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Compressive Strength of Fine Recycled Aggregate Concrete

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Abstract

The compressive strength of concrete containing fine recycled aggregates is the primary interest of the present study. Towards this end, fine recycled aggregate (FRA) sourced from crushed broken cement bricks obtained from a site building platform close to the University of Botswana was used as a replacement of fine natural aggregate (FNA) for concrete production. The FNA in concrete was replaced with 0%, 20%, 40%, 60%, 80% and 100% FRA. However, the free water-cement ratio was kept constant at 0.5 throughout. The hardened concrete was tested at periods of 3, 7, 14 and 28 days. It was observed that regardless of the replacement levels, the compressive strength of all concrete specimens increased with age. For ages 3 and 7 days, there appeared to be an initial decrease in the compressive strength with increasing replacement levels up to 60%. Beyond this replacement level, the trend was more uncertain. For ages 14 and 28 days, the initial decrease was apparent up to the 20% replacement level, however, the trend was noticeably uncertain beyond this stage. It was concluded that these inconsistencies arose because the dump site probably contained bricks sourced from different manufacturers. Notwithstanding, the results indicate that structural compressive strengths can be developed in concretes incorporating up to 100% fine recycled aggregates, using standard mixing procedures and economical mix designs.

Keywords: *Fine recycled aggregate, fine natural aggregate, concrete, compressive strength, replacement.*

1. Introduction

Recycling of construction waste material has attained prominence in the last few decades due to the marked depletion of the non-renewable natural resources such as gravel, stone, sand, wood, etc. This depletion coupled with the continuous industrial development, and the ever increasing world population, has made the search for alternative sources or new forms of construction materials a matter of urgency. It is universally accepted today that there is a need for sustainability and proper environmental management in order to conserve the earth's dwindling raw materials and reduce any negative environmental impacts. The latter is commonly attributed to the careless disposal of solid wastes and the indiscriminate proliferation of landfills that have been the practice up until recent times (Gumede and Franklin [1]).

It is generally accepted that concrete is the most widely used construction material and one which has played a significant role in the economic development of numerous countries around the globe. However this has come with a cost, for the construction industry has been plagued with intolerable levels of concrete waste generation over the years (Oyenuga and Bhamidiarri [2]). Fortunately concrete demolition waste has been demonstrated to be a very good source of aggregates for new concrete production. Indisputably, several investigations have revealed that concrete made with coarse recycled aggregates (CRA) obtained from concrete demolition wastes may possess strength properties similar to those of natural or conventional concretes (Evangelista and de Brito [3], Wagih et al [4], Khergamwala et al [5], Ngwenya and Franklin [6]). It can be confidently asserted that concrete made from CRA can be used for low, intermediate and high grade applications (Khatib [7]).In respect of the mechanical properties of concrete incorporating aggregates from demolished wastes, Franklin and Gumede [8] concluded that these properties notably compressive, splitting tensile and flexural strengths could be considered satisfactory in comparison to normal conventional concrete. However it should be noted that most of the previous research examined or cited in their study dealt principally on the replacement of the coarse natural aggregate (CNA) in concrete by CRA.

The major proportion of research on the use of demolished concrete wastes as aggregates for new concrete has dwelt on CRA replacing CNA for concrete production. Investigations on the replacement of fine natural aggregate (FNA) or sand with fine recycled aggregate (FRA) have been relatively scanty. A number of factors are attributed to this, primarily the greater porosity of FRA. This would result in higher water absorption ratios in such concrete as compared to normal crushed fine aggregate concrete resulting in poorer performance in respect of mechanical strength and durability (Wainright et al [9], Evangelista and de Brito [10], Yaprak et al [11], Fan et al [12], Ashiquzzaman and Hossen [13]). The fore-going notwithstanding, the necessity to consider the use of FRA has become more critical in concrete production given the

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boom in urban infrastructural development and the economic implications caused by the shortage of natural sands for this purpose.

There have been a number of studies related to the compressive strength of fine recycled aggregate concrete. Wainright et al [9] observed that concrete mixes with FRA could result in compressive strength increases of up to 5 MPa in some cases. Leite [14] noted that the incorporation of FRA in contrast to CRA increased the concrete's compressive strength. Khatib [7] observed a general loss of compressive strength with incorporation of fine recycled aggregates made from crushed concrete up to about 28 days, however the relative strength increased after this period; this was attributed to additional cementing action of unhydrated cement in the crushed concrete. Evangelista and de Brito [3] concluded that the compressive strength appears unaffected by fine aggregate replacement ratios up to about 30%, and for strength levels of the order of about 60 MPa. This was true up to about 28 days, however beyond that period, while the reference concrete's strength stabilized, that of the FRA concrete continued to increase, suggesting the presence of non-hydrated cement mixed with the FRA. Zega and di Maio [15] found that the compressive strengths of concrete made with FRA are similar to those of conventional concrete with maximum decreases of about 5%, for 30% replacement levels of FNA with FRA. Yaprak et al [11] noted that concrete produced using FRA exhibited compressive strength reductions of about 10% for 30% replacement levels; reductions of about 35% were observed for 100% FRA concrete. They concluded that there was a consistent reduction in strength with increase in the relative quantity of FRA. Ashiquzzaman and Hossen [13] studied the cementing property of FRA and deduced that there was some unhydrated cement in FRA concrete. They suggested that this would be beneficial if FRA was used to an extent as a replacement of sand in concrete.

As noted earlier, compared to studies on the use of CRA in concrete production, research on the influence of FRA on the mechanical properties of concrete was relatively sparse. Franklin and Gumede [8] observed that with respect to the utilization of recycled aggregate in concrete, there was a paucity of investigations in the South African sub-continent. Consequently a comprehensive programme was initiated along those lines at the University of Botswana (Gumede and Franklin [1], Ngwenya and Franklin [6]). However in contrast to the latter studies which concentrated on CRA, the focus of the present work is on the use of FRA in lieu of natural sand for concrete production. A major aim of the current study is to ascertain the influence of the replacement level of FNA with FRA on the compressive strength, from the viewpoint of locally sourced aggregates.

2. Materials and Methods

In general the constituents of all mixes were cement, water, fine natural aggregate, coarse aggregate and fine recycled aggregate. The cement was BOTCEM Portland cement CEM II/B-W 32.5R (Cement and Concrete Institute [16]) containing between 21% – 35% calcareous fly ash and manufactured in accordance with SANS 50197-1 [17]. The fine aggregate was locally available river sand with particle sizes passing through 4.75 mm sieve and possessing a fineness modulus of 3.1. The natural coarse aggregate was 13 mm maximum crushed aggregate obtained from Kgale Quarry. The recycled aggregates were extracted from cement concrete bricks which were obtained from a building site platform at the Botswana College of Engineering and Technology West Campus. These concrete bricks were further crushed in the laboratory to produce fine crushed bricks with particle sizes less than 4.75 mm in diameter. The procedure adopted was that initially, the broken bricks were soaked in a curing tank for approximately one week. Crushing was then carried out using a Proctor hammer as shown in Figure 1, until the particles were generally ascertained to be comparable to sand particles in size. The crushed mass was then oven dried and subsequently sieved in order to obtain the FRA shown in Figure 2.

Fig. 1 Crushing of bricks using a Proctor hammer

Fig. 2 Crushed mass of bricks

The mix design method was based on the Portland Cement Institute (PCI) approach as described by Owens [18]. The compacted bulk density and relative density of the cement, FNA and CNA were those provided by the suppliers, and these furnished reasonable engineering estimates of material characteristics. Trial mixes were carried out to assess the consistency and cohesiveness with minor adjustments being made where necessary to the mix proportions. The order for mixing was that the dry materials such as cement, coarse and fine natural and/or fine recycled aggregates were mixed alone first for about 30 seconds and then water was added slowly and the entire batch was mixed until the concrete appeared to be homogenous. This latter mixing was for a period of 2–3 minutes.

In determining the influence of incorporating FRA on the mechanical properties of concrete, six different mixes were utilized. The details of the final mix proportions adopted are shown in Table 1. The free water-cement ratio for all mixes was 0.5. The control mix (CM) had proportions of 1 (cement): 1.55 (fine natural aggregate or FNA): 2.35 (coarse natural aggregate or CNA), but did not include any recycled aggregate. In mixes CB20, CB40, CB60, CB80 and CB100, the FNA was replaced with 20%, 40%, 60%, 80% and 100% FRA in that order.

Steel moulds were cleaned and properly greased on the inside faces, then sealed at the bottom prior to the pouring of concrete. For each mix, twelve cubes of 150 mm in size were cast and vibrated in three layers in the moulds using a vibrating table. Subsequently the cast specimens were covered in polythene sheets at ambient temperature for 24 hours until de-moulding. The cubes were then immersed in water at a constant temperature of 25^{o}C in a curing tank. After 3, 7, 14 and 28 days, three cubes were removed from the curing tank, wiped clean, dried at room temperature for about one hour and then weighed for density measurement. Subsequently the cubes were crushed using a compression strength testing machine in accordance with the South African standard, SANS 195 [19], the loads being applied at a constant rate until the specimens failed. The failure load was recorded and the average of three test results was taken as the compressive strength of the concrete.

Table 1: Design quantities of component materials in kg/m^3

Mix	Cement	FNA	CNA	FRA	Water
CM	440	683	1032	0	220
CB20	440	546	1032	137	220
CB40	440	410	1032	273	220
CB60	440	273	1032	410	220
CB80	440	137	1032	546	220
CB100	440	0	1032	683	220

3. Results and Discussion

3.1 Density

The values of density in kg/m^3 for all mixes at different ages of curing are shown in Table 2 below.

Table 2: Density of concrete

Mix	Density (kg/m^3)			
	3 days	7 days	14 days	28 days
CM	2350	2361	2370	2370
CB20	2311	2370	2394	2376
CB40	2290	2320	2376	2385
CB60	2296	2293	2350	2350
CB80	2329	2317	2326	2311
CB100	2284	2314	2367	2370

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Densities ranged from 2284 to 2394 kg/m^3 for all concretes. The results suggest that apart from the 3 days test values, densities for all concretes attained peak values at 20% and/or 40% FRA replacement. This observation is brought out more clearly in Figure 3 which shows the variation of the average density with FRA replacement levels. Optimal densities drop beyond replacement levels in excess of 20% – 40% but appear to pick up again at higher replacement levels (60% – 80% in some cases, but 80% – 100% in others). From Figure 3, it is apparent that in general, the highest recorded densities occur at the 14th day curing period. In Figure 4 the densities of all mixes are plotted against age of curing.

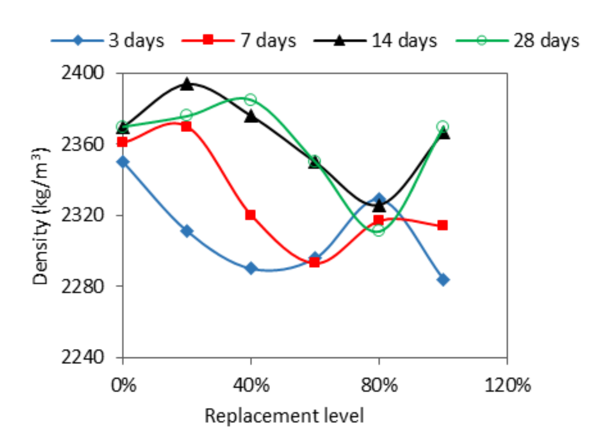

Fig. 3 Effect of crushed bricks content on density of concrete

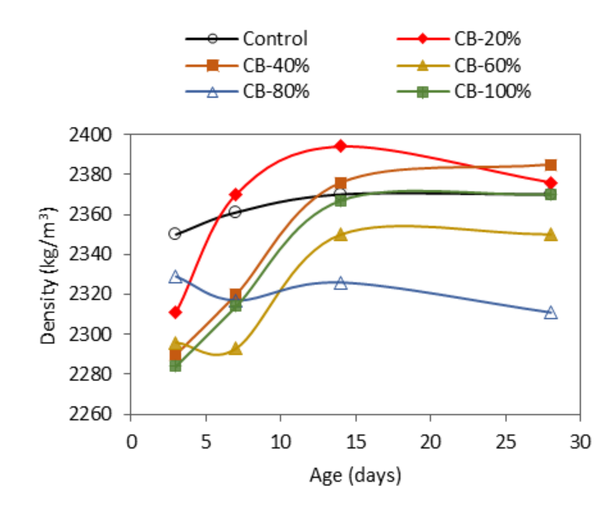

Fig. 4 Variation of density of concrete with age of curing

Generally speaking, the densities of all mixes increase with age. These increases are marked between 3-7 days; beyond this period, increases are less significant. Regardless of the FRA replacement percentage, the variation of density with age exhibits broadly the same general pattern for all concrete mixes.

3.2 Compressive Strength

The cube compressive strength for all concrete mixes at 3, 7, 14 and 28 days is presented in Table 3. It is obvious that irrespective of the concrete mix or the FRA replacement level, the compressive strength of all concrete increased with age. However for ages 3 and 7 days, there is an apparent decrease in compressive strength with increase in FRA replacement level up to 60%. Above this replacement level, the trend is somewhat uncertain, for the strength increases at 80% FRA but decreases again shortly after. For curing ages 14 and 28 days, there is an initial decrease in strength up to 20% FRA replacement level; beyond this level however, the variation is markedly uncertain, for the compressive strength rises at 40% FRA, falls at 60% FRA and rises once more at the 80% FRA mark. A possible explanation for this seeming anomaly may be due to the fact that the building site platform in all probability contained concrete bricks sourced from different manufacturers, although this could not be confirmed to any degree of certainty. This explanation however, is at odds with the findings of Wainright et al [9] who noted that the quality of the concrete from which the recycled aggregates are sourced appear to influence the porosity of the new concrete mixes made with them to a greater degree, than the compressive strength of the new mixes.

Table 3: Compressive strength of concrete cubes

Mix	Compressive strength (N/mm^2)			
	3 days	7 days	14 days	28 days
CM	31.1	38.8	49.5	51.6
CB20	30.5	38.0	40.0	47.5
CB40	30.3	36.6	45.9	52.6
CB60	24.8	33.0	42.3	48.6
CB80	33.5	42.6	46.1	49.5
CB100	25.9	36.4	49.7	53.1

The variation of compressive strength with age for all levels of FRA replacement is shown in Figure 5. This illustrates the previous observation that the strength of all concrete mixes increase with increasing age. Moreover the pattern of such increases appear similar, regardless of the level of FRA replacement. A comparison of strengths of all replacement levels in the region 20% – 60% FRA for all curing ages up to and including 14 days, reveals that these strengths are relatively lower than for the control mix. The 80% FRA replacement level on the other hand indicates different results. At 3 and 7 days, strengths are slightly higher than the control, while at 14 and 28 days, the strengths are only slightly lower (of order 4.1% – 6.9%). The situation for the 100% FRA replacement level is that the 14 and 28 days strengths are marginally higher than that of the control (of order 0% – 2.9%).

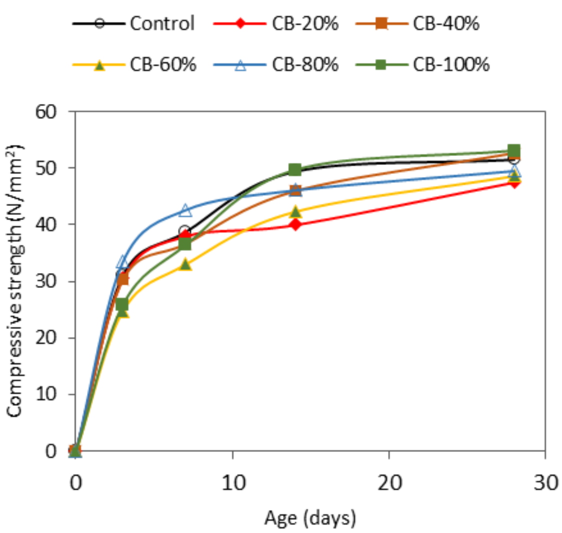

Fig. 5 Variation of compressive strength with age of concrete

These latter observations are brought out more clearly in Figure 6, where the compressive strength is plotted against the FRA content at different curing times. The results suggest that there are only modest changes in the compressive strength with respect to the replacement of fine natural with fine recycled aggregates. Considering the 80% and 100% FRA replacement levels, it is apparent that the 28 day compressive strength results are comparable to, or marginally higher than that of the control or reference concrete. This suggests that structural compressive strengths can be developed in concretes incorporating up to 80% – 100% FRA, provided standard mixing procedures and economical mix designs are adopted.

The above comments to the effect that only marginal increases in strength occur with respect to the replacement of FNA with FRA appear somewhat contrary to the results of Leite [14] who observed that at 100% FRA replacement levels, the compressive strength of FRA concrete mixes were about 10.5% higher than for the control concrete. However these observations are at odds with that of Khatib [7] who noted compressive strength reductions of about 29% at 100% FRA contents. The current study taken together with those of the two researchers cited here, would suggest that additional investigations are warranted in respect of the influence of the FRA content on the compressive strength.

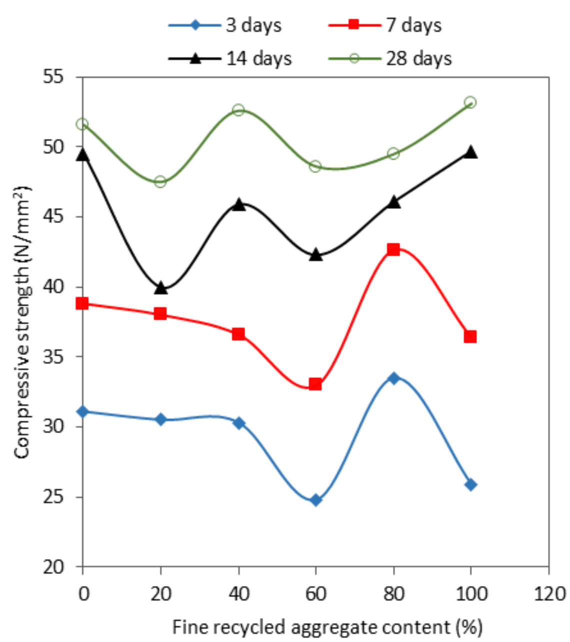

Fig. 6 Compressive strength for varying FRA content

4. Conclusions

The present study forms a portion of a continuing investigation at the University of Botswana on the assessment of the strength of concrete incorporating aggregates from locally sourced construction and demolition or CD wastes. Unlike investigations carried out thus far which have dwelt on coarse recycled aggregates (or CRA), the focus of the present work is the compressive strength of fine recycled aggregate (or FRA). Based on the study reported herein, a number of conclusions can be drawn.

Firstly, the densities of all concrete mixes attained optimal values at 20% and/or 40% FRA replacement levels. In broad terms, the highest recorded densities occurred at the 14th day of curing period; furthermore, the densities of all mixes generally increased with age. Secondly, for curing ages 3 and 7 days, there is an apparent decrease in compressive strength with increase in FRA replacement content up to 60%. Beyond this replacement level however, the trend is somewhat uncertain. In addition, for curing ages 14 and 28 days, there is an initial reduction in compressive strength up to 20% FRA replacement content. Beyond this level however, the variation is markedly uncertain. Thirdly, the compressive strength of all concrete mixes increased with age, irrespective of the FRA replacement content. Structural compressive strengths can be developed in concretes incorporating 80% – 100% FRA replacement levels, provided standard mixing procedures and economical mix designs are utilized. Finally, in view of the lack of unanimity in results of reported investigations to date, additional research is warranted in respect of the influence of the FRA content on the compressive strength of concrete.

References

[1] M. T. Gumede, and S. O. Franklin, “Studies on Strength and Related Properties of Concrete Incorporating Aggregates from Demolished Wastes: Part 2 – Compressive and Flexural Strengths”, Open Journal of Civil Engineering, Vol.5, 2015, pp. 175-184. http://dx.doi.org/10.4236/ojce.2015.52017

[2] A. A. Oyenuga, and R. Bhamidiarri, “Sustainable Approach to Managing Construction and Demolition Waste: An Opportunity or a New Challenge?”, International Journal of Innovative Research in Science, Engineering and Technology, Vol. 4, No. 11, 2015, pp. 10368-10378.

[3] L. Evangelista, and J. de Brito, “Mechanical Behaviour of Concrete made with Fine Recycled Concrete Aggregates”, Cement & Concrete Composites, Vol. 29, 2007, pp. 397-401.

[4] A. M. Wagih, H.Z. El-Karmoty, M. Ebid, and S.H. Okba, “Recycled Construction and Demolition Concrete Waste as Aggregate for Structural Concrete”, HBRC Journal, Vol. 9, 2013, pp. 193-200. http://dx.doi.org/10.1007/978-1-4471-4540-0

[5] P. C. Khergamwala, J. Singh, and R. Kumar, “Effect of Recycled Coarse Aggregates on Characteristic Strength of Different Grades of Concrete”, International Journal of Civil Engineering and Technology, Vol. 4, No. 6, 2013, pp. 186-192.

[6] L. M. Ngwenya, and S. O. Franklin, “Influence of Recycled Coarse Aggregate on some Properties of Fresh and Hardened Concrete”, International Journal of Innovative Science, Engineering & Technology, Vol. 2, No. 12, 2015, pp. 257-264.

[7] J. M. Khatib, “Properties of Concrete Incorporating Fine Recycled Aggregate”, Cement and Concrete Research, Vol. 35, 2005, 763-769.

[8] S. O. Franklin, and M. T. Gumede, “Studies on Strength and Related Properties of Concrete Incorporating Aggregates from Demolished Wastes: Part 1 – A Global Perspective”, Open Journal of Civil Engineering, Vol.4, 2014, pp. 311-317. http://dx.doi.org/10.4236/ojce.2014.44026

[9] P. J. Wainright, A. Trevorrow, Y. Yu, and Y. Wang, “Modifying the Performance of Concrete made with Coarse and Fine Recycled Aggregates”, in Proceedings of the Third International RILEM Symposium on Demolition and Re-use of Concrete and Masonry, Odense, October 1993, E & FN Spon, 1994, pp. 319-330.

[10] L. Evangelista, and J. de Brito, “Durability Performance of Concrete made with Fine Recycled Concrete Aggregates”, Cement & Concrete Composites, Vol. 32, 2010, pp. 9-14.

[11] H. Yaprak, H. Y. Aruntas, I. Demir, O. Simsek, and G. Durmus, “Effect of the Fine Recycled Concrete Aggregates on the Concrete Properties”, International Journal of the Physical Sciences, Vol. 6, No. 10, 2011, pp. 2455-2461.

[12] C. C. Fan, R. Huang, H. Hwang, and S. J. Chao, “The Effects of Different Fine Recycled Concrete Aggregates on the Properties of Mortar”, Materials, Vol. 8, 2015, pp. 2658-2672. doi:10.3390/ma8052658

[13] M. Ashiquzzaman, and S. B. Hossen, “Cementing Property Evaluation of Recycled Fine Aggregate”, International Refereed Journal of Engineering and Science, Vol. 2, No. 5, 2013, pp. 63-68.

[14] M. B. Leite, “Evaluation of the Mechanical Properties of Concretes made with Recycled Aggregates from Construction and Demolition Waste”, Ph.D. Thesis, Federal University of Rio Grande do Sul, Porto Alegre, Brazil, 2001, 390 pp.

[15] C. J. Zega, and A. A. di Maio, “Use of Recycled Fine Aggregate in Concretes with Durable Requirements”, Waste Management, Vol. 31, 2011, pp. 2336-2340.

[16] Cement and Concrete Institute South Africa, “Cementitious Materials for Concrete – Standards, Selection and Properties”, http://www.afrisam.co.za/media/13704/Cementitious_materials_for_concrete.pdf . Retrieved 22 April 2014.

[17] South African National Standards, “Cement Part 1: Composition, Specifications and Conformity Criteria for Common Cements - SANS 50197-1 (2000)”, 2000, Pretoria, The Bureau.

[18] G. Owens, “Fulton’s Concrete Technology”, 9th Edition, Midrand, South Africa, Cement and Concrete Institute, 2009.

[19] South African National Standards, “Sampling of Aggregates – SANS 195 (2006)”, 2006, Pretoria, The Bureau.

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