RECYCLED AGGREGATE CONCRETE: A SUSTAINABLE BUILT ENVIRONMENT

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Abstract
In the present study the influence of recycled coarse aggregate (RCA) obtained from three different sources having different ages of structures are on the properties of recycled aggregate concrete (RAC) are investigated. RAC mixes are prepared with each source of RCA separately. In order to assess the performance of RAC in comparison with normal concrete, two normal concrete mixes prepared with 100% natural coarse aggregate. Locally available natural sand is used in all mixes. The compressive strength and the characteristics of interfacial transition zone (ITZ) viz. porosity and microhardness of RAC are studied. The results reveal that the ITZ of RAC is relatively loose and porous than the ITZ in normal concrete.

Keywords: *Recycled aggregate concrete (RAC), compressive strength, interfacial transition zone (ITZ), porosity, microhardness.*

1 Introduction
Recycling of construction and demolition waste has been considered from two main environmental aspects point of view: solving the increasing waste disposal crisis and save the depletion of natural resources. In the recent time due to significant increase in prices of natural raw materials of construction, and rise in the cost of waste storage in many regions, it has also become a burning issue (Ajdukiewwicz and Kliszczewicz, 2007). There is a scarcity of conventional building materials due to rapid construction activity and growing demand of houses in urban areas. Rapid industrialization has lead to the generation of huge quantities of construction and demolition wastes, which arises major problems of disposal. The disposal and utilization of construction and demolition waste is one of the major problems in India. Factors such as sustainability, economy, shortage of land for the disposal and shortage of good quality of raw materials for construction make it imperative that the construction and demolition waste should be properly recycled (Asnani, 1996). The recycling technology, not only solves the problem of waste disposal, but reduces the cost and preserves environment also. This also gives the way for the sustainable built environment in the construction industry.

2 Review of Literature
In the recent past, several researchers have studied the influence of recycled aggregate obtained from both aspects of laboratory crushed materials as well as field demolished structural materials on mechanical properties of recycled aggregate concrete (Hansen, 1985; Bairagi et al., 1993., Sagoe-Crentsil et al., 2001., Rao et al., 2007., Padmini et al., 2009). Nevertheless, the information available on the influence of recycled aggregate on the characteristics of ITZ is scarce. In the present study an objective is to investigate the influence of RCA obtained from different demolished structures on strength and on the characteristics of ITZ viz. porosity and microhardness of recycled aggregate concrete.

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3 Experimental Details

3.1 Materials

Ordinary Portland Cement (OPC) of 43 grade conforming to Bureau of India Standard Specifications of IS: 8112 (1989) with specific gravity 3.14 is used in this study. The locally available natural sand and 20 mm maximum size natural coarse aggregate available from the local quarries conforming to the grading requirements of IS: 383 (1970) are used. The recycled coarse aggregates are obtained from three different demolished structures: two different demolished RCC culverts of different locations and a RCC slab of an old residential building. The recycled coarse aggregate obtained from the three sources are designated as RCA-S1, RCA-S2 and RCA-S3 respectively. The important properties of both natural and recycled coarse aggregates are presented in Table 1.

Table 1: *Properties of coarse aggregate*

Property	Coarse aggregate			
	Natural	RCA-S1	RCA-S2	RCA-S3
Specific gravity (SSD)	2.75	2.51	2.47	2.417
Water absorption (%)	1.129	3.92	3.009	3.934
Density (kg/l)	1.581	1.413	1.34	1.35

3.2 Concrete Mixes

Three recycled aggregate concrete mixes were prepared with 100% RCA obtained from each source. These mixes are designated as MM-RAC, MK-RAC and MV-RAC respectively. In all mixes, the letter M stands for the mix, the second letter represents the source of recycled coarse aggregate and RAC indicate the recycled aggregate concrete. In order to assess the performance of recycled aggregate concrete in comparison with normal concrete, two normal concrete mixes were prepared with 100% natural coarse aggregate and these are designated as M1-NAC and M2-NAC respectively. One corresponding to the RAC made with RCA obtained from the sources 1 and 2, and the other corresponding to RAC with source 3 RCA. The cement used in the test is OPC 43 grade manufactured by Ultratech Cement Co., India. While testing, some variation in the chemical composition is observed. Cement 1 is used for the RAC made with sources 1 and 2 RCA and corresponding normal concrete and cement 2 is used in RAC made with source 3 RCA and in corresponding normal concrete. In all mixes the locally available natural sand used as fine aggregate. All mixes were designed for M25 grade concrete in accordance with BIS (IS: 10262-1982). In all mixes, the free water-cement ratio was kept constant at 0.43 and slump was maintained in the range of 50-60 mm by adding Sika Viscocrete R-550 (l) superplasticiser. As the density of natural and recycled coarse aggregates is different, there is a little difference in the quantity of coarse aggregates. The details of all mixes are presented in Table 2.

Table 2: *Details of mix proportions (kg/m^3 of concrete)*

Mix Designation	Cement (kg)	Natural FA (kg)	Natural CA (kg)	RCA (kg)	Free w/c ratio	Super - plasticizer*	Slump (mm)
M1-NAC	401	574	1261	0	0.43	0.05	57.5
MM-RAC	401	574	0	1119	0.43	0.225	50
MK-RAC	401	574	0	1114	0.43	0.225	49
M2-NAC	401	574	1261	0	0.43	0.05	56
MV-RAC	401	574	0	1078	0.43	0.225	51

*percentage by weight of cement

3.3 Testing Procedure

3.3.1 Compressive strength

The compressive strength test was conducted on 100 mm cubes after 7 and 28 curing. Three cube specimens were tested for 7 days curing and six cube specimens were tested for 28 days curing. A total of 9 cube specimens were tested for compressive strength in each mix.

3.3.2 Sample preparation for measuring porosity and microhardness

Specimen preparation is very important for identifying the features in scanning electron microscopy (SEM). Also a flat polished smooth surface is required for measuring the microhardness. In the present study after 28 days of curing 10 – 12 mm thick slices were cut from a 100 mm diameter × 200 mm height cylinder at different heights using a precision diamond saw and kerosene as lubricant. From each slice again approximately 10 × 10 mm rectangular sections were cut. The specimens were then dried in desiccators for more than 3 days. The dried specimens were then vacuum impregnated with a low viscosity epoxy coded as Epoxil-43 and hardener as Epoxil-MH43 in a 3:1 ratio and allowed to harden at room temperature for 1- 6 hours. The impregnated specimens are then carefully ground and polished with different sizes of grit paper and finer grades of diamond paste. The polished specimens are then cleaned in an ultrasonic bath and dried in vacuum to remove any remaining lubricant from the surface. The specimens are then coated with a thin layer of carbon to prevent charging during backscatter scanning electron (BSE) imaging.

3.3.3 Scanning Electron Microscope

The JEOL-JSM-6490 is a high performance scanning electron microscope with a high resolution of 3.0 nm was used in the present study. It is coupled with an energy dispersive spectrometer (EDS), which facilitates the qualitative analysis of the major elements on the surface.

3.3.4 Microhardness

A UHL VMHT microhardness tester (VMH-001) was used in the present study to measure the microhardness of ITZ of both normal concrete and recycled aggregate concrete made with all the three sources of RCA. The usefulness of this method is its ability to determine the response to load of a volume element that is considerably smaller than the ITZ (Igarashi, 1996). The Vickers microhardness test was conducted on the same samples on which the BSE images were acquired using scanning electron microscopy for measuring the porosity. The configuration of the Vicker's microhardness test is shown in Fig. 1. The Vickers microhardness was measured at 14 - 16 points within the distance of 235 μm from the aggregate surface. The measurements were taken randomly at a constant load of 10 gf with 10 s time. The test was conducted on three samples for each mix and the average results are reported. Here the microhardness symbol HV 0.01 means the test load is of 10 gf.

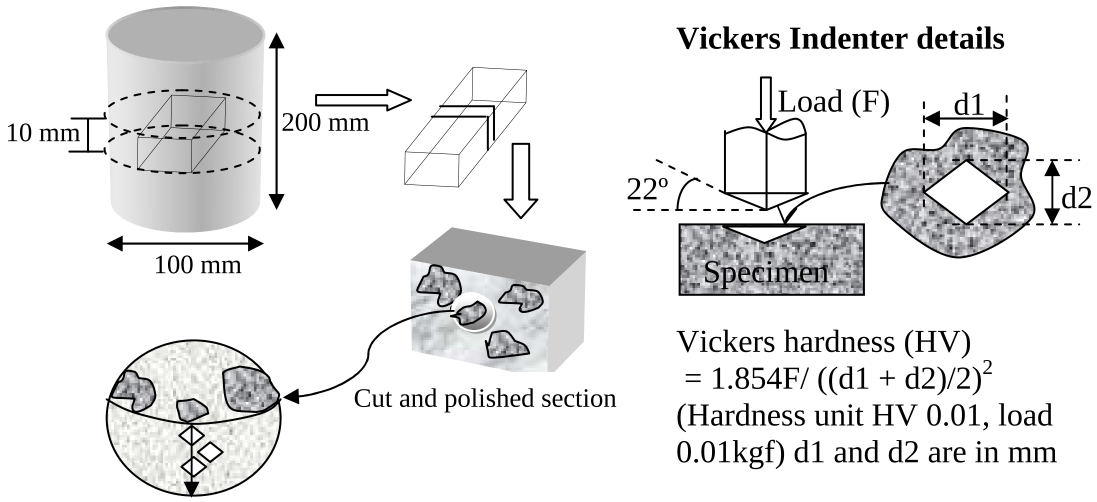


Fig. 1 *Configuration of the Vicker's microhardness*

4 Results and Discussion

4.1 Porosity

Porosity is the volume which has not been filled by the cement grains or by the hydration products. The resolution in backscatter SEM limits the measurement of pore sizes. In the present study approximately 20 BSE images were analysed using image processing techniques from three samples of each mix (M1-NAC, MM-RAC, MK-RAC, M2-NAC, MV-RAC). All images were captured at 512 × 512 pixels; each pixel is approximately 0.3 µm in each direction which covers an area of 0.09 μm^2. Therefore the minimum pore size that can be measured is 0.3 µm and these are generally called capillary pores. The mean area percentages of porosity of both normal concrete and recycled aggregate concrete made with recycled aggregate obtained from all the three sources are presented in Table 3.

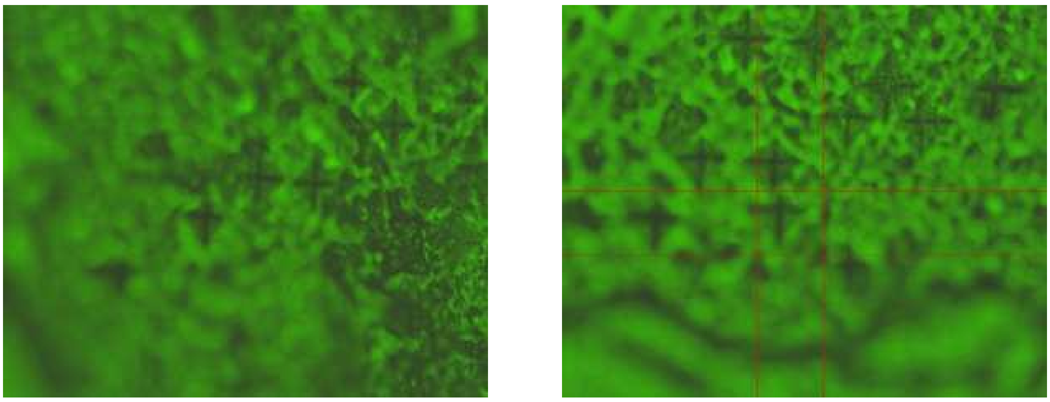
Table3: *Mean area percentages of porosity at ITZ*

Source of RCA	Mix designation	Porosity (%)
RCC culvert near Midinapur	M1-NAC0	15.22
	MM-RAC	20.28
RCC culvert near Kharagpur	M1-NAC	15.22
	MK-RAC	21.02
RCC slab of a old residential building, Vizianagaram	M2-NAC	16.79
	MV-RAC	21.00

It reveals that the porosity in recycled aggregate concrete made with RCA obtained from all the three sources are more than those of corresponding normal concretes. The area of porosity in normal concrete is in the range of 15.22% - 16.7%. Whereas, the porosity in RAC made with RCA obtained from sources 1, 2 and 3 are 20.28%, 21.02% and 21% respectively. Albeit there are some chemical reactions expected between the remnant cement particles in recycled aggregates and new cement mortar would create some interfacial bonding effects, the results indicates that the ITZ in recycled aggregate concrete is loose and porous than the ITZ in normal concrete. This may be due to the presence of old mortar in recycled aggregates, which absorbs more water during the initial stages of mixing leads to the higher porosity.

4.2 Microhardness

Vickers microhardness test is used to measure the microhardness along and across the width of the old ITZ. Typical microhardness indentations on various samples are shown in Fig. 2. The distribution of Vickers microhardness across the ITZ for both normal concrete and recycled aggregate concrete made with all the three sources of RCA are presented in Fig. 3.



(a) (b)

Fig. 2 *Microhardness indentations (a) normal concrete (M1-NAC) and (b) recycled aggregate concrete (MM-RAC)*

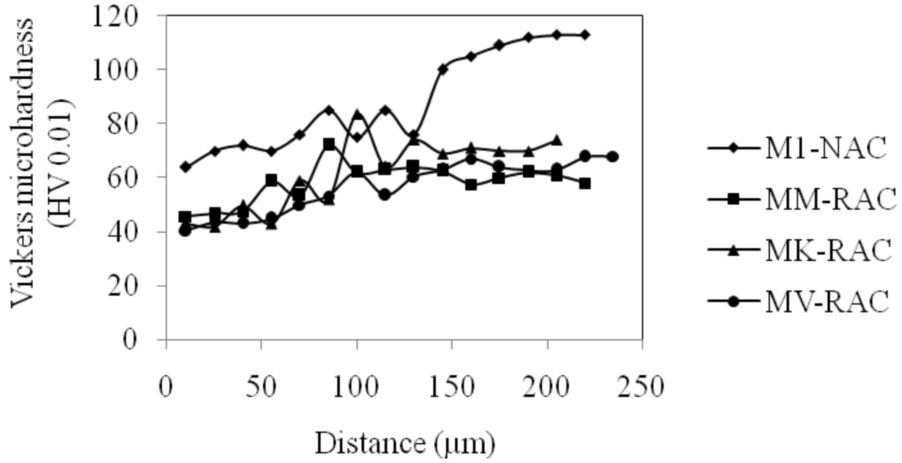


Fig. 3 *Gradients of Vickers microhardness of both normal and recycled aggregate concretes*

From the Figure it is ascertained that the Vickers microhardness increased with the distance increased from the aggregate surface in both normal concrete and recycled aggregate concretes made with all the three sources of RCA. In addition, it is observed that the Vickers microhardness upto 40 – 55 µm distance from the aggregate surface is not varying much in both normal concrete and recycled aggregate concrete. However, beyond these distances the Vickers microhardness is progressively increasing upto around 150 µm distance and thereafter almost it is constant. Lower value of Vickers microhardness indicates the presence of more microcracks and micropores which is an indication of higher porosity. The variation of Vickers microhardness across the ITZ defines the width of ITZ: the width of ITZ in both normal concrete and recycled aggregate concrete is within the range of 40 – 55 µm. Similar results are obtained in SEM examinations, the porosity near the aggregate surface (10-50 µm) is much higher than that of bulk paste in all the concretes. The variation in Vickers microhardness of RAC is almost same irrespective of the source of RCA. However, the Vickers microhardness of normal concrete is higher than that of recycled aggregate concrete made with all the sources of RCA across the ITZ. This may be due to the presence of old mortar adhered to RCA in RAC, which absorbs more water at the initial stages of mixing leads to the lesser hydration compounds and more porosity.

4.3 Compressive Strength

The compressive strength of both normal and recycled aggregate concretes for different testing ages is presented in Fig. 4.

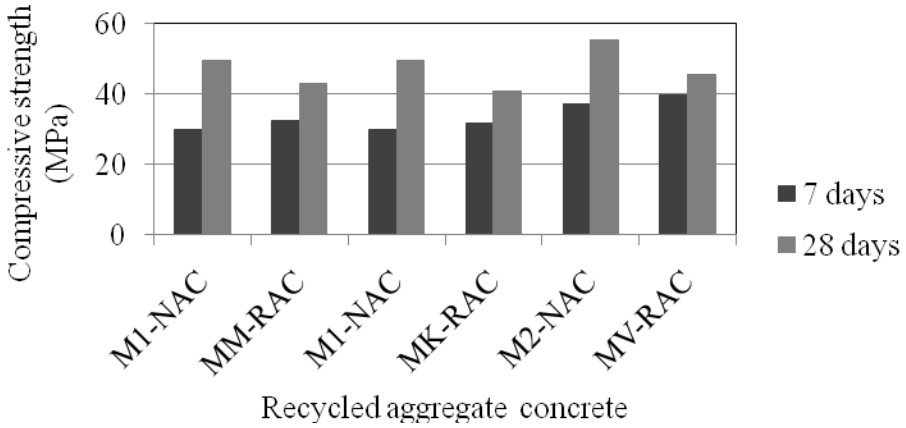


Fig. 4 *Development of compressive strength with age*

It is observed that in all mixes the target strength is achieved. It reveals that the strength gaining rate is relatively slow in case of all the recycled aggregates concrete compared to normal concrete between 7 days to 28 days curing period. There is an increase of approximately 13% - 25% of the compressive strength in recycled aggregate concretes when normal concrete strength increased by approximately

33% - 40% in the last 21 days of 28 days curing. This indicates that the recycled aggregate concretes attained more early strength than normal concretes. It was reported in the literature that the increase in compressive strength of RAC at early age is mainly due to high absorption capacity of old mortar adhered to the recycled aggregates and the rough texture of recycled aggregates that provide improved bonding and interlocking characteristic between the mortar and recycled aggregate themselves (Etxeberria et al., 2007). The compressive strength of RAC after 28 days of curing is less than that of normal concrete. The reduction in compressive strength after 28 days of curing in recycled aggregate concrete is in the order of 13% - 17% compared to the corresponding normal concrete.

5 Closing Remarks

The influence of recycled coarse aggregate obtained from three different demolished structures on strength and microstructural characteristics of ITZ are investigated. Based on the experimental results the following conclusions may be drawn.

- The target strength can be achieved in recycled aggregate concrete irrespective of the type of RCA, However, the compressive strength of recycled aggregate concrete was found to be lower than that of corresponding normal concrete after 28 days of curing.
- A relatively loose and porous interfacial transition zone is present in recycled aggregate concrete made with all sources of RCA compared to ITZ in normal concrete. The porous interfacial transition zone in recycled aggregate concrete may be attributed to the higher absorption capacity of recycled aggregates.
- The microhardness of ITZ in recycled aggregate concrete was found to be lower than that of normal concrete ITZ. The lower values of microhardness indicate the higher percentage of porosity.

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