23rd Australasian Conference on the Mechanics of Structures and Materials

2014

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Publication details

Haikmoller, T, Olofinjana, A & Gerber, C 2014, 'Comparing the variability in mechanical properties of concrete made from recycled concrete aggregates', in ST Smith (ed.), *23rd Australasian Conference on the Mechanics of Structures and Materials (ACMSM23)*, vol. I, Byron Bay, NSW, 9-12 December, Southern Cross University, Lismore, NSW, pp. 237-242. ISBN: 9780994152008.

COMPARING THE VARIABILITY IN MECHANICAL PROPERTIES OF CONCRETE MADE FROM RECYCLED CONCRETE AGGREGATES

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ABSTRACT

Concrete is the most widely used construction material and we expect its dominance in the mix of construction materials to continue. In view of the environmental impact associated with concrete production, recycling provides a credible path for gaining some green credentials. Recent reports have proven that recycled concrete aggregates (RCA) in proportion of less than 30% of overall aggregate has produced concrete with compressive strengths greater than 25MPa and comparable to those made from fresh quarried aggregate materials. The use of recycled concrete however, is still restricted to non-structural applications mainly because of the reliability issues in service and there is little information on the variability expected in reported values and how these compared with conventional concrete. In this study, we investigated the variability experienced with measurements in laboratory properties of concrete made with various proportions of recycled aggregates using standard split tests. Data obtained were subjected to Weibull statistics and variability is expressed in terms of Weibull modulus. It is shown that characteristic strengths determined through Weibull statistics followed similar trend with previously published data on compression strengths. The Weibull moduli of 10 – 24 determined for RCA concrete are comparable to those of quality controlled normal concrete thus suggesting reliability was not compromised with replacements of natural aggregate with RCA.

KEYWORDS

Recycled concrete, RCA, compression strength, aggregate, Weibull modulus.

INTRODUCTION

Concrete is the most widely used construction materials with annual global average production estimated at 1 ton per person (Menard et al., 2013, Marie and Quiasrawi, 2012). Since, the making of fresh concrete demands large supplies of fresh quarried aggregates, water and cement, the continual consumption of concrete for construction at annually increasing rates require steps to mitigate the well-known environmental impact of continued consumption of these raw materials. While cement production itself has a large environmental impact that are being addressed with new materials additives and processing (Jacobsen. *et al*. 2013, Wang *et al*., 2013a, Wang *et al*, 2013b, Ekincioglu *et al.*, 2007), it is equally important to explore the reduction of use of natural quarried aggregate materials. With new developments and redevelopments, a lot of construction and demolition wastes become accessible as potential resource materials for construction. The use and re-use of waste or recycled concrete in place of fresh aggregates would therefore represent a significant environmentally friendly step. It is reported (Commonwealth of Australia, 2011) that in 2009, Australia, produce a total 14.5m tons of C & D wastes consisting about 81% waste concrete. Whilst the present recycling rate is estimated to range from 40 to 60% (Commonwealth of Australia, 2011, Tam, 2009). The present practice in Australia is to use the recycled concrete from demolition wastes in low grade non-structural applications as fillers, road base; a practice now being referred to as "downcycling" and is not regarded as an efficient recycling route .

The application of recycled concrete aggregate (RCA) in making concrete has been a subject of many research (eg. see Rahal, 2007, Barbudo, *et al*, 2013, Knoeri,. *et al*.,2013, Tam, *et al*., 2005, Thomas, *et al*., 2013, Ismail, S. and Ramli,2013) and many of the outcomes indicated that concrete made from that RCA are generally weaker in strength that drops to unacceptable levels when RCA aggregate proportion exceed 30%. Nonetheless, many of these results also indicated that concretes made with RCA gives acceptable strengths that can find applications for structurally non-critical components. The main problems with using RCA in concrete mixes appear to stem from the micro and macro structures of RCA concrete that may be related to the comminution process in the aggregate generation (Menard *et. al.*, 2013). For these reasons, less interest exist in using RCA and in Australia, their use is reduced completely to low grade applications mostly as fillers(Wang, 2013a). Environmentalists consider such applications as "downcycling" and not being a true recycling with minimum reduction in environmental impact. And in any case, re-use of waste concrete is yet to reach 100% utilization as has been the practice in Japan and Netherlands. It is therefore important to learn from practices elsewhere (Tam, 2009), to enhance the chance of 100% recycling rate. Additionally, many of the research work has focussed mainly in assessing static mechanical properties and little attention (Etxeberria, *et al*,2007) has been paid to reliability and statistical variation of performance indices that may result from macro and micro-structural morphologies. Here we report the comparison of variability in mechanical properties of normal concrete and that with various replacement proportion of RCA.

SUSTAINABILITY ISSUES AND PRESENT PRACTICES

Unfortunately cement production is rated as one of the top human activities responsible for greenhouse gas. Though significant environmental impact exist for the consumption of aggregate and water, the use of cement alone rings loud when considering the environmental impact of construction activities. The talk of recycling as means of reducing environmental impact of construction materials usage is a welcome development in giving the construction industry some green credentials.

Recycling in our modern world has been propagated as a means of promoting sustainability. Quantity of waste generated has generally been correlated with population. The massive urbanisation that is currently going on in in many regions suggest that waste management and sustainability are inadvertently related. Recycling waste has a strong role to play with sustainability and importantly how our consumption and waste generation affects the environment. We need however to subject recycling process to rigorous life cycle assessment (LCA) to gauge the overall impact on the environment. The general tendency is that for most materials, when everything is factored in, recycling provide a practical option to reduce environmental impact. Knoeri, *et al* (2013), carried out a rigourous LCA for using RCA as replacement for natural aggregate and it was concluded that consuming RCA would lead to much less impact on the environment.

Concrete recycling is about the recovery and processing wastes to be used as aggregates. Though many analyses of LCA does take account of recovering reinforcement steel but the main focus of the concrete recycling industry is still the business of harvesting for aggregates. If we consider the material and product flow in the cycle of concrete, at the moment, 40–60 per cent of concrete waste still end up in disposal. Following LCA recommendation (Knoeri *et. al*.,2013), when waste concrete is recycled, the overall life cycle, has a 30 per cent less impact on the environment. There is therefore a significant environmental advantage to reach 100% recycling rate Figure 1 illustrates schematically the role and steps for RCA in the life cycle of construction materials in construction. The ultimate would be to completely remove the disposal step.

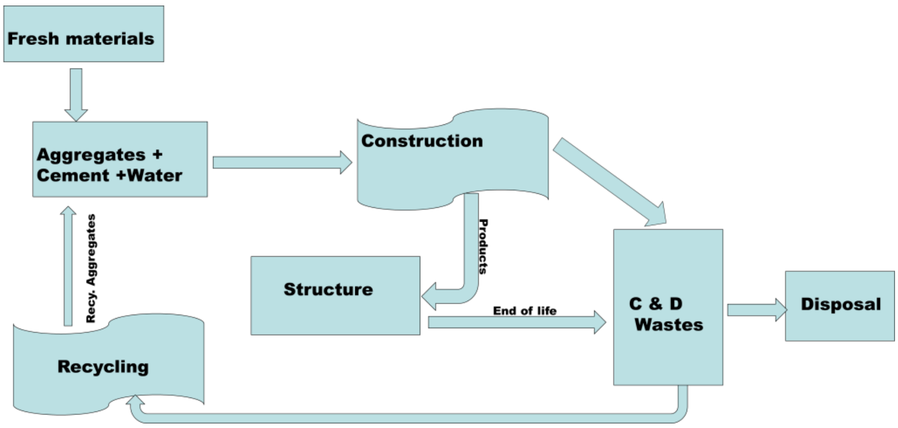

Figure 1. Schematic illustration of the role of recycling in the construction industry

The main problem in using RCA relates to the quality and how these are embedded into different standards. There are differences in the way the different standard have approached to specifying and grading RCA. Generally RCA are classed according to density and water absorption with significant variations in acceptable levels according to different standards (McNeil, *et. al.* 2013). Present practices of using RCA in concrete mixes are mostly limited to 30% of total aggregates but practices do varied globally as given in Table 1. The low demand for RCA and the low grade applications apparently affects its worth and the recycling rates achieved. In Australia, the present recycling rate is reported (Commonwealth, of Australia, 2011) to be about 50% and one can imagine the balance would end up in landfills. There is therefore some work to be done is convincing the construction industry about the reliability of RCA as construction material. We have therefore studied the mechanical properties and its variability with RCA processed from Buderim resource center in Sunshine Coast.

Table 1. Allowed replacement of RCA in structural concretes (McNeil, et. al., 2013)

	RCA Grade	**% allowed**
Germany	X0 Coarse	35 – 45
	XC1 to XC4, XF1 and XF3 Coarse	25 – 45
	Fines	Not allowed
RILEM	Coarse >4mm	20 – 100 (depending on types)
	Fines <4mm	Not allowed
Netherlands	Coarse	≤20
	Fine	≤20
Belgium	Coarse	100
	Fine	Allowed with restrictions
Denmark	Coarse	100
	Fine	≤20
UK	Coarse	≤20
	Fine	Not allowed

EXPERIMENTAL

Concrete samples were cast in cylindrical moulds 100mm diameter by 200mm high, as outlined in AS 1012.8.1(2000), tests for compression and direct tensile strengths.. The as–cast cylindrical concretes were cured in temperature controlled bath and were subjected to test after 28 days curing. A typical concrete mix is given in Table 2. The RCA content for 10 and 20 mm were varied from 0 – 100%.

The compression and the split (indirect tensile) tests were performed respectively according to Australian standards, AS1012.10-2000 and AS1012.9-1999.

Table 2. Concrete mix

Content	***Amount (kg)***
NA + RCA 10mm	21.6
NA + RCA 20mm	5.62
Sand	18.11
Cement	14.66
Water	7.33

RESULTS AND DISCUSSIONS

Processing Strength Data Using Weibull Statistics.

For identical samples, each of volume V, in a gauge length, when a body of ceramic is subjected to loading stress (σ), the survival probability $(P_s(V))$ is defined as the fraction of identical samples that will survive a given stress and can be written as (Zberg, et al, 2009):

$$P_s(V) = \exp\left[-\left(\frac{\sigma}{\sigma_o}\right)^m\right] \quad (1)$$

where σ_o is the characteristic strength and m is the Weibull modulus.
For any set of data a plot of $\ln\left[\ln\left(\frac{1}{P_s(V)}\right)\right]$ versus $\ln\sigma_f$, gives a straight line with gradient m and intercept $m\ln(\sigma_o)$ From a data fitted to this equation both m (Weibull modulus) and σ_o (characteristic strength) can be obtained. Physically, the $\sigma_o$is the stress at which the probability of survival is 37%. The modulus m represents a measure of diversity in measurements of mechanical properties. A large m of the order of 10^2 is typical of metallic samples where a single measurement can be used reliably to represent property. For ceramics m is much lower but values generally are an indication of how flaws are uniformly distributed and thus specify reliability of measured values. We have applied this method here to compare variability in RCA concrete.

Mechanical Properties and Variability

The variability in the indirect tests results were subjected to Weibull statistics. All the data fitted very well to Weibull model of exploring variability. A sample plot for 20% RCA replacement is shown in Figure 2. The summary of mechanical properties and Weibull modulus are given in Table 3.

The compressing strength for 100%NA was 38MPa and with split strength of 3.5MPa. These were in accord with the mix design and for the water cement ratio. However, with gradual replacement of NA with RCA, these values increased peaking at 10 %. The variation of strength with % replacement of RCA for the mix is shown in Figure 3. Increase in strength is thought to be related to the quality of of RCA, which were sieved and graded to different size consist. The morphology of RCA is thougt to be responsible for the observed strength increase. The NA consist of very sharp ends which under test conditions the localised stress ahead of a sharp aggregate can be amplified in many order of magnitude. The more rounded RCA by virtue of their morphology therefore would reduce such stress concentrating effects, hence the observed increase in strength of samples with RCA.

The Weibull modulus as given in Table 3, do not vary very much, with values of 10 to 24. These values are typical of a quality controlled concrete. It thus suggests that the use of RCA to replace NA, do not increase variability as have been suggested by previous studies (Etxeberria, *et. al.* 2007).

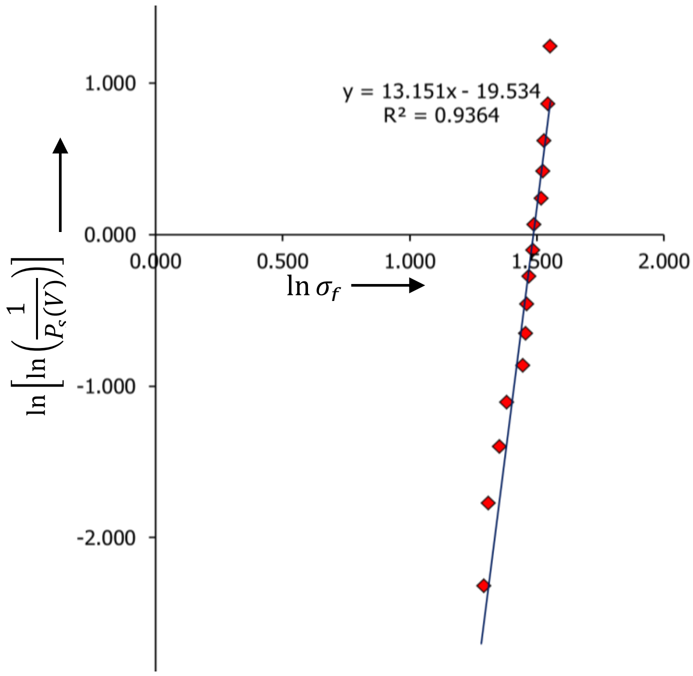

Figure 2. A typical Weibull plot for determining the Weibull modulus and characteristic

Table 3. Mechanical properties and variability from Weibull statistics

% RCA	$\sigma_C(MPa)$	$\sigma_T(MPa)$	m	σ_o
0	38.4	3.53	14	3.7
10	82.6	4.4	16	4.5
20	71.3.	4.3	13	4.4
40	56.6	4.2	24	4.2
60	52.94	3.9	10	4.1
80	49.3	3.8	12	3.9

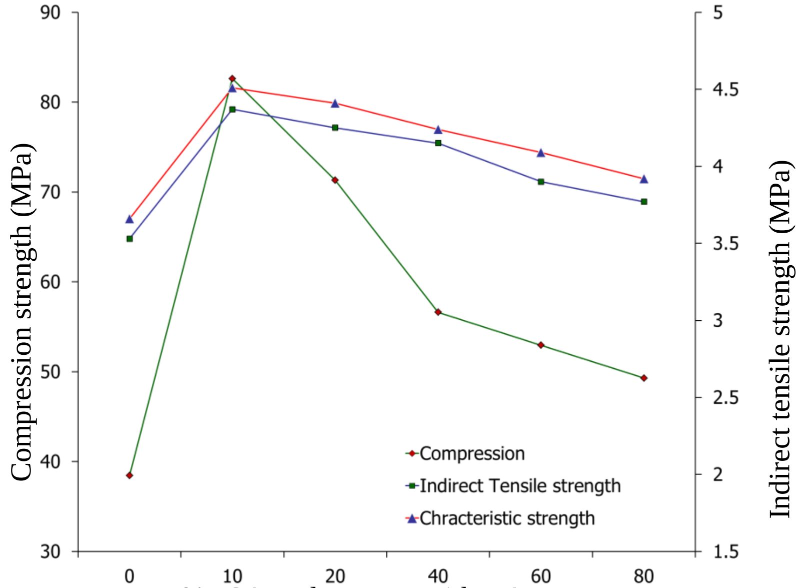

Figure 3. Effect of RCA substitution for NA on concrete strength

CONCLUSIONS

This paper has discussed the need for reuse of recycled concrete aggregate as a construction material. Samples of RCA concrete of various mixes were tested and found to be of similar strength with those of natural aggregates. The variability in test results were explored using Weibull method of analysis. The Weibull moduli determined suggest that the use of quality RCA do not add variability to mechanical indices as previously suggested. The Weibull moduli varied from 10 to 24 and were comparable to that of 100% NA concrete.

ACKNOWLEDGMENTS

We like to express our gratitude to the Sunshine Coast Council for giving us access to the Buderim resource recycling centre and for providing us with unlimited amount of graded RCA. Thanks are also due to Bernard Black and Hue Allen for the technical support provided.

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