The 2018 Structures Congress (Structures18)
Songdo Convensia, Incheon, Korea, August 27 - 31, 2018

Green Concrete using RCA for a Better Sustainable Environment

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ABSTRACT

In this paper, the properties of the aggregate, wet and dried concrete as well as the structural behavior of beam element in 4-point bending have been investigated for different percentages of recycled concrete aggregate (RCA). The mechanical properties RCA were slightly lower than virgin aggregate. The beam specimens had similar failure loads also the number of cracks as well as the deflection typically increased with increasing percentage of RCA used in the mixture. It was concluded that 1) the cube compressive strength of 100% RCA concrete was lower by 10 to 12% when compared to fresh concrete. The petrography analysis shown that the bonding between the aggregate and the cement was of lower quality when high percentage of RCA was used. Nevertheless, all concrete mixes were acceptable. Tests performed on beam specimens subjected to 4-point bending shown that all specimens had similar failure loads.

1. INTRODUCTION

Singapore is developing fast and its landscape is changing rapidly. It is facing tremendous challenges for its urban development as it lacks natural resources. For civil engineering construction, the raw materials for concrete such as the cement, coarse and fine aggregate (as well as part of the water) are imported from Malaysia, Myanmar and even Japan. Therefore, it is paramount for Singapore to reduce its importations and promote recycling of waste materials when possible. Singapore aims to achieve a target of at least 80% of green buildings by 2030.

Over the 20th century more and more concerns were raised regarding the depletion of natural resources and environmental degradation. The 1992 Earth Summit and the 2012 United Nations Conference on Sustainable Development held in

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Rio de Janeiro were both cornerstones for sustainable development.

Globally, the amount of waste is increasing rapidly. This includes waste from construction and demolition. Therefore, many governments have now introduced various measures aimed at reducing the amount of waste and promoting reuse and recycling, where it is technically, economically, or environmentally possible and acceptable. Therefore, for the construction industry it is important to recycle and reuse materials that has been reclaimed from demolition work. This will decrease the amount of waste produce and the depletion of non-renewable natural resources. Studies investigating the potential applications of recycled concrete aggregate (RCA) are increasing worldwide. Materials recover from demolition were initially recycled for non-structural applications such as road construction with little added value. The recycling of RCA for structural applications became popular with the studies from dos Santos et al. 2004 and Gonzalez et al. 2004 for example. Etxeberria 2006 shown that up to 25% of RCA can be reused safely in fresh concrete and it was shown that the strength of the concrete can be kept constant by adjusting the water/cement ratio (w/c) in the mixture.

Other studies from Sagoe-Crentsil et al., 2001 and Kwan Ho Kim et al., 2010 have shown that the reclaiming process affects the shape and texture of the aggregate and therefore its quality and properties (mechanical and chemical for example.) The properties of the fresh and dried concrete and the quality of the final product are influenced by the quality (shape and amount of old mortar) of the aggregate. The quality of the aggregate depends heavily on the reclaiming process used. Therefore, there is a need to classify the quality of the aggregate, as suggested by Butler et al., 2014.

It was shown that old mortar attached to reclaimed aggregate increases the sulfate content of the raw aggregate (Sanchez de Juan et al., 2009). It was also shown that RCA has high water absorption (due to the old mortar attached to RCA) and therefore the workability of concrete is affected as well as the properties of the dried concrete (Koulouris et al., 2004). For example, it was shown that the modulus of elasticity is affected by the percentage of RCA used in the mixture (Shi Cong Kou et al., 2008). Other studies investigated the mechanical properties of concrete that used 100% RCA as coarse aggregate (Babu et al., 2015). It was found that a concrete grade 40 can be achieved using 100% of RCA as coarse aggregate. It was reported, by Talamona et al., 2012, that high strength (70MPa) concrete can be made using RCA and the it is suitable for structural applications. The possibility to surround the aggregate with a coating was investigated (Martirena, 2017) and it was shown that the mechanical properties of the final product improved.

This paper aims to investigate the possibility to use RCA in fresh concrete. Therefore, the properties of a concrete grade 40 made of a mixture of virgin aggregates and RCA was investigated as well as the behavior of structural beam elements under four-point bending.

2. RESEARCH METHODOLOGY

The material properties of the raw material (i.e. coarse and fine aggregate and RCA), fresh and dried concrete were investigated using standard testing methods. Beam specimens were tested under 4-point bending until failure.

For this investigation, the aim was to achieve a concrete Grade 40 using 0, 20, 40, 60, 80 and 100% of RCA in the different mixture, keeping the w/c ratio and the slump (100mm±25) constant. For each batch, 2m3 of concrete were prepared for each mix to cast the different specimens, such as cubes and beams for example. The first batch was made using virgin aggregate only (0% RCA), the following batches included an increasing percentage of RCA, i.e. 20, 40, 60, 80 and 100% respectively. The basic concrete mixture used is shown in Table 1. The percentage of RCA was increased by replacing 190 kg (i.e. 20% of the 950 kg of coarse aggregate) of virgin aggregate by the same weight of RCA for each mix. The slump of the fresh concrete was controlled by admixtures such as P88 and S21.

Table 1: Basic concrete mixture

	kg/m^3
OPC	400
Coarse aggregate	950
Fine aggregate	785
Water	185

2.1 Properties of the raw materials fresh and dried concrete

Standard testing methods were used to measure specific material properties of the concrete. The standards used were either for US, UK or Singapore. The properties and the appropriate the standards used are summarized in table 2.

Table 2: Material Properties versus standard

Material Properties Measured	Standard Reference
Particle size distribution, fine particles, bulk density, density, water absorption and the crushing value of the aggregate	SS73:1974
The flakiness index	SS73: Part 5.1:1992
The impact value	BS812: Part 112:1990
Sulphate	SS73: Part 18:1992
Slump (fresh concrete)	ASTM C143
Concrete compressive strength (cube) at 1, 3, 7 and 28 d.	SS78: Part A16:1987
Petrographic	ASTM C856-040

2.2 Beam specimens under 4-point bending

The six beam specimens were cast on the same day, covered with wet damp cloth and sprayed with water several times a day for seven days. After curing the specimens were taken out of the molds and transported and stored in a dry place.

The specimens were 5-meter long (span 4.5m) and 300x200mm in cross section. Two T25 rebars were used as tensile reinforcement. The stirrups were Ø8mm mild steel spaced at 150mm. Two T10 rebars were used as top reinforcements. The elastic modulus, yield and ultimate strength of the rebars (top and bottom) and the stirrups were measured using a standard tensile test machine. The concrete cover was 20mm. The loads were applied at 1.5 meter of each support dividing the specimen in three equal sections of 1.5 m, the middle section being subjected to pure bending. Figure 1 shows a specimen after testing, part of the specimen, the spreader beam, the hydraulic jack and 3 LVDTs can be seen.

The specimens tested after 18 months under 4-point loading. The load increment was 3.5kN up to 21kN and 7kN for 21kN to failure. The load was maintained constant for at least 3 minutes, then the beam was visually inspected to detect any crack or crack propagation. Figure 1 shows the experimental set up where the cracks have been highlighted with markers. Three LVDT's were used to measure the deflection of the specimens. A load cell was placed between the actuator and the spreader beam to measure the total load applied to the specimen. The load and deflection at the center of the specimen were recorded using a data acquisition system and stored.

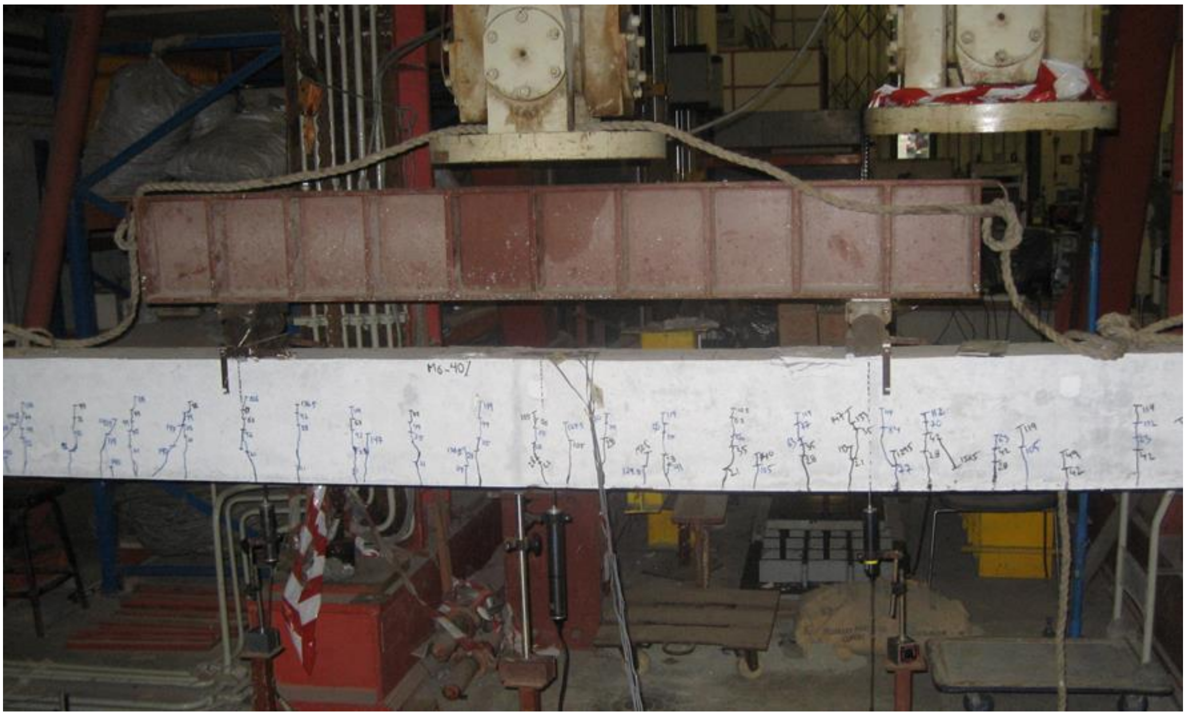

Figure 1: Specimen after testing

3. RESULTS AND DISCUSSION

In this section the properties of the aggregate, fresh and dried concrete, petrography analysis and the mechanical behavior of the beam in bending are discussed.

3.1 Properties of the aggregate

Figure 2 shows the particle size distribution for virgin aggregate and RCA. The figure shows the maximum and minimum values acceptable according to SS73:1974. The distribution of the virgin aggregate is within the standard but not the RCA. A linear interpolation between the RCA and virgin aggregate size distribution, shown that if RCA and virgin aggregate were to be mixed together the mix would be within the standard limits when up to 60% of RCA is used (and 40% virgin aggregate). As the RCA provided was from the best quality (grade A) available in Singapore it was decided to proceed with this batch of aggregate.

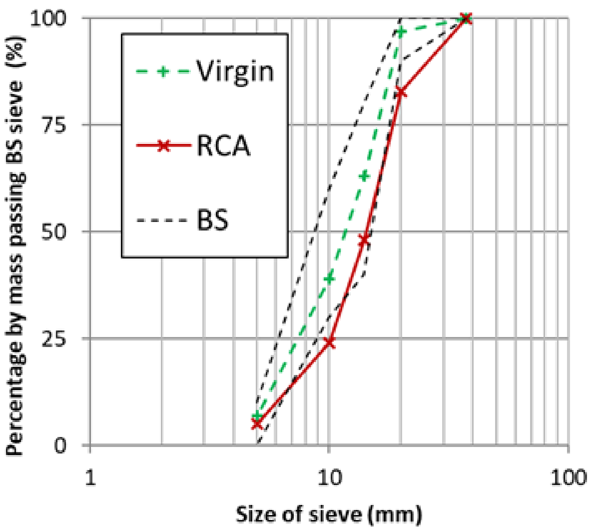

Figure 2. Particle size distribution of coarse aggregates

Table 3 summarizes properties of virgin aggregate and RCA. It must be noted that the properties denoted with * represent averaged values of two samples.

As seen in Table 3 for the six types of density (bulk and relative) the virgin aggregate was heavier than the RCA by approximately 12%. Nevertheless, the apparent relative densities were similar. The water absorption was 10 times higher for RCA compared to virgin aggregate. This was due to the mortar that was still pasted to the aggregate after it was reclaimed from concrete waste. Mortar is a porous material therefore it is lightweight and can absorb water.

To reclaim aggregate from concrete from demolition it needs to be subjected to mechanical stress to extract it from the surrounding mortar. Therefore, the crushing and impact values were higher for RCA than virgin.

As RCA had some mortar attached to it and as there was friction between the aggregate while handling, this mortar created dust and small particles. This explains the value of the fine content for RCA is higher than the one of virgin aggregate. The flakiness percentage was found to be similar for both types of aggregate.

The sulfate content was 4.5 times higher for RCA than virgin aggregate. This is consistent with the finding from Sanchez de Juan et al., 2009 and can be explained by the presence of old mortar.

Table 3: Properties of coarse aggregate

		Virgin aggregate	Recycled aggregate
Bulk density (Mg/m^3)*	Uncompacted (as receive)	1.45	1.31
	Compacted (as receive)	1.56	1.38
	Uncompacted (oven dry)	1.46	1.29
	Compacted (oven dry)	1.53	1.38
Relative density on an oven dried basis (Mg/m^3)*		2.6	2.34
Relative density on A SSD basis (Mg/m^3)*		2.61	2.46
Apparent relative density (Mg/m^3)*		2.63	2.64
Water absorption (%)*		0.45	4.7
Aggregate crushing value (%)*		17.7	28.7
Aggregates Impact Value (AIV) (%)*		20.7	29.6
Fines content (%)		0.6	0.9
Flakiness index (%)		12	11
Total sulfate content (%)		0.13	0.66

3.2 Properties of fresh concrete

The slump measured for all concrete mix was within the limits of 100mm±25. This shows that the slump can be controlled with admixtures.

3.3 Cube compressive strength

Figure 3 shows the evolution of the averaged cube compressive strengths as function of the age of the concrete (from 1 day to 28 days). After one day, the maximum difference in strength was observed between the concrete with virgin aggregate (reference concrete) and 80% RCA. The strength of 80% RCA concrete is 16,4% lower that the reference concrete. After 3 days, the maximum difference is 5.4% while increasing again to 10.6% after 7 days. At 28 days, the maximum difference is almost 9.7%. At that age, the strength can be divided in three, i.e. 1. the reference concrete and the one with 20% RCA have the highest strength, 2. followed by the concrete with 40 and 60% RCA that is approximately 7% weaker and finally 3. the weakest concrete was the one with the highest percentage of RCA (80 and 100%). All the mixes achieved the requirement of a concrete grade 40.

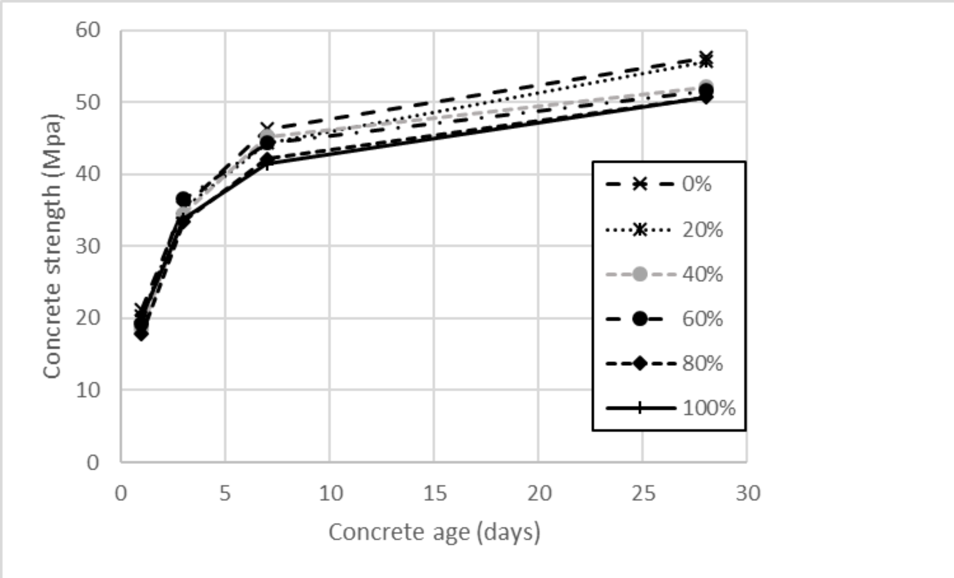

Figure 3: strength of the concrete as function of its age

3.4 Petrography

Visual observations shown that the cement matrix was light grey in color and appeared homogeneous for the six samples. The coarse aggregate size ranged from 5 mm to 20 mm and they were evenly distributed in the concrete. Neither segregation nor cracking could be observed on the specimens. The air content in concrete under fluorescent light was estimated to be between 1.5 and 3% for all specimens. These values are typical for air content for concrete. Air voids caused by water absorption material were observed under fluorescent light as shown in Figure 4. These voids were created by the old porous cement that was initially dry; it therefore absorbed water from the fresh cement paste. The voids shown in figure 4 are for specimens with 40, 60, 80 and 100% RCA.

Observations at the interface between cement and aggregate shown that for low percentage of RCA, the cement paste and aggregate were well bonded together while as the percentage of RCA was increased the bonding quality changed to fairly bonded. No cracks were observed in any specimens. It was concluded that the bonding was satisfactory for all specimens.

3.5 Structural behavior

It was observed that the 1st cracks appeared at a load of 14 kN for the specimens made of virgin aggregate (reference specimen) only and 20% RCA. At failure, the reference specimen had a larger number of cracks and they were deeper than the ones from the specimen with 20% RCA. For the specimen with 40% RCA the 1st crack appeared at a higher load than the reference specimen and the one with 20% RCA. For the remaining specimens, the first crack appeared at a lower load. For the specimen made of 100% RCA the first cracks appeared at 3.5kN which is a very low load when compared with the other specimens. This was probably due to high internal tensile stresses that have been created by the shrinkage of the concrete during curing. Also, for this specimen two more cracks appeared at a load of 10.5kN and their depths were 30 and 65 mm.

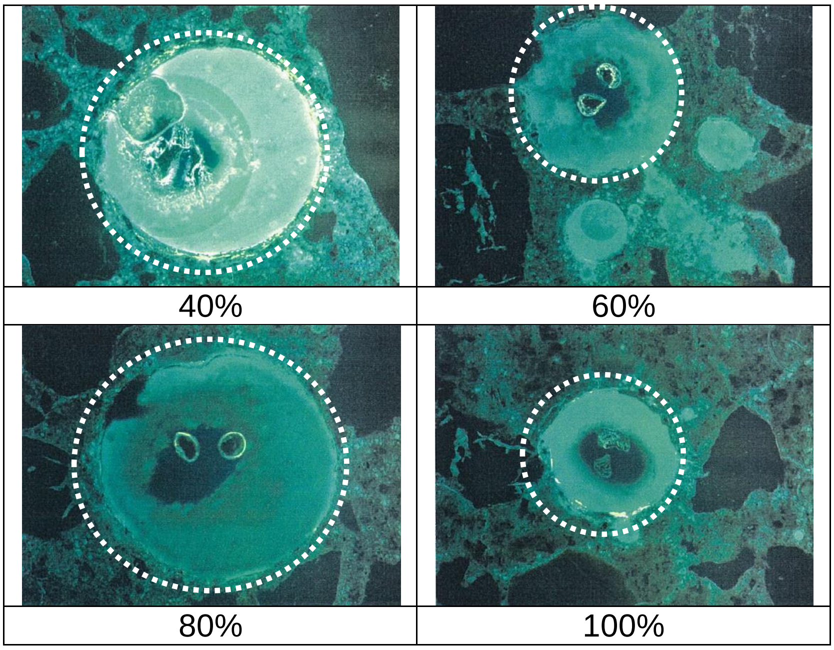

Figure 4: Air voids caused by water absorption material under fluorescent light

Figure 5 shows the load displacement diagram for all specimens tested after 18 months. As can be seen all specimens have very similar failure loads. The stiffness of the beams is very similar it can be seen, figure 26, that the specimen made of 100% RCA has the lowest stiffness.

Table 4 summarizes the data recorded for the cube compressive strengths of concrete on the day of testing of the specimens and the failure load of the specimens. After 18 months, there was a variation of 16% between the highest and lowest the compressive strength. The ultimate loads of the beam specimens were very similar ranging between 158kN to 163kN for 100% RCA and the reference specimens respectively. The difference between the weakest and strongest specimens is approximately 3%. This shows that RCA has little effects on the load capacity of under reinforced beams in bending.

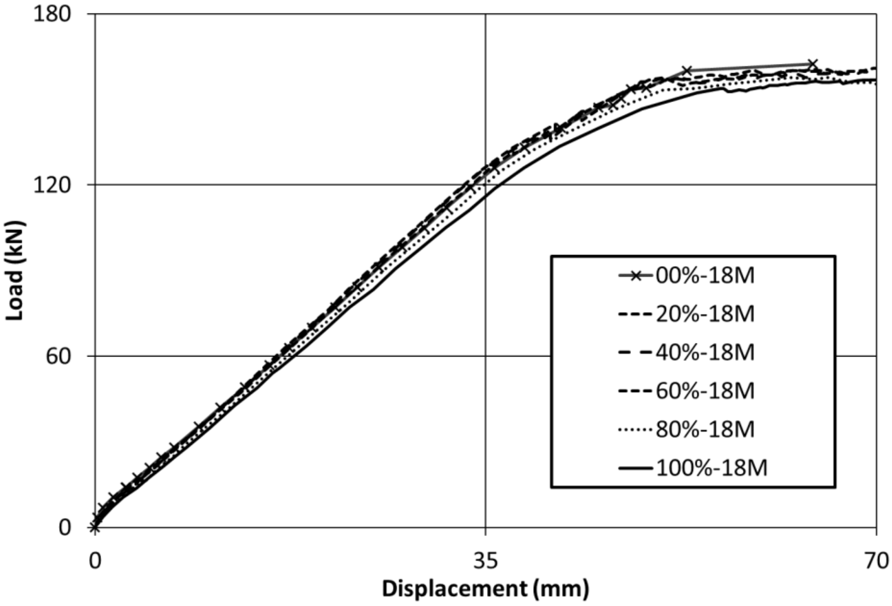

Figure 5: Load deflection of specimens at 18 months

Table 4: Concrete strength on the day of testing and failure load

Concrete mix (% RCA)	Average compressive strength (MPa)	Failure load (kN)
Reference (0% RCA)	67	163
20% RCA	65.44	161
40% RCA	63.85	162.7
60% RCA	64	162.2
80% RCA	59.16	159.6
100% RCA	56.31	158

4. CONCLUSIONS

Experimental data has shown that the mechanical properties, crushing and impact values for example, of the RCA were lower quality than virgin aggregate. Nevertheless, the properties of RCA meet the criteria set by the standards.

It was shown that, even when 100% RCA is used in the mixture, a concrete grade 40 with a constant slump and w/c ratio can be obtained by adjusting the amount the admixture.

Air voids caused by water absorption material, such as old mortar, were observed from the petrography for specimens with 40% or more of RCA in the mixture.

The bonding between the cement paste and the aggregate was found to be satisfactory for all mixes. The quality of the bonding is slightly poorer as the percentage of RCA in the mixture is increased. No cracks were observed for any of the specimens.

Similar failure loads were recorded when beam specimens are subjected to 4-point bending. The specimens with high percentage of RCA are less stiff than the reference specimen. For high percentage of RCA the number of cracks increased and/or the cracks were deeper. Also, the first crack appeared at lower load when the percentage of RCA is important. This may be of concern when considering corrosion of the rebars and it needs to be further investigated.

Based on the current results, it can be concluded that RCA can be used for structural applications. Currently further investigation is needed for high percentages of RCA, i.e. above 40%, as cracks are more likely to appear. Properties like shrinkage and creep should also be further investigated.

5. ACKNOWLEDGEMENTS

This work has been funded by MND Research Fund Committee, administered through Building and Construction Authority (BCA), Singapore. The Investigator would like to thank MND and BCA for their contributions. The investigators would like to thank Pan-United Ltd for supporting this research project and sponsoring experiments as well as NTU's technicians and project officer Chelladurai Subasanran, David Tui Cheng Hoon and Negar Roghanian for assisting with laboratory experiments.

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