Advances in Concrete Construction, *Vol. 5, No. 4 (2017) 303-311*
DOI: https://doi.org/10.12989/acc.2017.5.4.303

Mechanical behavior of concrete comprising successively recycled concrete aggregates

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(Received May 24, 2017, Revised June 21, 2017, Accepted June 25, 2017)

Abstract. The concrete industry of developing countries like India consumes majority of natural resources. The increase in population has necessitated the construction of more and more structures. Further many structures have completed their life span or have undergone damages thus warranting the demolition of these structures. India produces approximately 23.75 million tons of recycled concrete aggregate (RCA) annually. The natural resources are depleting at a higher rate with the increasing demand of concrete industry. This difficulty can be reduced with the use of RCA in land fill and concrete manufacturing. Use of RCA can provide cost savings and better energy utilization. This paper presents mechanical behavior of concrete comprising successively recycled concrete aggregate. Mechanical properties of recycled concrete get affected with number of recycling. In mix design successive recycled concrete aggregate (SRCA) was used in place of natural aggregates (NA) with 100% replacement. The test results of the compressive, flexural strength and pulse velocity were obtained for 14 and 28 days of curing age which showed significant improvement in results.

Keywords: recycled concrete aggregate; waste; strength; workability

1. Introduction

The growth of urbanization and industrial growth had led to the problem of waste generation. After demolition of old roads and buildings the wastes generated is often considered worthless and disposed off as demolition waste (McNeil and Kang 2013). Solid waste is a problem which is faced globally and use of recycled concrete aggregate in concrete industry can consume solid waste (Verian *et al*. 2013). The use of RCA in new construction applications is a relatively new technique. The expected rise in construction global market is 5.2% per year up to 2015 (Arora and Singh 2016). This paper focuses on strength of RCA. The beginning of RCA started at the end of World War II, when there was excessive demolition of buildings and roads, to get rid of waste material and rebuild Europe. In the 1970s, the United States began to reintroduce the use of RCA in non-structural uses, such as fill material, foundations and base course material. Since this time, some research has been conducted regarding how viable RCA is, to replace unused NA in

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http://www.techno-press.org/?journal=acc&subpage=7 ISSN: 2287-5301 (Print), 2287-531X (Online)

structural concrete (Buck 1976).

One of the main reasons to use RCA in structural concrete is to make construction more "green" and environmental friendly. Some major environmental issues associated with construction are that it "takes 50% of raw materials from nature, consumes 40% of total energy and creates 50% of total waste". The use of RCA on a large scale may help to reduce the effects of the construction by reusing waste materials and preventing more NA from being harvested (Oikonomou 2005, Saini and Ashish 2015). RCA concrete with two samples of different age groups was investigated in reference to compressive strength. RCA was examined for different properties which proved lower compressive strength in older recycled aggregate (Ashish and Saini 2017, Sahoo *et al*. 2016). The suitability of RCA was examined with durability and mechanical properties which showed RCA is inferior as compared to natural aggregates but it was observed that using additives can lead to better performance of RCA (Kisku *et al.* 2017). Investigations performed on RCA for split tensile strength showed less affect of using RCA as compared to NA. The result showed high or same split tensile strength in comparison of NA (Kang *et al.* 2012).

The demolition caused to highways, old buildings produces waste aggregates (C&D wastes) which has created a problem for all over world. So substitutes are required for meeting the need of natural aggregates in construction industry. The yearly C&D waste is estimated up to 25% from total waste generated in India i.e., 48 million tons (Ghosh *et al*. 2011). Estimated waste in India is predicted to be 11.4 to 14.7 million tones yearly out of which brick and concrete contribution is approximately 7 to 8 million tones (TMS150 2001).

The usage of RCA has come to light from past decades in place of coarse aggregates (Heeralal *et al*. 2009). It has been observed by the researchers that mechanical properties of RCA and NA are not alike (Lin *et al*. 2004) and experiments are needed to choose appropriate mix for getting desired properties with RCA. In these experiments, by replacing RCA with NA partially and fully mechanical properties of concrete were studied under static loading (Zaharieva *et al*. 2003).

It is recognized that as fracture process of RCA is not similar to normal concrete, so compressive strength of normal concrete is higher than that of with RCA concrete with same water cement ratio (Yang *et al*. 2011). From SEM investigations it was studied that loose and porous hydrates are observed in normal RCA but dense hydrates are observed in high strength RCA (Poon *et al*. 2004). A method has been investigated to improve the strength of concrete made with RCA, by detecting micro-cracking in concrete using acoustic emission technique under compression (Watanabe *et al*. 2007). The relationships of recycled aggregate (RA) for compressive strength and stress-strain curves are obtained with different replacement percentages by experiments (Xiao *et al.* 2005). Likewise concrete made with RCA as compared to concrete made with NA gives lower modulus of electricity (13-18%), lower strengths (1-15%) and reduction in fracture energy (27-45%).

A platform called OpenSees was used to model pre cast recycled aggregate concrete finite element models. Dynamic response was also studied for pre-cast recycled aggregate concrete (Pham *et al*. 2015). RCA of 20 years old was replaced up to 100% and mix design of 50 MPa showed 35 MPa after replacement. Durability and mechanical properties were studied. (Saravanakumar and Dhinakaran 2013). The mechanical properties of hardened concrete made with RCA and rheological properties of fresh concrete made with RCA under static load have vast literature available (Hilsdorf and Kesler 1966, Holmen 1979). Fresh and hardened concrete from sites were studied for its properties and tests showed RCA made with old concrete gives better opportunities for reuse (Shah *et al.* 2013). Compressive strength was found to be higher on replacement of natural aggregate with RCA but tensile compressive strength was smaller on

Table 1 Physical properties of SRCA and NA

Type of aggregate	Specific gravity	Bulk density (kg/m^3)	Water absorption (%)	Impact value (%)	Fineness modulus
SRCA	2.46	1425	4.93	27.86	7.15
NA	2.65	1780	0.80	16.85	6.98

Table 2 Chemical properties of cement and fly ash

Oxides	OPC	Fly ash
Calcium oxide (CaO)	64.38	18.42
Silica Oxide (SiO_2)	21.58	36.47
Aluminium oxide (Al_2O_3)	4.39	16.95
Iron oxide (Fe_2O_3)	4.255	20.05
Magnesium oxide (MgO)	1.02	2.54
Potassium oxide (K_2O)	0.74	0.89
Sodium oxide (Na_2O)	0.31	0.80
Sulphur trioxide (SO_3)	2.74	3.54

Table 3 Mix proportion of concrete made with or without SRCA

Nomenclature	Replacement (R)%	Fly ash (Kg/m^3)	Cement (Kg/m^3)	Fine aggregate (Kg/m^3)	Natural aggregate (Kg/m^3)	SRCA (Kg/m^3)	Water (liters/m^3)
R-00	0	148	385	560	1200	0	185
R-10	10	148	385	560	1080	120	185
R-20	20	148	385	560	960	240	185
R-30	30	148	385	560	840	360	185
R-40	40	148	385	560	720	480	185
R-50	50	148	385	560	600	600	185
R-60	60	148	385	560	480	720	185
R-70	70	148	385	560	360	840	185
R-80	80	148	385	560	240	960	185
R-90	90	148	385	560	120	1080	185
R-100	100	148	385	560	0	1200	185

replacement (He *et al*. 2015). RCA with silica fume was analyzed for Compressive strength using gene expression programming (Abdollahzadeh *et al*. 2016). The sustainable growth of construction industry is widely studied by different researchers to contribute in this field some of the publications on different waste materials are (Casuccio *et al*. 2008). Yaragal *et al.* (2016), Ashish *et al*. (2011), Ashish *et al.* (2016a), Ashish *et al.* (2016b), Ashish *et al.* (2016c), Dar *et al.* (2015) Kumar *et al.* (2014), Kumar and Ashish (2015a), Kumar and Ashish (2015b), Kumar *et al.* (2015), Verma *et al.* (2016) and Wani *et al.* (2015).

2. Experimental investigation

In this investigation, concrete collected from Ambala (India) was used to prepare concrete

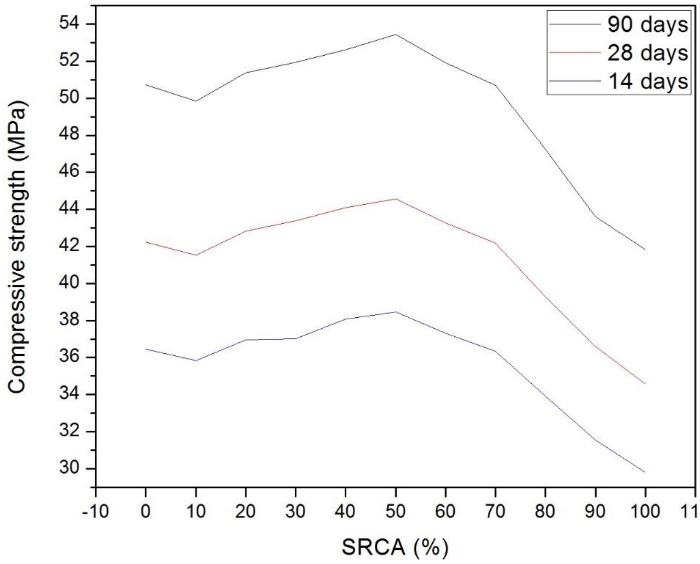

Fig. 1 Effect of SRCA as NA replacement on compressive strength of concrete

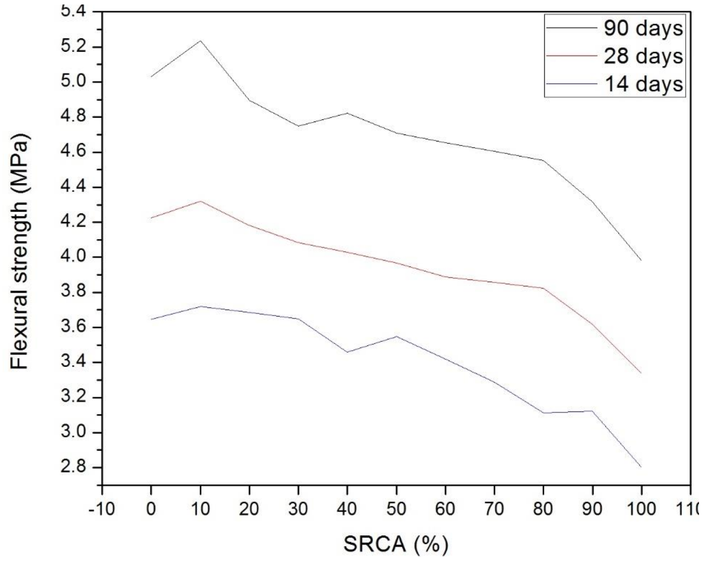

Fig. 2 Effect of SRCA as NA replacement on flexural strength of concrete

cubes made of RCA, they were tested for compressive strength. The cubes made with RCA were crushed by mini jaw crusher and dried. The new sample was prepared using old RCA called as successive recycled concrete aggregate (SRCA). The test specimens of 150 mm×150 mm×150 mm cubes for determining compressive strength at 14, 28 and 90 days were cast conforming to BIS: 516 (1959). For flexural strength beam specimens of size 100 mm×100 mm×500 mm were cast and four-point flexural loading. Flexure strength was determined at 14, 28 and 90 days as per BIS: 516 (1959). Pulse velocity of concrete was determined on all concrete mix at the curing ages of 14 and 28 days as per ASTM C597 (2016).

Table 4 Compressive and flexure strength of concrete made with or without SRCA

Nomenclature	Compressive strength (MPa)			Flexural strength (MPa)		
	14 days	28 days	90 days	14 days	28 days	90 days
R-00	36.46	42.24	63.40	3.646	4.224	5.031
R-10	35.82	41.52	62.33	3.720	4.318	5.235
R-20	36.97	42.84	64.23	3.686	4.181	4.895
R-30	37.03	43.38	64.94	3.650	4.085	4.750
R-40	38.07	44.10	65.78	3.459	4.027	4.821
R-50	38.47	44.58	66.81	3.548	3.966	4.710
R-60	37.32	43.26	64.88	3.420	3.888	4.654
R-70	36.34	42.18	63.38	3.289	3.858	4.605
R-80	33.93	39.30	59.06	3.114	3.823	4.554
R-90	31.57	36.60	54.53	3.122	3.618	4.315
R-100	29.79	34.56	52.28	2.801	3.336	3.980

3. Materials and mix proportions

As per BIS: 8112 (2013) specifications, cement of 43 grade OPC was used. No lumps were there in cement used. Sand was used as per specification BIS: 383 (1970). In experiment, specific gravity of SRCA used was 2.65, specific gravity of NA used was 2.46. SRCA well graded upto 12.5 mm size and aggregate crushing value around 30% was used. As per BIS 2386-1 (1963); BIS: 2386-2 (1963); BIS: 2386-4 (1963) specifications natural coarse aggregate and successive recycled concrete aggregate were used. Properties of SRCA and NA are depicted in Table 1 and chemical properties of cement and fly ash in Table 2. Table 3 shows mix proportions for SRCA and NA concrete mixes.

4. Compression strength and flexural strength

Compressive strength of concrete samples was tested for 14, 28 and 90 days as per BIS: 516 (1959). The same is depicted in Table 4 and Fig. 1, compressive strength of 100% SRCA concrete specimen was 29.79 MPa, 34.56 MPa and 52.28 MPa for 14, 28 and 90 days respectively and for 100% natural aggregates concrete specimen, compressive strength was 36.46 MPa, 42.24 MPa and 63.40 MPa for 14, 28 and 90 days respectively. It is observed that maximum compressive strength was obtained when 50% NA were replaced with SRCA and the strength at 14 days, 28 days and 90 days was found to be 36.46 MPa, 42.24 MPa and 63.40 MPa respectively. Etxeberria *et al.* (2007) made similar observations. Low water availability in SRCA leads to weak interfacial transition zone (ITZ) due to which low compressive strength was achieved. NA has high compressive strength as compared to SRCA. It cannot be used in high strength concrete but it can be used in medium strength concrete. Moreover, it was observed that compressive strength of SRCA increases with increase in replacement ratio of SRCA up to 50% replacement and thereafter it exhibited a downward trend.

It was investigated that flexural strength of SRCA concrete increase up to 10% of NA are replaced with SRCA and thereafter at higher replacement level it exhibited a downward trend.

Table 5 UPV value of concrete made with or without SRCA

Nomenclature	Pulse velocity (m/s)	
	14 days	28 days
R-00	6707.78	7269.39
R-10	6629.26	7267.38
R-20	6812.19	7463.85
R-30	6855.00	7555.41
R-40	6833.82	7742.39
R-50	7124.77	7771.07
R-60	6898.65	7254.94
R-70	6747.97	6992.18
R-80	6261.92	6474.06
R-90	5811.58	5995.53
R-100	5477.27	5623.23

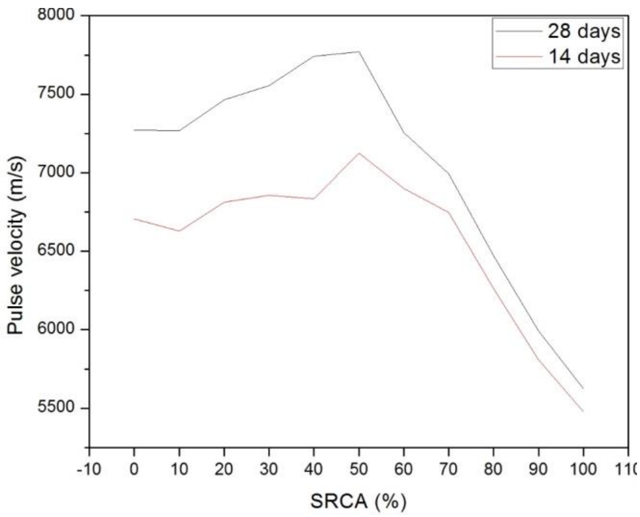

Fig. 3 Effect of SRCA as NA replacement on ultrasonic pulse velocity of concrete

Table 4 and Fig. 2 represent flexural strength 2.801 MPa, 3.336 MPa and 3.980 MPa for 14, 28 and 90 days of 100%.

SRCA concrete specimen respectively, however, 100% natural aggregates concrete specimen has flexural strength 3.646 MPa, 4.224 MPa and 5.031 MPa for 14 days, 28 days and 90 days respectively. With the replacement of 10% NA by SRCA, maximum flexural strength can be achieved i.e., 3.720 MPa, 4.318 MPa and 5.235 MPa for 14, 28 and 90 days respectively. Bairagi *et al*. (1993) made similar observations.

5. Pulse velocity

It was investigated that ultrasonic pulse wave of SRCA concrete is higher than NA concrete.

Table 5 and Fig. 3 depicts 100% SRCA has ultrasonic pulse wave 5477.27 m/s and 5623.23 m/s for 14 and 28 days respectively however 100% natural aggregates has ultrasonic pulse wave 6707.78 m/s and 7269.39 m/s for 14 and 28 days respectively. With the replacement of 50% NA with SRCA, maximum ultrasonic pulse wave can be achieved i.e., 7124.77 m/s and 7771.07 m/s for 14 and 28 days respectively. No significant effect was noticed on the value of UPV by the SRCA replacement.

6. Conclusions

It is concluded that when NA are replaced with SRCA in manufacturing of concrete same improvement in compressive strength and flexural strength can be achieved but when the replacement level increase then it trends to affect adversely the compressive strength and flexural strength of concrete. From UPV results it is inferred that no significant alteration is noticed when NA are replaced with SRCA.

However, the concrete made by replacing NA with SRCA makes the gainful use of the waste obtained from the demolition of structures and hence tackles the disposal problem of waste material.

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