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Influence of Waste Concrete Aggregates on the Performance and Durability of OPC Concrete

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ABSTRACT

The effects of using crushed waste concrete as course aggregates upon compressive strength and carbonation were investigated. Waste concrete cubes, which had been tested for compressive strength in compliance with construction specification, were crushed and utilized as coarse recycled aggregates in new concrete. It is important to mention that, in order to simulate the real life conditions, waste concrete with very minimal information about its originality was used in its natural moisture condition. Tests on the aggregates showed that the recycled concrete aggregates have lower specific gravity and bulk density but have higher water absorption capacity than the natural aggregates. The resistance to mechanical actions such as impact and crushing for recycled concrete aggregates is also lower. Concrete mixes with design strength of 30 N/mm^2, 35 N/mm^2 and 40 N/mm^2 were prepared using this recycled aggregates as coarse aggregates and tested. From the strength point of view the recycled aggregate concrete compared well with natural aggregate concrete. Therefore, it could be considered for various potential applications. With respect to resistance to carbonation the recycled aggregate concrete shows comparable performance.

***Keywords**: Waste Concrete, Aggregate, Compressive Strength, Recycled Concrete, Durability*

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Introduction

Concrete, being the most widely used construction material, has seen its consumption rise with the growth in population and urbanization. However, along with an increased consumption, there is also an increased generation of wastes. Waste concrete is derived from a number of sources. The most common are from demolished concrete structures, fresh batch leftovers, and waste concrete cubes that have been tested for compliance with building specifications. This debris is usually thrown away, as landfill or dumped and causing environmental pollution. In some area in developed countries such as the United States, Europe and Japan natural aggregates are becoming scarce and bringing aggregates from far away places increases the cost of concrete [1]. Since control of waste materials pollution is increasingly important, recycling these waste concrete materials seem to be an inevitable solution. Researchers have tried to relate the quality of recycled aggregate concrete to the properties of the original concrete and paste, the state of deterioration of the old concrete, crushing procedure, and the new mix composition, [2-5]. It is generally accepted that the cement paste from the original concrete that adhered to the recycled aggregate plays an important role in determining the performance of recycled aggregate concrete. The qualities of the paste and the interface zones, as well as the paste content of the original concrete, thus influence the properties of the recycled aggregate concrete. Regarding the strength development of recycled aggregate concrete conflicting results were obtained by investigator in the United States, Europe and Japan. Among these are Frondistou Yannas [6], Hansen and Narud [7], Ravindrajah *et al*. [8, 9], Yoda *et al*. [10] and Diah *et al*. [1]. From these findings, it seems that further research is needed to understand the behavior of recycled aggregate concrete as a structural material.

Most researchers have made the original concrete in the laboratory to have control of the properties and mix proportions of the original concrete and to be able to study some specified properties of recycled concrete under controlled conditions. However, this will be different if field-demolished concrete or waste concrete that has been exposed to climatic conditions is used to produce recycled aggregate.

In Malaysia, very little is known about the use of recycled aggregate in manufacture of new concrete, particularly with respect to behavior of the material under local climatic conditions. Therefore, the main thrust of this investigation is to evaluate recycled aggregate concrete from waste concrete cubes (with granite as coarse aggregate) that have been exposed to local climatic conditions for use as coarse aggregate in new concrete, as such material is likely to provide both environmental and economic advantages. In this study, an investigation has been carried out to quantify the properties of concrete made by fully replacing natural coarse aggregate with recycled aggregate. The properties investigated were aggregate characteristic, workability, compressive strength development and resistance to carbonation of the resulted recycled aggregate concrete.

Materials and Techniques

Materials

The materials used in this study were ordinary Portland cement in compliance with MS 522, river sand and coarse aggregate, which comply with BS 882:1992. The waste concrete used in this study was concrete cubes brought from neighboring construction, which sent concrete cubes for compressive strength testing at 7 and 28 days in compliance with construction specification. The range of the compressive strength of these cubes was between 25 and 35 N/mm^2. These cubes were first broken into smaller pieces by the help of crushing machine and than into smaller pieces in a jaw crusher to produce recycled aggregate of nominal maximum size of 20 mm. The crushed products were then sieve into single size fraction of 20 mm and 10 mm. The 20 mm and 10 mm coarse aggregate for the concrete mix were then combined in the ratio of 2:1 respectively for both the natural and recycled aggregate concrete mix.

Physical Properties of Aggregates

The grading is as shown in Tables 1 and 2 and in accordance with BS 812 Part 3: 1985. The physical properties of all the aggregates in terms of specific gravity, bulk density, aggregates impact and crushing values, and water absorption are presented in Table 3 in accordance with BS 1881 [11].

From the results obtained it seems that the recycled aggregate have lower resistance to impact and crushing load and have higher water absorption. This is mainly due to the present of low density and more porous old mortar attached to the recycled aggregates, which also contributed to the lower specific gravity and bulk density.

Table 1: Sieve Analysis of Fine Aggregate

Sieve Size (mm)	Percentage Passing %
5.00	96.2
2.38	82.5
1.18	50.9
0.60	20.9
0.30	3.6
0.15	0.7
pan	0.0

Table 2: Sieve Analysis of Recycled Aggregate (RA) and Natural Aggregate (NA)(Granite)

Sieve Size (mm)	Natural Aggregate		Recycled Aggregate	
	20mm	10mm	20mm	10mm
37.5	100.0	100.0	100.0	100.0
20.0	99.92	100.0	100.0	100.0
14.0	69.5	99.41	65.0	69.4
10.0	26.0	98.5	32.5	30.9
5.0	5.2	28.7	2.5	2.36
2.0	0.0	5.1	0.0	0.09
pan	0.0	0.0	0.0	0.0

Table 3: Physical Properties of Aggregates

Properties	Recycled Aggregate	Natural Aggregate
Specific Gravity:		
Saturated surface dry (SSD)	2.31	2.55
Oven Dried	2.23	2.52
Apparent	2.41	2.6
Loose Bulk Density (kg/m^3)	1255	1390
Aggregate Impact Value %	31.4	16.5
Aggregate Crushing Value %	31.0	16.0
Water Absorption %	3.3	1.35

Mix Design of Recycled Aggregate Concrete (RAC) and Natural Aggregate Concrete (NAC)

The characteristic design strengths chosen for the concrete mixes at 28 days were 30, 35 and 40 N/mm^2. This covered the range of design strengths that is for commonly used in practice. Two sets of mixes were prepared one for natural aggregate concrete and one for recycled aggregate concrete. The water cement ratios of the mixed were 0.64, 0.58 and 0.55 respectively. Since there is no existing standard method of designing concrete mixes incorporating recycled aggregates the recycled aggregates concrete mixes were derived simply by replacing the natural coarse aggregates proportion in the natural aggregate concrete mix design developed using the DOE: method, with recycled coarse aggregate. All the concretes were mixed in a 0.04 m3 horizontal pan mixer. The concrete mixes were prepared namely NAC 30, NAC 35, NAC 40, RAC 30, RAC 35, and RAC 40. The notation indicates that for NAC 30 the concrete mix was for natural aggregate concrete of design strength 30 N/mm^2, RAC 30 was recycled aggregate concrete of design strength 30 N/mm^2.

Compressive Strength Development Test

For each concrete mix, 12 nos. of 100 mm cubes where made in standard steel moulds. After 24 hours the cubes were removed from the mould and placed in water at 23 °C until testing. The cube specimen was then tested for compressive strength in accordance with BS 1881: Part 116 [12]. Reported observations are average of three results of compressive at each age.

Carbonation Measurements

The sample for carbonation investigation were left in the laboratory ambient environment for up to 1 year after casting and after cured in water. The depth of carbonation was determined by spraying the surface of the broken concrete, which has been split perpendicular to the exposed faces with solution of phenolthalein.

Results and Discussion

Workability

The freshly mixed concrete mixes were tested immediately after mixing for workability using slump test. The test result showed that the natural aggregates concrete mixes show better workability with a slump for 60 – 75 mm, than the recycled aggregate concrete mix (RAC) with slump measurement ranging between 40 – 60 mm. The lower slump is attributed to the higher water absorption of the recycled aggregate concrete which reduced the effective water cement ration and hence workability.

Compressive Strength Development

Figures 1 to 3 show the compressive strength development of all the mixes. All the mixes attained the 28 days design strength of 30 N/mm^2, 35 N/mm^2 and 40 N/mm^2. For the same design strength the RAC attained higher strength compared to the corresponding NAC mixes. The rate of compressive strength development was also higher for RAC compared to NAC mixes. The strength development trends of RAC and NAC were similar.

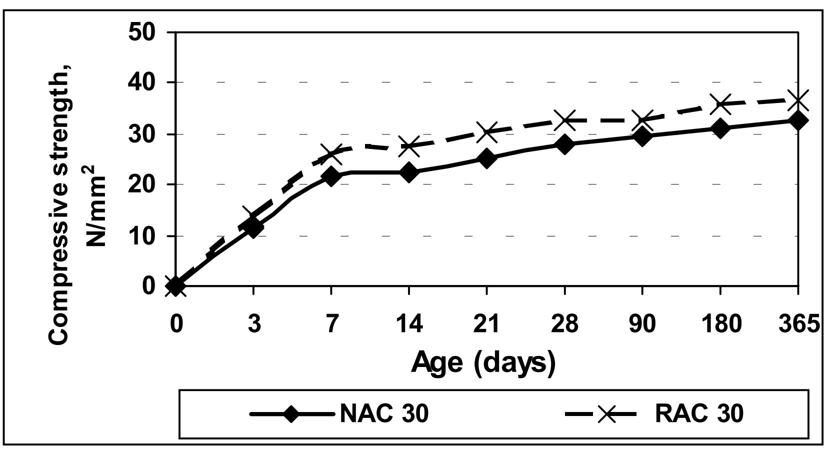

Figure 1: Compressive Strength Development of Recycled Aggregate Concrete (RAC) and Natural Aggregate Concrete (NAC) for Design Strength 30 N/mm^2

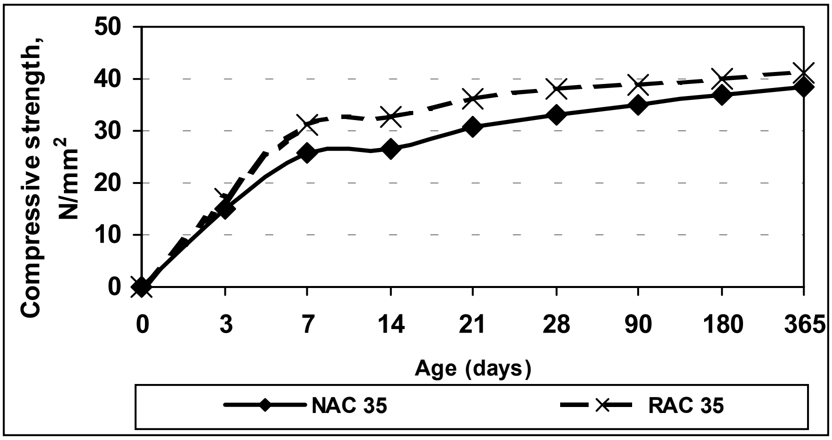

Figure 2: Compressive Strength Development of Recycled Aggregate Concrete (RAC) and Natural Aggregate Concrete (NAC) for Design Strength 35 N/mm²

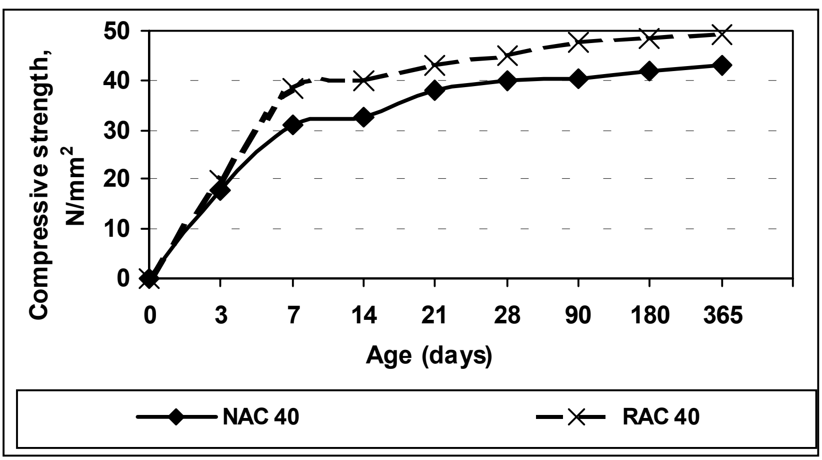

Figure 3: Compressive Strength Development of Recycled Aggregate Concrete (RAC) and Natural Aggregate Concrete (NAC) for Design Strength 40 N/mm²

The higher compressive strength of the RAC may be attributed to high water absorption of recycled concrete aggregates which reduced the effective water content; since the water absorption was not taken into account during the design as compared to previous researchers [6-10] hence the water cement ratio of the RAC mixes.

Table 4 shows the relative compressive strengths of recycled and natural aggregate concrete at 3, 7, 28 and 90 days. It can be seen that at 3 days the compressive strength of the RAC mixes was 2 – 17 % higher than that of the corresponding NAC mixes. At 7 days the RAC mixes was 39 – 48 % higher than that of the NAC mixes, and at 28 days the strength of the RAC mixes was 13 –16 % higher than the corresponding NAC mixes.

Table 4: Relative Compressive Strength of Recycled Aggregate Concrete (RAC) and Natural Aggregate Concrete (NAC)

Mix	Relative compressive strength			
	Age of Curing (Days)			
	3	7	28	90
NAC 30	100	100	100	100
RAC 30	117	139	115	114
NAC 35	100	100	100	100
RAC 35	112	142	113	117
NAC 40	100	100	100	100
RAC 40	102	148	116	114

Effect of Water Cement Ratio

Figure 4 shows the effect of water cement ratio on the 28 days strength of the mixes. Generally the trend is similar for the NAC and RAC mixes, which is the higher the water cement ratio the lower the compressive strength.

Resistance to Carbonation

Figure 5 illustrates the relationship between the depth of carbonation and compressive strength at 28 days. It can be seen that the difference between the RAC and NAC was very small and the differences diminishes as the strength of the concrete increases and this is in agreement with Levy *et al*. [4]. Hence the replacement of natural coarse aggregate with recycled coarse aggregate in concrete does not show detrimental effect.

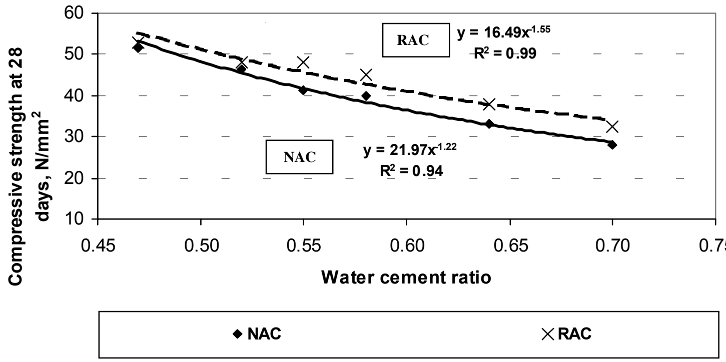

Figure 4: Relationship between 28 days Compressive Strength and Water Cement NAC and RAC

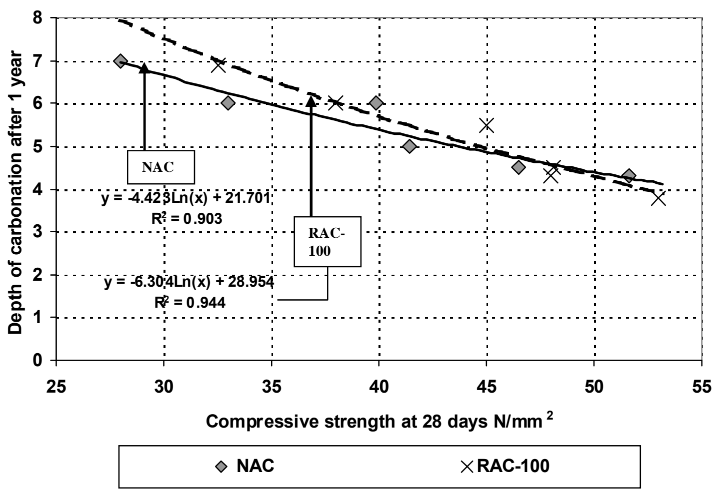

Figure 5: Relationship between Depth of Carbonation and Compressive Strength of Recycled Aggregate Concrete (RAC) and Natural Aggregate Concrete (NAC)

Conclusion

The replacement of natural coarse aggregates with recycled concrete aggregate was found to be advantageous to the compressive strength development of recycled aggregate concrete. For all mixes, the recycled aggregate concrete mixes manage to attain the required designed strength and have compressive strength 13 – 16 % higher than the corresponding natural aggregate concrete at 28 days. From the results obtained in this study, the recycled aggregate concrete could be considered for various potential applications, such as slabs, foot pavements, and drain and medium strength structural concrete elements. With respect to resistance to carbonation the recycled aggregate concrete is comparable to the NAC mixes.

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