$	0%	SCVAC	5	700	7.6	8.0
with 6%	60%	SCRAC-60	4	660	9.0	8.9
silica fume	100%	SCRAC-100	4	650	9.6	9.0

concrete mix less workable. For all subsequent experimental investigation of mechanical properties of TSMA$_{sfc}$, the replacement of fly ash by silica fume was taken was 6%. In present investigation, there is an effort for improving the mechanical properties of SCRAC by advanced mixing approach with addition of silica fume. Different mechanical properties are determined with TSMA$_{sfc}$ for 6% replacement of fly ash with silica fume. The maximum percentage of silica fume was kept up to 6% as the fresh properties did not satisfy for addition of more percentage of silica fume. Presence of silica fume in the concrete mix enhances the mechanical properties of concrete because the small size and spherical shape of silica fume fills the voids in the mix. As the voids get fill up, the microstructure of the concrete is improved because of denser pore structure. With the increase of percentage of RCA, the mechanical properties are decreases as RAC possess two ITZs i.e. new ITZ and old ITZ. The old mortar present in RCA forms a weak link in RAC, which contains many pores and cracks. These pores and cracks consume more water causing lesser hydration reaction at the ITZ.

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Table 7. Experimental Results on Mechanical Properties of Self Compacted Concrete in Different Proportion of RCA Using NMA, TSMA, and TSMA$_{sfc}$.

Mixing methods	% of replacements	Mix designation	Compressive strength (N/mm^2)			Flexural strength (N/mm^2)			Splitting tensile strength (N/mm^2)		
Days cuing			7	14	28	7	14	28	7	14	28
NMA	0	VASCC	23.5	25.9	36.4	3.25	4.23	4.60	2.55	2.78	3.00
	50	SCRAC-50	20.0	22.9	32.6	2.00	3.34	3.43	1.68	1.86	2.05
	100	SCRAC-100	19.5	21.0	30.1	1.87	3.00	3.00	1.42	1.67	2.00
TSMA	0	VASCC	24.1	26.0	38.3	3.67	4.53	4.71	2.70	3.00	3.09
	50	SCRAC-50	21.5	23.8	35.2	2.42	3.48	4.00	2.00	2.18	2.35
	100	SCRAC-100	20.0	22.1	34.0	2.00	3.23	3.48	1.57	2.02	2.30
TSMA$_{sfc}$	0	VASCC	25.9	27.0	39.0	3.78	4.68	4.80	3.00	3.12	3.19
	50	SCRAC-50	22.1	24.9	36.3	2.68	3.81	4.24	2.15	2.63	3.09
	100	SCRAC-100	21.0	23.0	35.4	2.45	3.45	3.90	1.80	2.49	2.70

Hence RAC becomes more porous, less density, and absorbs more water as compared to VCA causing lesser strength and resistance to freezing and thawing [9][10]. Table 7 presents a detail comparison of mechanical properties for NMA, TSMA and TSMA$_{sfc}$ (present mixing approach), for different percentage of RCA replacement. Experimental results show that the TSMA gives better mechanical properties than NMA as a stronger interface zone is developed in case of TSMA. Moreover, in TSMA$_{sfc}$ the cement and silica fume improves the aggregate matrix bond in RAC resulting less porous ITZ and better strength of RAC.

IV. CONCLUSION

Based on the above context, the following conclusions are drawn:

- Large quantities of C&D waste are produced in urban environments, causing serious disposal problems. These C&D waste was found to be suitable for using in place of VCA.
- Nan Su mix proportioning method can be employed for producing SCRAC. This is conducted after number of trials.
- Based on the experimental results from present study, it is observed that the workability of SCRAC decreases with the increase in percentage of RCA.
- The mechanical properties of SCRAC mixes decreased with an increase in recycled aggregate content.
- SCRAC with 6% silica fume (SF) exhibited satisfactory EFNARC guidelines for workability. Moreover, by addition of silica fume all the mechanical properties are significantly improved.
- In this study, two stage mixing approach is proposed to strengthen the old and new ITZ of the SCRCA,

providing a stronger ITZ by filling up the cracks and pores within RCA.

- The mechanical properties like compressive strength, flexural strength, split tensile strength and static modulus of elasticity are marginally affected by replacement of virgin aggregate by 100% RCA.
- Present two stage mixing approach ($TSMA_{sfc}$) gives better properties of RAC than the TSMA recommended in the open literature. The increase in the strength of mortar and concrete is due to the addition of silica fume and portions of cement. Cement and silica fume improves the aggregate matrix bond in RAC resulting less porous ITZ and better strength of RAC.

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