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Properties of Concrete made with Recycled Concrete Aggregate

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ABSTRACT:

Properties of concrete made using recycled concrete aggregate as coarse aggregate were investigated. Five mixes were made using 26.5 mm maximum aggregate size and water/cement ration of 0.50. A control concrete mix was prepared with 100% natural crushed coarse aggregate (NA) while another four mixes were made with recycled aggregate (RA) at 30, 50, 70 and 100% replacement levels. The properties studied were workability, compressive strength measured at 3, 7 and 28 days, flexural strength and abrasion resistance which were determined at 28 days.

The results showed that, in general terms, there was improvement in the workability of the concrete mix (i.e. increase in value of slump) with increases in the amount of recycled aggregate in the mix. As for compressive strength development, the general tendency was for reduction in compressive strength with increases in the proportion of RA in the mixes.

At the age of 28 days, the highest compressive strength value of 36 MPa was observed on the mix containing !00% NA while the lowest value of 31 MPa was obtained on the 100% RA mix. No specific trend could be observed in the other properties investigated. Nonetheless, the results indicate that there are potentials for the use of RA in the manufacture of concrete.

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TECHNICAL PAPER

Folarin T. Olorunsogo

SYNOPSIS

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1.0 INTRODUCTION

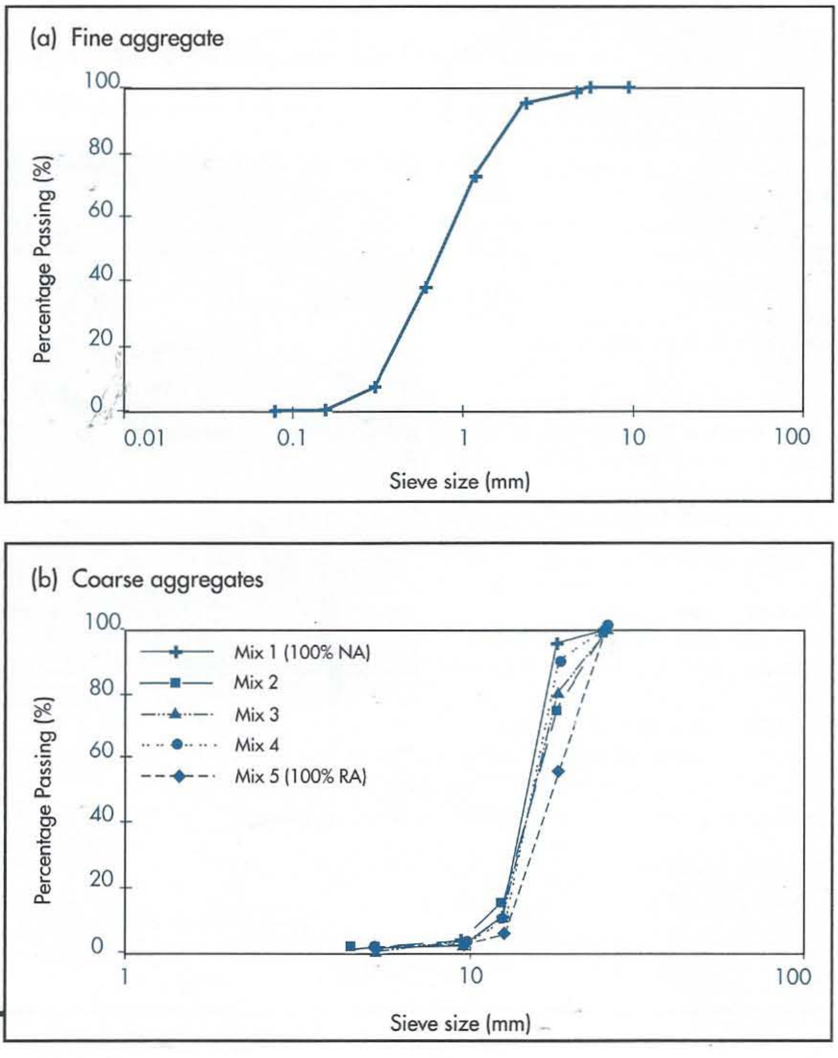
With the ever increasing world population there is a growing need for facilities which in turn require the use of finite natural resources. For this reason, many industries, backed by government's support and regulations, are now looking for ways of re-using materials in manufacture of new products. This process has been in operation for a number of years and the construction industry worldwide is no exception. In Europe and other developed countries, recycling of building materials started about the end of the Word War II when bricks and other materials that were recovered from the ruins of the war were utilised for reconstruction of amenities. Although, in those days, the use of recycled materials in this manner may be regarded as a means of solving an economic problem, recycling as a means of sustainable use of materials did not actually start until fairly recently. In South Africa, very little is known about the use of recycled aggregate in manufacture of concrete. This is probably due to lack of knowledge about the behaviour of the material. Therefore, there is a need to investigate and understand the behaviour of concrete using recycled aggregate (RA) (with or without natural coarse aggregate (NA)) as such material is likely to provide both environmental and economic advantages. In this study, a preliminary investigation has been carried out to quantify properties of concrete made by partially or fully replacing natural coarse aggregate with RA. The properties investigated are workability, compressive strength development, flexural strength and abrasion resistance.

2.0 EXPERIMENTAL DETAILS

2.1 Materials

The materials used in this study are ordinary Portland cement (OPC), natural fine (Umgeni sand) and coarse (crushed granite rock) aggregates with recycled aggregate. All the materials including the recycled aggregate were obtained from local suppliers. The recycled aggregate which was processed to 26.5-mm maximum aggregate size using the conventional method used in preparation of natural coarse aggregate was obtained from concrete and brick recyclers who are situated in Clairwood, Durban. Constituents of the finished recycled aggregate are shown in Table 1. Due to the nature of the original demolished structure it can be seen that the finished product (i.e. recycled aggregate) consists of materials such as dust, mortar, brick and stone/mortar conglomerate. The dust and stone/mortar constituted the lowest (1.9%) and highest (84.6%) proportions respectively. Gradings of the aggregates are shown in Figure 1. Table 2 shows the physical properties of all the aggregates in terms of relative density, moisture content, fineness modulus, compacted and loose bulk densities.

FIGURE 1: GRADINGS OF AGGREGATES



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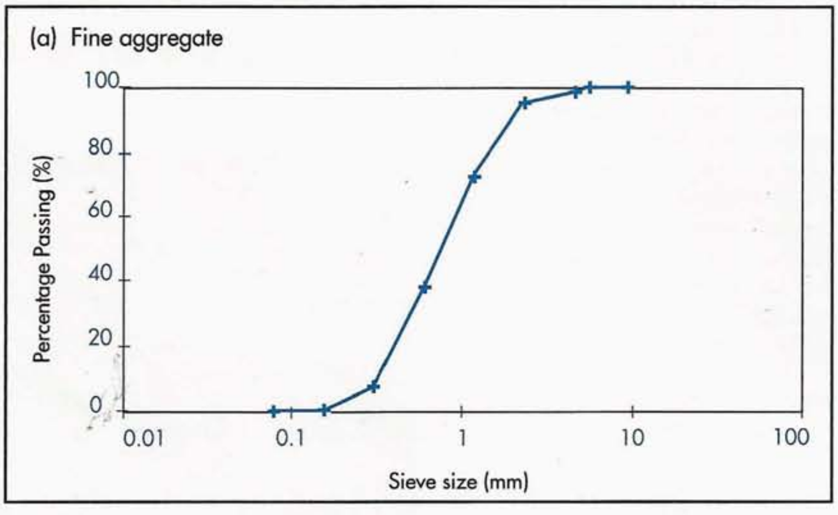


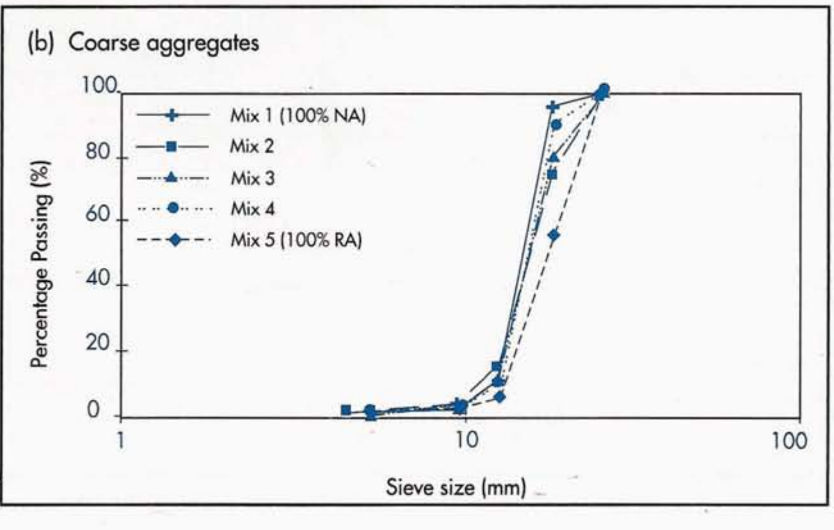


TABLE 1: Constituents of recycled aggregate (% by mass)	
Dust	1.9%
Mortar	7.1%
Brick	6.4%
Stone / Mortar	84.6%

2.2 Mix Design

Five concrete mixes, as shown in Table 3 were prepared. Since, there is no existing standard method of designing concrete mixes incorporating recycled aggregate, the method of mix design proposed by the Cement and Concrete Institute (C&CI) was employed to design a concrete mix containing 100% natural coarse aggregate. The mix was designed to have a 28-day target compressive strength of 30 MPa. The RA mixes were derived simply by partially replacing (by mass) the natural coarse aggregate proportion in the control OPC mix with RA at 30, 50, 70 and 100% replacement levels.

2.3 Testing Procedures

2.3.1 Properties of aggregates

Classification of the constituents of RA was carried out visually after determining the percentage of dust content by sieve analysis. The sieve analysis and determination of fineness modulus of fine aggregates were carried out in accordance with SABS 829(1). Bulk density and relative density of the aggregates were determined using the methods suggested by SABS 845(2) and BS 1377: Part 2(3) respectively.

2.3.2 Properties of concrete

All concrete properties investigated were monitored following standard procedures. Workability, compressive and flexural strengths of the mixes were measured in accordance with the procedures prescribed in SABS Methods 862(4), (861(5) & 863(6)) and BS 1881(7) respectively. Abrasion resistance of the concrete mixes was determined using the method of assessment proposed by C&CI(8).

3.0 RESULTS AND DISCUSSIONS

3.1 Workability

Workability of all mixes (1-5) was studied by carrying out slump tests at 0, 15 and 30 minutes after completion of concrete mixing. Figure 2 shows the results of the slump tests. As expected, it can be seen that, slump values for all mixes decreased with time, with all mixes achieving a nominal slump of 75±25 mm.

The effect of increasing RA at certain proportion on the slump of concrete is shown in Figure 3, which indicates that there was a tendency for improved workability (i.e. increase in slump value) with increasing proportions of RA in the mixes. Mix 5 (100% RA) exhibited 45, 63 and 312% higher slump values than mix 1 (0% RA) at 0, 15 and 30 minutes after mixing respectively. Similar slump improvements for mix 3 (50% RA) were 35, 37 and 188% more than mix 1, respectively.

The results obtained in this study are contrary to the findings of de Vries(9) and di Niro et al.(10). de Vries reported that because of the more angular shape and higher water absorption capacity of RA, total water demands of concrete using RA were higher than those

TABLE 2: Physical properties of aggregates

Type of Aggregate	Relative Density	Moisture Content (%)	Fineness Modulus	Compacted Bulk Density (kg/m³)	Loose Bulk Density (kg/m³)
Natural Fine Aggregate (FA)	2.60	4.53	2.9	1441	1200
Natural Coarse Aggregate (NA)	2.61	5.13	—	1458	1344
Recycled Coarse Aggregate (RA)	2.60	5.32	—	1397	1362

TABLE 3: Mix proportions

Mix No.	Cement (kg/m³)	% of Recycled Aggregate	Fine Aggregate (kg/m³)	Coarse Aggregates (kg/m³)		Water (litre)
				Recycled	Natural	
1	395	0	563	0	1196	198
2	395	30	563	361	835	198
3	395	50	563	598	598	198
4	395	70	563	835	361	198
5	395	100	563	1196	0	198

TABLE 4: Assessment criteria for concrete surfaces subjected to severe conditions[8]

Surface quality classification	Average penetration depth (mm)		
	Wire brush test		Silicon carbide test
	General concrete*	Concrete pavers	
Excellent	< 0.5	< 0.5	< 1.0
Good	0.5 to 1.5	0.5 to 1.0	1.0 to 2.5
Fair	1.5 to 2.0	1.0 to 1.5	2.5 to 3.5
Poor	> 2.0	> 1.5	> 3.5

** Concrete surfaces which have not been treated by delayed trowelling.*

TABLE 5: Comparison of penetration depths with C&CI assessment criteria for concrete surfaces.

Mix	Surface Quality Classification	
	General Concrete	Concrete Pavers
1	Fair	Poor
2	Poor	Poor
3	Fair	Poor
4	Fair	Poor
5	Poor	Poor

without. In their investigation, di Niro et al. observed that an optimum proportion of RA existed which produced significant improvement in workability.

The mixes investigated in the present study contained RA which were relatively more round in shape than the NA. Although, both aggregates had about the same moisture content (5.13% for NA and 5.32% for RA) the water absorption capacity was not determined. The observed tendency for improved workability with increasing proportion of RA may, therefore be explained partially, with the round shape of the RA compared to the more angular shape of the NA. Another factor which may be responsible for the observation made in this study could be the higher percentage of fines and well graded nature of the RA compared to NA as shown in Figure 1 (b).

FIGURE 2: WORKABILITY

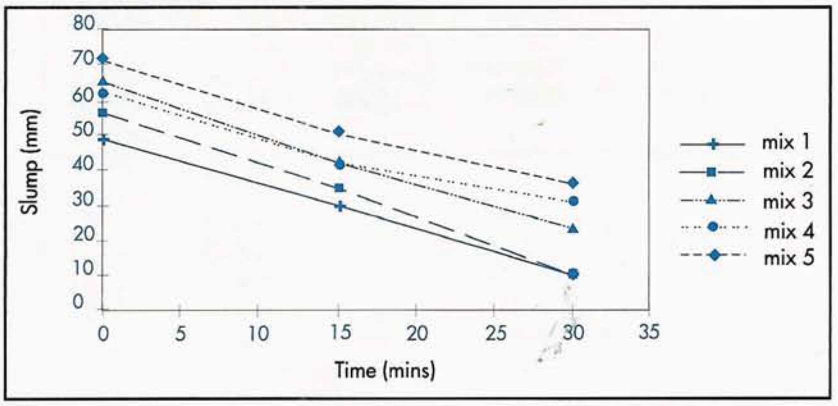
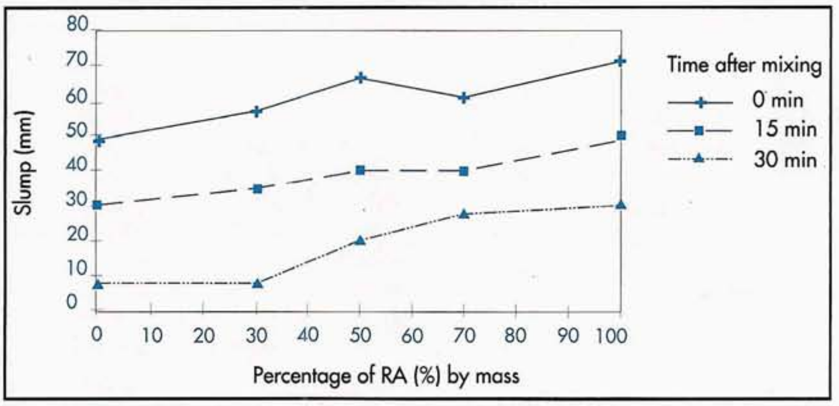


FIGURE 3: EFFECT OF PROPORTION OF RA ON WORKABILITY



3.2 Compressive Strength

Figure 4 shows the compressive strength development of mixes 1-5. All mixes attained the 28-day design target strength of 30 MPa with the highest and lowest strengths associated with mixes 1 (36.0 MPa) and 5 (31.1 MPa) respectively. Mix 3 which contained 50% RA developed a 28-day compressive strength of 33.6 MPa. Considering the effect of proportions of RA used in each mix, (as illustrated in Figure 5) it is observed that there was a tendency for slight reductions in compressive strength the higher the proportion of RA in the mixes at all the ages of testing. This is expected since the RA used in this study contained certain proportions of materials such as dust, mortar and brick which are weaker in strength than the actual stones in the mix. Another reason for reductions in compressive strength with increase in proportions of RA in the mix is probably the smoother texture and rounder shape of the RA used when compared with the NA.

The results obtained in this study are similar to the findings of previous investigators such as di Niro et al.(11) and de Vries(9). di Niro et al. also reported slight decreases in compressive strength with increases in the proportions of RA. They found that of all the replacement levels considered (i.e. 0, 30, 50, 70 and 100% RA) only the 30% RA mix achieved the design target strength of 40 MPa (43 MPa). Comparing the 0% and 100% RA mixes, di Niro et al.(11) and de Vries(9) reported reductions in compressive strengths of up to 20% while in this study the similar value was 14%. With the results of compressive strength reported in this and other studies(9,11,12) it is evident that there is potential for use of RA in production of medium strength concrete. Further study is, however, required to establish the possibility of preparing high performance concrete using RA.

3.3 28-day Flexural Strength

Results of the 28-day flexural strength test are presented in Figure 6. All mixes, except mix 4 (70% RA) which exhibited a flexural strength of 6.25 MPa, attained a minimum flexural strength of 7 MPa at 28 days. There is no specific trend in the relationship between the proportion of RA included in concrete mix and flexural strength. However, the results obtained here on the mixes in which RA were included are comparable with flexural strength of the concrete containing 100% NA. This signifies that, on the basis of flexural strength only, concretes in which RA are included will perform satisfactorily (i.e. to similar standard as achieved by those concretes containing only NA as coarse aggregate).

3.4 Abrasion Resistance

Abrasion resistance is the ability of a concrete element to resist wear which may arise as a consequence of attrition by sliding, scraping or percussion(13). Evaluation of concrete resistance to abrasion is somewhat difficult since the destructive action differs depending on the nature of the actual cause(s) of the wear. In this study, the wire brush method of assessment proposed by C&CI(8) was employed to evaluate abrasion resistance of all the mixes investigated at 28 days. The results obtained are shown in Figure 7. Mixes 3 and 4, which contained 50 and 70% RA respectively performed the best with penetration depths of 1.60 mm and 1.61 mm respectively, followed by mix 1 (0% RA) which had a penetration depth of 1.85 mm. The poorest performance in terms of ability to resist abrasion was recorded for mixes 2 (2.26 mm) and 5 (2.25 mm) with RA contents of 30% and 100% respectively. As can be seen in Figure 7, there is no clear relationship between abrasion resistance and proportion of RA included in the mixes.

Using the performance criteria for concrete surfaces subjected to severe conditions as suggested by C&CI(8) (see Table 4), the abrasion resistance of mixes 1-5 has been graded as shown in Table 5. From the table, it is seen that all the mixes, including the 100% NA

FIGURE 4: COMPRESSIVE STRENGTH DEVELOPMENT

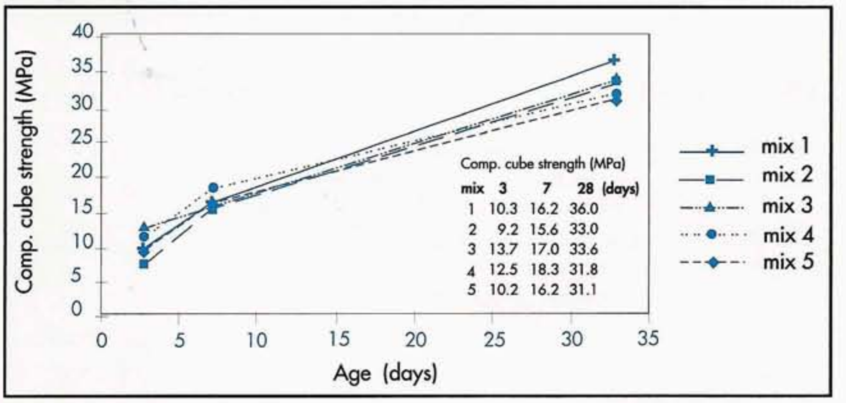


FIGURE 5: EFFECT OF PROPORTION OF RA ON COMPRESSIVE STRENGTH

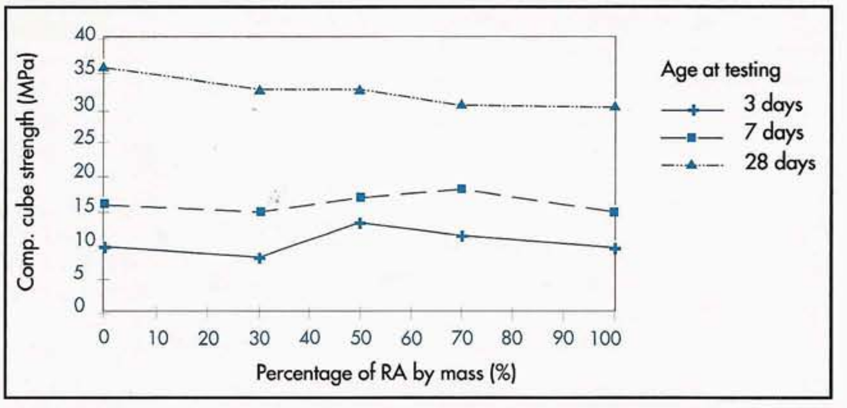


FIGURE 6: FLEXURAL STRENGTH AT 28 DAYS

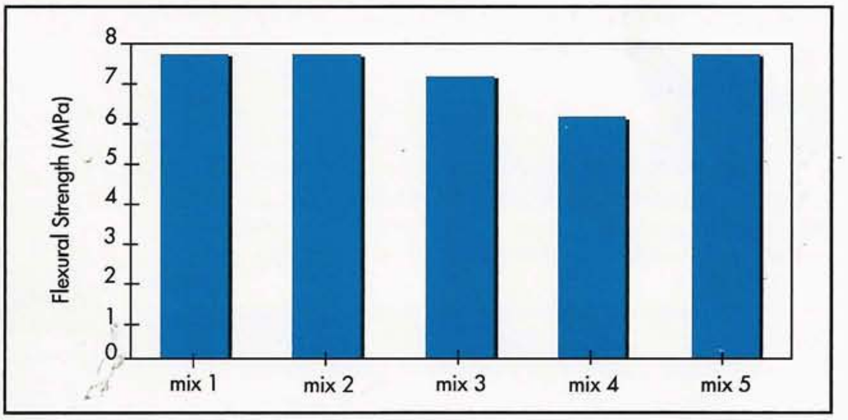
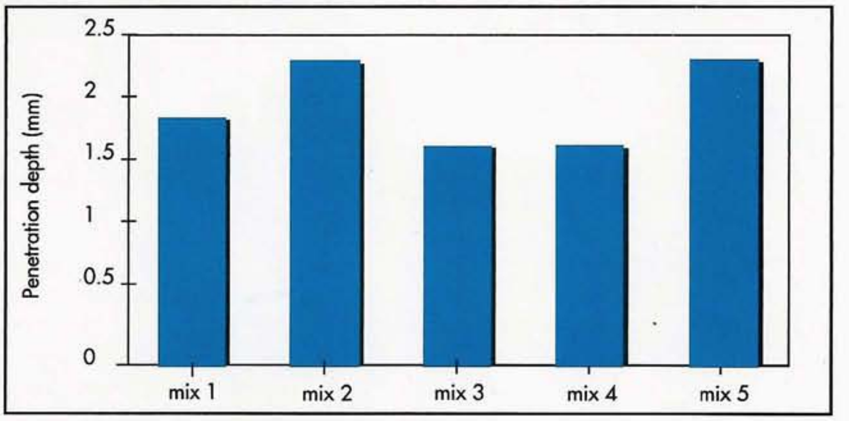


FIGURE 7: ABRASION RESISTANCE



mix, are not suitable for use in concrete pavements but may be used in ordinary concrete applications where abrasion is of little significance; such as domestic garages, driveways and pathways. According to C&CI, concretes with penetration depths greater than 1.5 mm are not suitable for use in concrete pavements. It should be noted, however, that there is a tendency for low strength concrete mixes to exhibit poor resistance to abrasion(14). As the concrete mixes in this work were designed to have a 28-day compressive strength of 30 MPa, it does not necessarily follow that concrete in which RA is included is not always suitable for use in severe conditions. Further tests are currently being carried out to evaluate the behaviour (including abrasion resistance) of high performance concrete which are made with RA.

4.0 CONCLUSIONS

Inclusion of recycled aggregate led to improvement in workability and reductions in compressive strength of concrete mixes. The reasons for this are attributed to the relatively round shape of, and higher percentage of fine particles in the recycled aggregate compared to natural coarse aggregate.

As for the other properties (i.e. flexural strength and abrasion resistance) investigated, no distinct relationship could be established between any of the properties and proportion of recycled aggregate in concrete mixes. Nevertheless, the results indicated that the performance of mixes incorporating recycled aggregates is comparable to the concrete mix in which 100% natural coarse aggregate was used.

From the results obtained in this study there are potentials for use of recycled aggregate in manufacture of concrete. However, clearly, further research must be carried out in order to fully quantify and understand the behaviour of recycled aggregate concrete.

ACKNOWLEDGEMENTS

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Fola Olorunsogo lectures and carries out research in Concrete Structures and Materials at the University of Durban-Westville. Before now he was engaged in research activities in Structural Engineering and Concrete Technology at the Universities of Sussex and Leeds, both in the UK. He spent a brief period in industry with Pell Frischmann Consultants also in the UK as an Engineer. Afterwards, he went to Obafemi Awolowo University, Ile-Ife, Nigeria, where he lectured and was the Chairman of the Civil Engineering Department.

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