Short-Term Mechanical Properties Of Recycled Coarse Aggregate Concrete

Part A: Compressive Strength

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***Abstract*—This study forms part of a broader investigation into the utilization of recycled coarse aggregate in civil engineering. In the current work, coarse stones obtained from mortar bricks sourced locally were used to replace natural aggregates in proportions of 0%, 20%, 40%, 60%, 80% and 100%, for the production of concrete. Compressive strength tests were conducted on the manufactured specimens after 3, 7, 10, 14 and 21 days of curing. The results demonstrated that the compressive strength of all specimens increased in proportion to the number of days cured, but reduced with an increase in the recycled coarse aggregate (RCA) fraction. Notwithstanding, all specimens ultimately reached the targeted compressive strength. In addition the 0% and 20% RCA fractions had broadly similar compressive strengths for all curing days. Furthermore equations were proposed for the estimation of strengths of RCA fractions in the longer term, that is, at 42 and 56 curing days.**

Keywords—Recycled; coarse; aggregates; fraction; compressive; strength

I. INTRODUCTION

The problem of concrete and its production is a pervasive one. Not only is concrete used in the majority of buildings and structures that are in existence globally at present, but in addition its production utilizes vast amounts of the earth's raw materials. When the design life of such buildings or infrastructures has been exceeded and the need for demolition arises, this has constituted a further problem since it has all too often led to environmental degradation and indiscriminate dumping of demolished wastes in both designated landfills and unauthorized areas. Recycled concrete aggregates (RCA) used effectively assist in minimizing the afore-mentioned issues to an extent, since a major portion of the demolished waste can be re-used in new concrete production, or more accurately, as recycled aggregate concrete. Also in broad terms, unprocessed recycled aggregates may be employed for bulk fills, embankment protection, drainage structures as base or fill, road construction and noise barriers. With reference to the adoption of recycled aggregate concrete for new constructions, the emphasis has been on the use of coarse recycled aggregates as replacement for coarse natural aggregates in concrete manufacture. The adoption of fine recycled aggregates in lieu of fine natural aggregates has not been generally favoured due to the greater porosity of the former, which gives rise to higher water absorption ratios and consequently poorer performance in relation to mechanical strength and durability [1].

The mechanical properties of recycled coarse aggregate concrete (RCAC) has been the subject of numerous reviews. However it should be noted here that although the tensile, flexural and impact strengths of such concretes are of great interest, it is the compressive strength that constitutes the pre-eminent mechanical characteristic and hence has naturally received a greater deal of attention from previous investigators. Studies on the compressive strength include those of [2]–[10], amongst others. There is broad agreement that the compressive strength decreases roughly proportionately with increase in percentage RCA replacement levels. There is also some unanimity that the quantity of adhering mortar has significant influence on the compressive strength of the resulting concrete as it could give rise to further areas of weak bonds in the recycled aggregates.

Within the context of the Southern African sub-continent and more specifically the Republic of Botswana, there has been relatively few investigations carried out on RCA based on aggregates sourced locally. It is with the foregoing in mind that the present study has been executed. It forms part of a broader investigation into the mechanical characteristics of recycled aggregate (primarily coarse) concrete being conducted at the University of Botswana [11]. However unlike a number of previous studies, it is the early age compressive strength of RCAC that is of special interest. On account of the widespread use and consequent proliferation of mortar bricks as construction wastes on numerous building sites, coarse aggregates extracted from such bricks have been employed as recycled aggregates for concrete production in the present investigation.

II. EXPERIMENTAL PROCEDURES

A. *Materials, mix proportioning and casting*

Ordinary Portland cement of specification 52.5 N, manufactured by PPC Ltd. was used for the study. This cement is ideal for a broad range of applications in the building, construction, ready-mix, pre-mix and concrete products manufacturing industries. It has initial and final setting times of 170 and 250 minutes respectively, a specific area (Blaine) of 400m^2/kg, and compressive strengths at 2 and 28 days of 28 MPa and 58 MPa respectively. Also it has a relative density of 3.14 and soundness (Le Chatelier expansion) of 1.0 mm. Crushed fine aggregates passing a 4.75 mm sieve and possessing a fineness modulus of 3.12 and specific gravity of 2.34 was employed. This stone dust had a greyish black colour when dry, but appeared slightly reddish when wet. The natural coarse aggregates were obtained locally from Kgale Quarries. These were aggregates passing through a 19 mm aperture sieve and came from granite rock. They had a specific gravity of 2.64 and a fineness modulus of 2.59. Samples of the dry stone fine aggregate and natural granite coarse aggregate are shown in Figs. 1 and 2 respectively.

For the recycled coarse aggregates, mortar bricks were acquired locally from Babirwa Bricks Industry and crushed using a hammer to reduce them to smaller sizes. Subsequently, a crushing machine was employed to reduce the materials sizes even further. The stones were all collected and sorted from the other mortar pieces by grading using sieves and a vibrating machine. Aggregates that passed through the 19 mm sieve but were retained by the 13.2 mm sieve were collected. These mortar stones served as the recycled coarse aggregates for the mix. They were used to replace the natural coarse aggregates in fractions of 20%, 40%, 60%, 80% and 100%. Samples of the recycled coarse aggregates are shown in Fig. 3.

Fig. 1: Dry stone dust fine aggregate

Fig. 2: Natural granite coarse aggregate

Fig. 3: Graded recycled coarse aggregate

The mix design method adopted was that specified in the Department of Environment (DoE) revised procedure as described by [12]. Required information such as that from the sieve analysis of both coarse and fine aggregates was used in order to find the proportions of the concrete ingredients. Preliminary slump testing was also initiated in order to determine an acceptable mix for these proportions. The specification was for a characteristic compressive strength at 28 days of 50 MPa and a slump range of 30–60 mm. Due to the porous nature of mortar coarse aggregates, the water-cement ratio of every mix had to be adjusted in order to supplement the water that would be absorbed by the recycled coarse aggregates. From absorption tests carried out, the percentage absorption of water was found on average to be 7 % and the water-cement ratio was revised accordingly. Six different concrete mixes corresponding to the different RCA fractions were employed. For the control mix representing an RCA replacement fraction of 0%, a water-cement ratio of 0.47 was adopted. The cementitious materials, fine and natural coarse aggregates were kept constant at 447 kg/m^3, 662 kg/m^3 and 1081 kg/m^3 respectively representing a concrete mix ratio of 1:1.48:2.42 in proportion of cement, fine and coarse aggregates. However for the remaining five RCAC mixes, the water-cement ratios, the cement content and the fine aggregate content were kept constant at 0.5, 447 kg/m^3 and 662 kg/m^3 respectively. In the 20 % RCA replacement mix, the natural coarse aggregate (NCA) and the recycled coarse aggregate contents were 865 kg/m^3 and 216 kg/m^3 respectively. For the 40 % RCA replacement mix, the NCA and RCA contents were 649 kg/m^3 and 432 kg/m^3 respectively. These values were progressively adjusted for increasing RCA replacement fractions. For the 100 % RCA replacement mix, the NCA and RCA contents were 0 kg/m^3 and 1081 kg/m^3 respectively.

A total of seventy two (72) cubes of 100 mm sizes were cast for the compressive strength tests, in addition to thirty-six (36) beams of dimensions 100 mm x 100 mm x 400 mm for a complimentary investigation. The moulds for all specimens were provided by laboratory staff; all cast specimens were vibrated by means of a vibrating table and subsequently covered with wet hessian and translucent plastic sheets for 24 hours. They were then de-moulded and placed in a constant temperature curing bath for a total of 3, 7, 10, 14 or 21 days as required, prior to testing.

B. Testing methods

The tests on hardened concrete specimens were carried out at 3, 7, 10, 14, and 21 days after curing, for each recycled coarse aggregate replacement fraction. An Amsler compression test machine was utilized for this purpose, loading being applied at a constant rate of 0.3 ± 0.1 MPa until specimen failure. The procedures were done in accordance with the South African standards SANS 5863: 2006 [13]. Any unusual behaviour of the test pieces during crushing was noted and analyzed afterwards. The compressive strength test set-up is shown in Fig. 4. The hardened beams for a complimentary investigation to the work reported herein were subjected to impact testing. However, no further details of this latter study will be presented subsequently.

Fig. 4: Compressive strength test

III. RESULTS AND DISCUSSION

Compressive strength test results were determined at 3, 7, 10, 14, and 21 days for all replacement fractions. Average values were calculated and used in the current study. The variations of average compressive strength with the recycled coarse aggregate fraction for the specified curing days are shown in Figs. 5 to 7. Also indicated in each graph is the corresponding trend line and its equation. It is obvious that for all specified days, the compressive strengths of the specimens decrease as the replacement fraction of recycled coarse aggregates increases. This decrease is approximately linear, as previously confirmed by [7, 9, and 10]. In Fig. 8 the variation of compressive strength with number of curing days is shown. As expected, in all cases in general, the compressive strengths of the specimens increase as the number of curing days increased. Also it is apparent that the compressive strengths of the specimens with the 20 % replacement fraction are very close to those of the control samples, or 0 % replacement fraction. Furthermore a comparison of the 0 % and 100 % RCA fractions in respect of the variation of the compressive strengths with curing days reveals that there is a significant difference in strengths between the two RCA fractions. It is interesting that these differences are approximately constant up until the 14 days of curing. The differences are 22.9 MPa, 23.7 MPa, 22.8 MPa, and 21 MPa for 3, 7, 10, and 14 curing days respectively. These translate to 75 %, 70 %, 62 %, and 55 % for the curing days listed in that order. However at the 21 curing days, this difference had reduced considerably to 16 %. A close examination of Fig. 8 additionally reveals that irrespective of the percentage replacement fraction for the RCA specimens, they all attained the target compressive strength of 50 MPa, by 21 days of curing. Consequently in practical situations, admixtures could be used to accelerate the hydration of RCAC mixes.

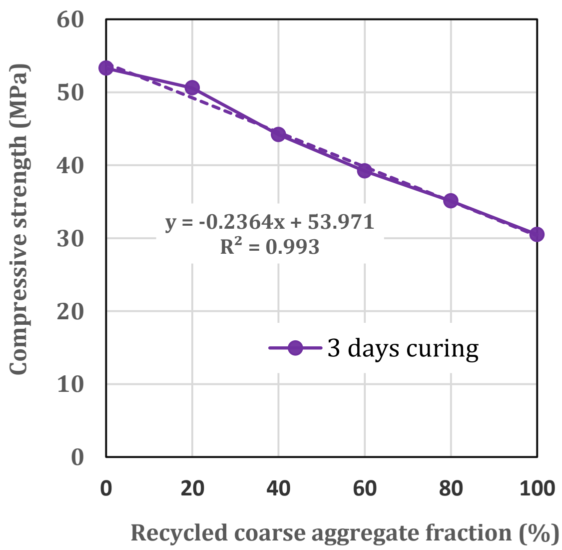

Fig. 5: Variation of compressive strength with recycled coarse aggregate fraction for 3 days of curing

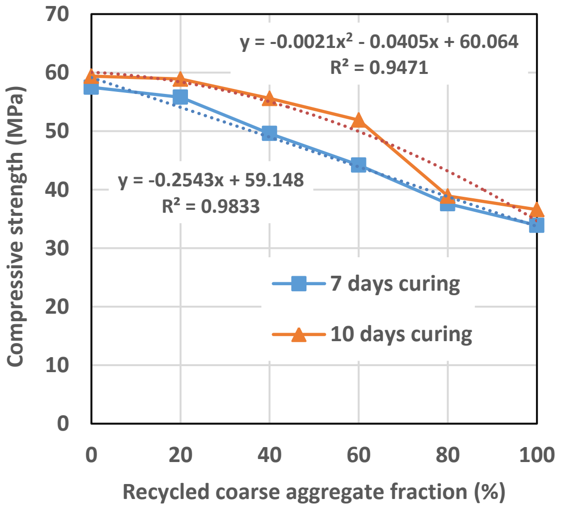

Fig. 6: Variation of compressive strength with recycled coarse aggregate fraction for 7 and 10 days of curing

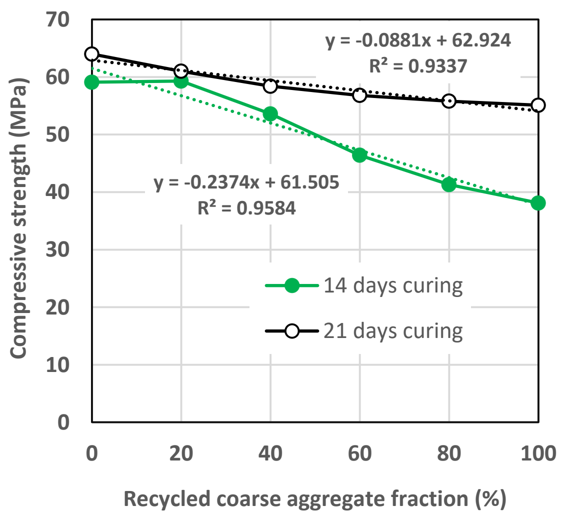

Fig. 7: Variation of compressive strength with recycled coarse aggregate fraction for 14 and 21 days of curing

The preceding findings suggest that when the recycled coarse aggregates are added in the mix, the compressive strength is compromised as a result. This reduction in strength has been demonstrated by previous investigators to be the consequence of the difference in strength between the natural coarse aggregate and the RCA. In the present study the natural coarse aggregate was obtained from crushed granite rock whereas the RCA on the other hand came from crushed mortar bricks. The type of coarse aggregate obviously has an effect on the compressive strength of concrete. This has been noted by [14, 15, 16 and 17] amongst others. They suggested that the variability of the type of coarse aggregates used had an effect on the nature of the concrete produced. The variously formed concrete would have different strengths and general performances. In the present study the mortar formed recycled coarse aggregates would have weaker bonds than the natural granite coarse aggregates, and this would lead to a gradual decrease in compressive strength as the percentage RCA fraction increased in the mix.

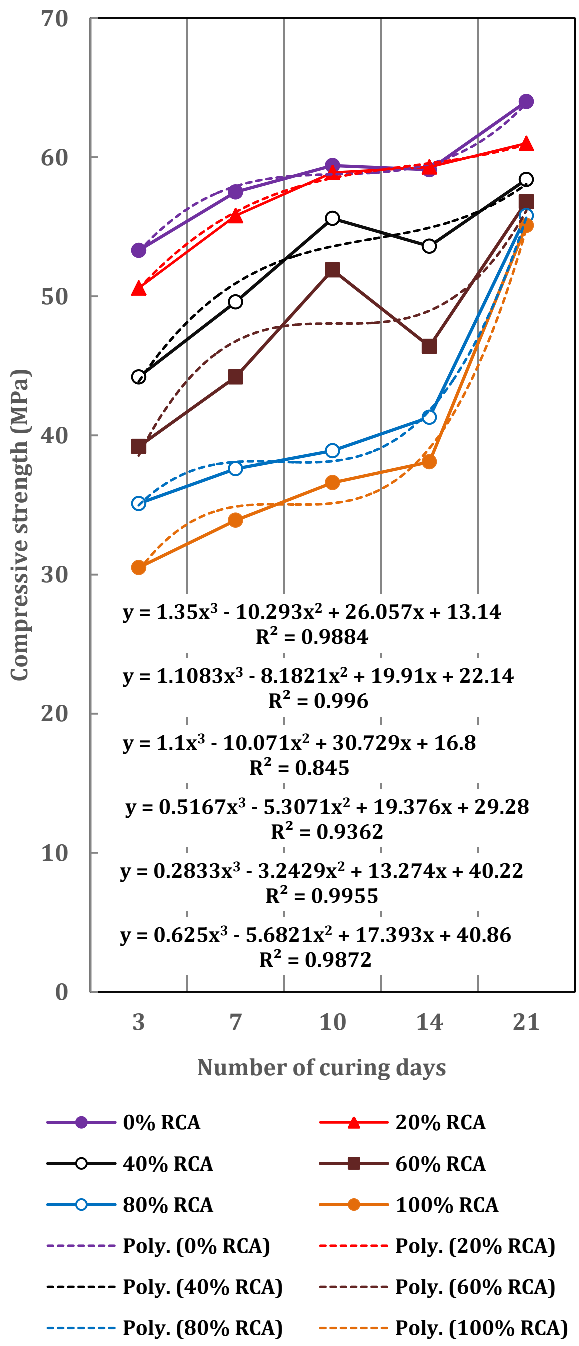

Fig. 8: Variation of compressive strength with number of curing days

In Fig. 8 the trend lines have been indicated alongside the variation of compressive strength with number of curing days. These trend lines are polynomial equations, and the coefficients of correlation R^2 for the whole spectrum of tests range from 0.845 (for the 60 % RCA fraction only) to 0.996. In fact for all the other RCA fractions, R^2 ranges from 0.936 to 0.996. These values demonstrate to a large degree the trustworthiness of the estimated strengths. The compressive strengths of the recycled coarse aggregate concrete at 28, 42 and 56 days can therefore be estimated from the results of the short-term mechanical characteristics. .

IV. CONCLUSIONS

The work in the present study was executed in order to determine the short-term compressive strength of recycled coarse aggregate concretes containing different percentages of RCAs used as a replacement for natural coarse aggregates in the concrete mix. The compressive strengths were assessed after curing at 3, 7, 10, 14 and 21 days. The RCA in addition to the NCA were secured locally. Based on the investigations carried out, the following conclusions have been drawn.

1. The compressive strengths of the recycled coarse aggregate concretes reduced with increase in the percentage of RCA present in the mix. This reduction was approximately linear for all fractions of RCA used.
2. Recycled coarse aggregate concretes containing 20% RCA replacement fractions yielded comparable compressive strengths to the control values, or, to those specimens containing 100 % natural coarse aggregates. It is therefore safe to conclude that the most feasible replacement rate that may be employed using recycled construction rubble is 20 % RCA from mortar bricks.
3. Although all RCA concrete specimens took a while to reach the target compressive strength of 50 MPa, they all eventually did by the 21 days curing time. This implies that in practice the rate of hydration could be quickened using admixtures if need be.

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