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Short term durability of recycled coarse aggregate concrete – the influence of calcium sulphate on compressive strength

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ABSTRACT: *The work reported herein forms part of a preliminary investigation in the Republic of Botswana into the issue of durability of recycled coarse aggregate concrete (RCAC). Towards this end, recycled coarse aggregate (RCA) obtained from laboratory stockpile of crushed and uncrushed cubes and beams which had been manufactured earlier using broken kerb stones at the University of Botswana Academic Hospital construction site, was utilized for the production of six different concrete mixes. For these mixes, the ratio of RCA to the total aggregate was varied in the proportion 0%, 20%, 40%, 60%, 80% and 100%. All manufactured specimens were cured using clean potable water on one hand, as well as water containing 5% calcium sulphate in solution on the other hand, for comparative purpose. The compressive strength of the concrete was assessed after 3, 7, 14, 21 and 28 days.It was found that in general an increase in the RCA replacement level led to a decrease in the compressive strength. Furthermore the specimens cured in clean potable water had higher compressive strengths than those cured in acqueous solution containing 5% cxalcium sulphate in practically all cases ; an exception to this however was at the 40% and 60% RCA replacement levels at 7 days. It was concluded that calcium sulphate had an influence on the compressive strength of RCAC, though not at all RCA ratios and ages of curing.*

KEYWORDS –*Coarse aggregate,compressive strength,concrete, durability, recycled*

I. INTRODUCTION

It is widely recognized at present that there is an urgent need for satisfactory environmental management of construction waste materials like gravel, stone, sand, wood, etc. This is largely due to the stark reality of the marked depletion of the earth's non-renewable natural resources. Coupled with this has been the slow response of putting in place adequate sustainability measures to address the problem. This is particularly true in developing or third world countries where in addition, the irresponsible disposal of solid wastes and wanton proliferation of landfills have constituted standard practice up until recent times (Gumede & Franklin, 2015).

A major proportion of the solid wastes is concrete, which is arguably the most widely used construction material (Oikonomou, 2015) and has played a significant role in the economic well-being of several nations scattered round the globe. Fortunately as noted by Franklin and Gumede (2014), construction and demolition wastes such as concrete could be recycled and the resulting aggregates used in new concrete production. Consequently with proper planning and the adoption of such procedures as recycling, the quantity of wastes earmarked for landfills could be minimized, thus aiding in the conservation of the earth's natural resources as well as ensuring the protection of the environment.

There have been several investigations reported in the literature on the use of recycled aggregates in concrete. Notable amongst these are the researches of Katz (2003), Rao et al. (2007), Rakshvir and Barai (2006), Wagih et al. (2012), etc. The main thrusts of these studies have been the compressive, flexural and split tensile strengths as well as the modulus of elasticity of recycled aggregate concrete; a useful summary of these findings has been given by de Brito and Saikia (2013). It is evident that the mechanical properties of recycled aggregate concrete (RAC) compared to natural aggregate concrete (NAC) are somewhat dependent on the source and type of the recycled coarse aggregate utilized. Another fact worth mentioning here is that the major proportion of research has been on the use of recycled coarse aggregate replacing natural coarse aggregate in concrete production.

Research on the use of recycled fine aggregate has been reported by Khatib (2005), Evangelista and de Brito (2010), Yaprak et al. (2011), Fan et al. (2015), Ashiquzzaman and Hossen (2013) and Franklin and Maroba (2016).However these latter investigations in contrast to the use of recycled coarse aggregate are relatively sparse, due to the high water absorption ratios in recycled fine aggregate concretewhich gives rise to poorer performance in respect of mechanical properties and durability (Fan et al., 2015). For this reason in particular, while the use of recycled coarse aggregate concrete has been encouraged in several countries, the use of recycled fine aggregate concrete has not been so favoured.

The use of recycled coarse aggregate concrete for low grade or low risk applications has been generally accepted on account of the large volume of research that has been carried out in respect of its physical and mechanical properties. However with reference to durability of recycled coarse aggregate concrete in aggressive environments, additional studies need to be carried out if this material is to find wider implementation particularly in structural applications (Said et al., 2017). Furthermore on account of the heterogeneity of recycled aggregates, water-cement ratios and types of cement used, comparison of results found in the literature is rather difficult (Thomas et al., 2013).

Previous studies on the durability of recycled coarse aggregate concrete (RCAC) have been reported by Sagoe-Crentsil et al. (2002), Fung (2005), Tam & Tam (2007), Thomas et al. (2013), Jimenez & Moreno (2015), Said et al. (2017) and Guo et al. (2018). The focus of these investigations taken together has been on the deformation and permeability characteristics, performance levels for both short term and long term, resistance to carbonation and chloride penetration, resistance to reinforcement corrosion, fire resistance, alkali-silica reaction, freeze-thaw resistance and sulphate attack. Regarding the influence of sulphate attack on the mechanical properties of recycled aggregate concrete however, there is relatively little information in the literature. Arafa et al. (2017) investigated the effect of magnesium sulphate ($MgSO_4$) solution on the compressive strength. Different concentrations (6% and 9%) of $MgSO_4$ solution were used for 30, 60 and 90 days immersion of cured RCAC specimens. In all cases there was a consistent decrease in compressive strength as the period of immersion as well as the $MgSO_4$concentration increased.

The present study seeks to supplement the available information on the effect of sulphates on the mechanical properties of RCAC. However for the study, 5% calcium sulphate ($CaSO_4$) in solution has been utilized. It is felt that this limit represents a reasonable estimate to what may be expected to exist in practice

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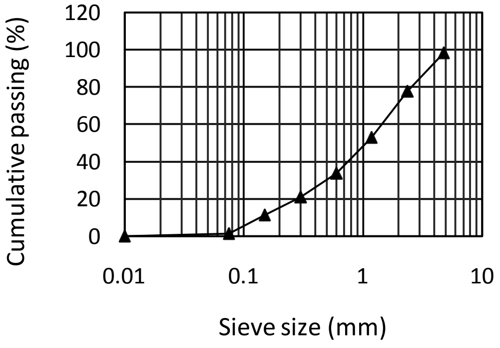
II. METHODOLOGY

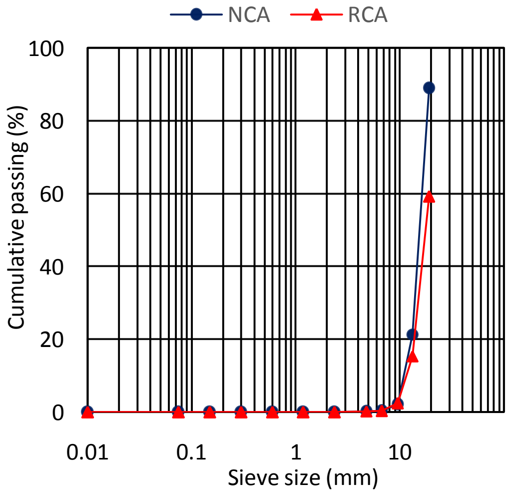
2.1 Materials, mix proportions and casting

Locally available river sand passing through a 4.75 mm sieve and possessing a fineness modulus of 3.04 was utilized as natural fine aggregate (NFA). Dolomite natural coarse aggregate (NCA) obtained from a local quarry at Belabela with maximum nominal size of 19 mm was employed. The recycled coarse aggregate (RCA) was obtained from the Civil Engineering Structures Laboratory stockpile of crushed and uncrushed cubes and beams which had all been produced from identical concrete mixes for an earlier unrelated study. The consignment of cubes and beams was processed in a crusher with maximum jaw width of 19 mm, and ultimately sieved. The fraction between 4.75 mm and 19 mm was used as the RCA. The particle size distributions for the fine aggregate, the NCA and RCA are shown in Fig. 1.The fine aggregates are well graded; the recycled coarse aggregates fall almost exclusively within the 9.5 mm and 19 mm sieve sizes.

The cement used was Ordinary Portland Cement CEM I 42.5N manufactured to SANS 50197-1/EN 197-1. The mix design method was essentially based on the Portland Cement Institute procedures described by Owens (2009) supplemented by recommendations given in SANS 2001-CC2. Mixing was carried out using a laboratory batch mixer which had the advantage of preventing loss of water or material. The concrete mixes were prepared with a water-cement (w/c) ratio of 0.5 and the selected characteristic strength was 30 MPa at 28 days. Tap water having a pH value of approximately 7.0 and free from impurities was used for manufacture of fresh concrete. Six different mixes were produced because the natural coarse aggregates were substituted with 0%, 20%, 40%, 60%, 80% and 100% recycled coarse aggregates in that progression. For each mix, thirty 150 mm cubes were cast; these were then covered with polythene sheets shortly after manufacture for 24 hours. Afterwards one-half of the concrete specimens were cured in a regulated water bath and the remaining one-half were cured in water containing 5% calcium sulphate in solution. Details of the mix proportions employed are shown in Table 1.



(a)



(b)

Fig. 1. Particle size distribution of (a) natural fine aggregate, (b) natural and recycled coarse aggregates

Table 1: Mix quantities for 1 m^3 fresh concrete

Mix type	Cem. (kg)	NFA (kg)	NCA (kg)	RCA (kg)	Water (kg)
RC-0	420	873	819	0	210
RC20	420	873	655	164	210
RC40	420	873	419	328	210
RC60	420	873	328	419	210
RC80	420	873	164	655	210
RC100	420	873	0	819	210

2.2 Testing procedures

Slump tests were carried out in accordance with ASTM C 143 standard (2012) for the six different concrete mixes in order to assess the consistency and workability.The slump test gives a good measure of the mobility and stability of the concrete.Here the freshly made concrete is placed in three successive layers in an open-ended sheet metal mould shaped like a truncated cone. Every layer is then tamped 25 times with a standard rod and the mould is then carefully lifted vertically. The reduction in height between the original and the displaced position of the centre of the top surface of the concrete is taken as the slump.

Compression tests were also conducted in accordance with BS 1881-108:1983. Three 150 mm cubes were subjected to loading at 3, 7, 14, 21 and 28 days. The loading was applied at constant rate up until failure. This procedure was carried out for all specimens cured in clean potable water as well as those cured in water containing 5% calcium sulphate in solution. In general for all cases, the compressive strength was taken as the average value of the three cube test results.

III. RESULTS AND DISCUSSION

3.1 Slump tests of fresh concrete

The results of the slump tests are shown in Fig. 2. It is apparent that there is a progressive decrease in slump with increase in the RCA content. For the range 20% – 100% RCA content, there was a corresponding slump reduction of 22.9% – 57.1%. These results are in very close agreement with those of Gumede and Franklin (2015). It would appear that increased inter-particle friction between angular shaped particles with increment in RCA content together with the greater surface area for angular particles is a patent or logical explanation here, as noted by Ngwenya & Franklin (2015) and Patil et al. (2013).

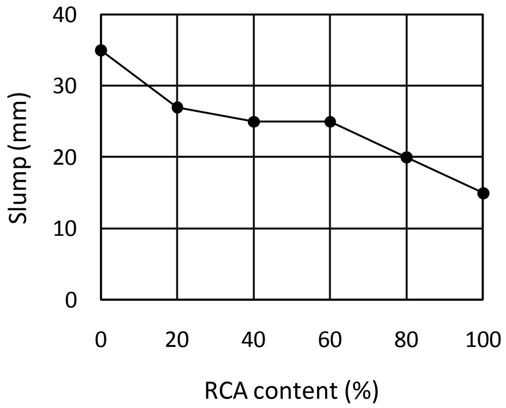


Fig. 2. Relationshipof slumpto RCA content

3.2 Compressive strength

The results of the compressive strength tests are shown in Figs. 3 to 9for the different RCA replacement levels of 0%, 20%, 40%, 60%, 80% and 100%. It is apparent from Figs. 3 and 4 that the compressive strength for all specimens increased with age. This is true regardless of whether the test cubes were cured in potable water or cured in an acqueous solution containing 5% calcium sulphate. From Figs. 5 to 9, it should be noted that the compressive strength is influenced by the level of RCA replacement of natural coarse aggregates. More specifically, as the relative amount of recycled coarse aggregate is increased, the compressive strength of the concrete reduces, regardless of the mode of curing of the specimens. The reduction is most significant at the 100% RCA content.

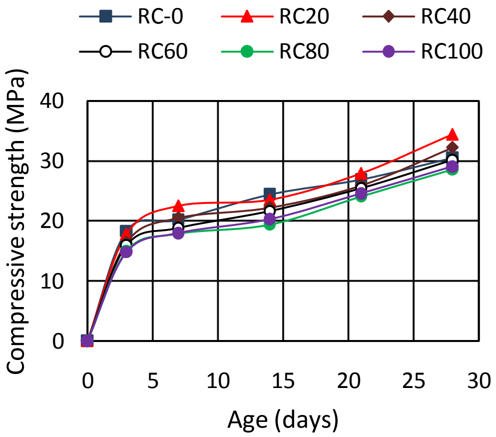


Fig. 3. Compressive strength at various ages for curing in potable water

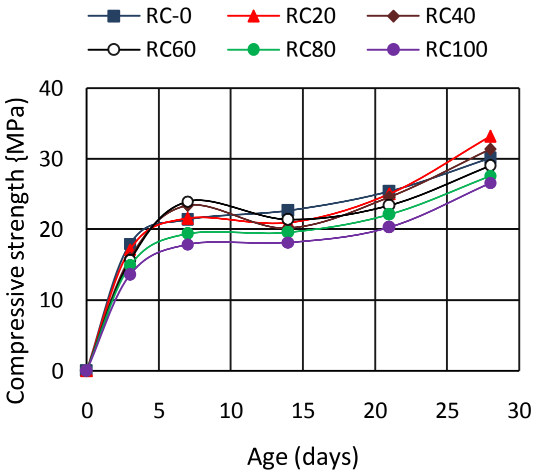


Fig. 4. Compressive strength at various ages for curing in calcium sulphate solution

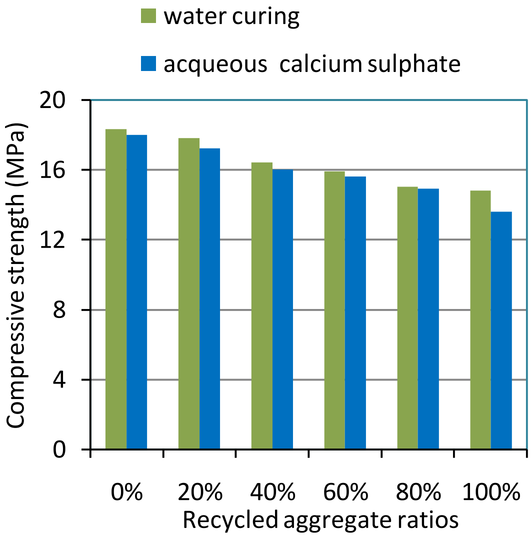


Fig. 5. Compressive strengths for different RCA contents at age 3 days

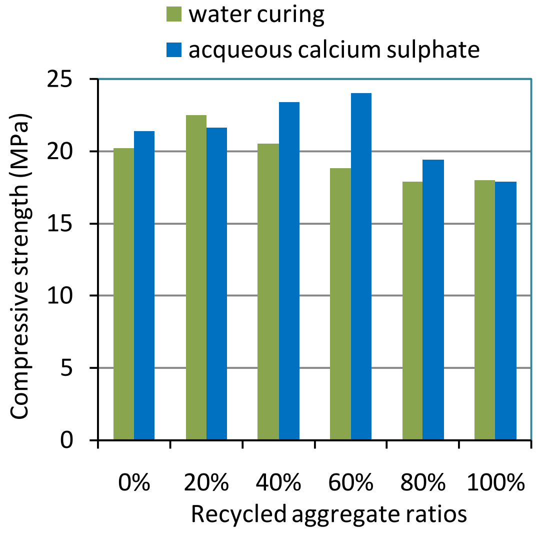


Fig. 6. Compressive strengths for different RCA contents at age 7 days

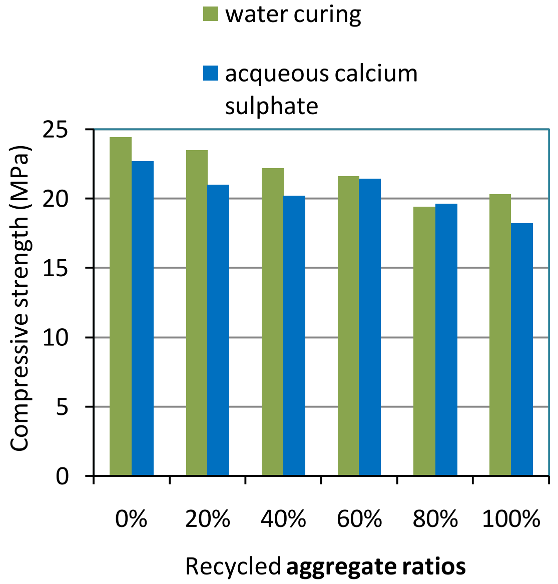


Fig. 7. Compressive strengths for different RCA contents at age 14 days

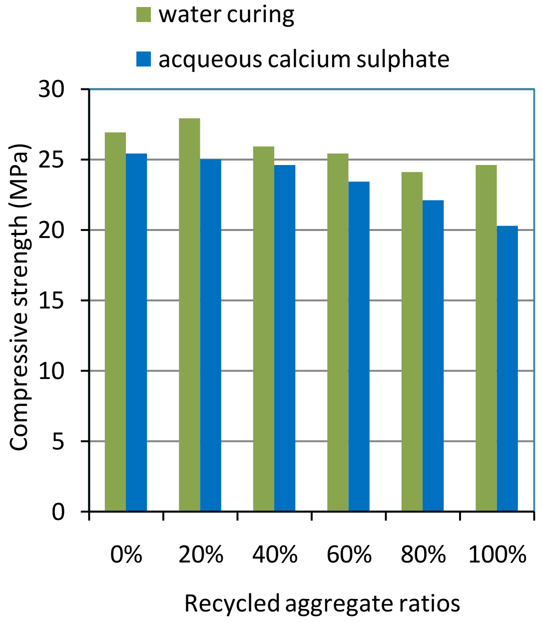


Fig. 8. Compressive strengthsfor different RCA contents at age 21 days

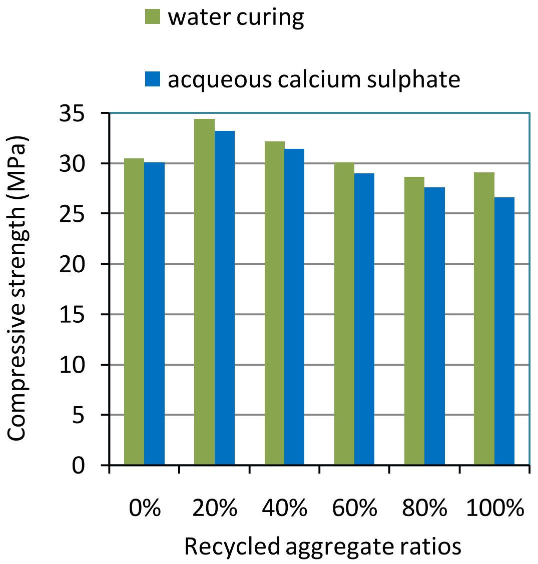


Fig. 9. Compressive strengths for different RCA contents at age 28 days

All specimens cured in clean potable water produced higher compressive strengths than those cubes cured in 5% calcium sulphate acqueous solution in practically all cases. However a notable exception to this was at the 40% and 60% RCA replacement levels at 7 days for which the specimens cured in calcium sulphate acqueous solution produced strengths of 23.4 MPa and 24

MPa respectively. These values are higher than those for cubes cured in potable water only – 20.5 MPa and 18.8 MPa for the 40% and 60% RCA contents respectively. Compared to the specimens cured in potable water, the reduction in compressive strength at 28 days for specimens cured in the 5% calcium sulphate acqueous solution ranged from 1.3% to 8.6% for RCA replacement ratios between 0% and 100% respectively. Hence from the foregoing it may be safely concluded that calcium sulphate has an influence on the compressive strength of recycled coarse aggregate concrete in general, although not at all RCA ratios nor ages of curing.

IV. CONCLUSIONS

The problem of durability of recycled coarse aggregate concrete is one of on-going interest. In the present study an attempt has been made to assess the influence of calcium sulphate on the compressive strength of RCAC. Based on the experimental investigation reported herein, a number of conclusions have been drawn. Firstly there is a progressive decrease in slump with increase in the RCA content; more specifically, the workability of the fresh RCAC mixes is lower than that of the NCA concrete mixes. Secondly the compressive strength of the concrete reduces as the relative amount of RCA is increased, irrespective of the mode of curing of the concrete. Thirdly test specimens cured in 5% calcium sulphate acqueous solution generally had lower strengths than those cured in potable water at 28 days; the reduction ranges from 1.3% – 8.6% for corresponding RCA contents in the range 0% – 100%. However at 7 days for RCA contents of 40% and 60%, concrete cured in calcium sulphate acqueous solution had significantly higher strengths (14.1% and 27.7% respectively) than concrete cured in potable water. Hence while curing in calcium sulphate solution generally results in a decrease in compressive strength at 28 days, such reductions are not always true for all RCA ratios and ages of curing.

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