Reusable Concrete Debris as Aggregate Replacement on the Properties of Green Concrete

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Abstract The sustainability of renewable resources is affected by the rapid booming of the construction sector. The massive production of construction and demolition waste by this sector has given drawbacks to the environment as well. An environmentally friendly approach to overcome the disposal of waste materials is via the recycling process. The main objective of this study is to investigate the properties of concrete made by Coarse Aggregate Associated with Concrete Production (CAACP) and Fine Aggregate Associated with Concrete Production (FAACP). Both CAACP and FAACP were obtained from concrete debris from crushed concrete. Some percentage of the concrete debris will be used as an aggregate replacement for concrete production. Six different concrete mixes containing 10, 20 and 30% of coarse and fine aggregate replacement were prepared accordingly. The concrete samples were tested for its strength at 3,7 and 28 days of curing age. The physical properties of the recycle aggregate were also carried out in order to investigate the possible factor that may affect the fresh and hardened concrete. It can finally be concluded that green concrete can be produced by FAACP or CAACP and possibly to produce higher strength compared to the conventional concrete strength.

Keywords Concrete debris · Aggregate replacement · Strength

1 Introduction

The growth of the concrete construction industry in this country has given an adverse effect to the environment as well as to human health. McNeil and Kang [5], claimed that the construction industry uses at least 50% of raw materials from

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natural resources, consume 40% of total energy and produces 50% of total construction waste. A good initiative should be taken into consideration in order to reduce and control these issues which may affect the future of mankind. Ganiron [8] in his paper agreed that builders, developers and contractors must consider an appropriate location and solution to place all debris made and what can be done to lessen its disposal to landfills.

Green concrete consists of recycling materials from construction wastes are widely used as an initiative to reduce concrete debris in the industry. It can be produced by replacing some portion of concrete with recycling non-renewable materials such as coarse or/and fine aggregates. According to Al-Gahtani et al [1], green concrete has the potential to achieve sustainable development economically and environmentally.

The use of green concrete in the construction industry may help in preserving the environment, natural resources, and also to reduce the cost of construction. Aggregate replacement in green concrete needs to be investigated in order to maintain and preserve its strength for construction purpose. In this research, the strength of green concrete with different replacement of aggregate from concrete debris will be studied and the optimum replacement of aggregate from the concrete waste will be recommended for future reference.

This research will focus on investigating the properties of concrete made by Fine Aggregate Associated with Concrete Production (FAACP) and Coarse Aggregate Associated with Concrete Production (CAACP). Concrete debris is considered as aggregate replacement in green concrete in order to save and sustain natural resources that are not replenished. This research is important in order to study the suitability of green concrete in the construction industry. In addition, this research comprises aggregate testing as a preliminary study to find the physical properties of the fine and coarse aggregate associated with concrete production (concrete debris) and natural aggregate. Several tests on fresh and hardened concrete will be carried out to determine the properties of green concrete compared to conventional concrete as well.

2 Methodology

2.1 Materials Preparation

Crushed granite with a maximum size of 20 mm was used as coarse aggregate for concrete production in this research. Coarse aggregate should be washed using clean water before the mixing process. Natural sand with a maximum size of 4.75 mm was used as fine aggregate. Aggregates were left to air dry for at least one day before being used for the mixing process. This process helps to avoid excessive water usage or altering the water requirement in the concrete mix. Tasek Ordinary Portland Cement Type 1 conforming to MS 522 was used in this research. Clean tap

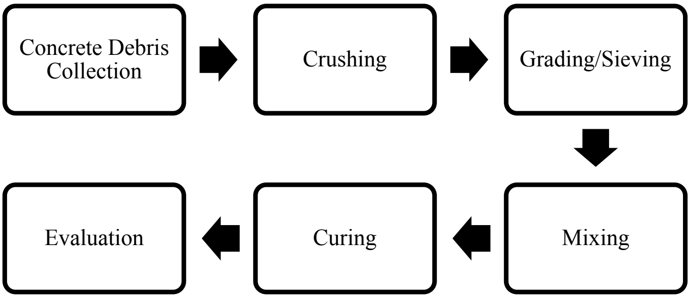

Fig. 1 Methodology flowchart

water from IIUM Civil Engineering laboratory was used. The temperature of water used for mixing and curing process is preferably 20 °C and should be clean from any impurities. Concrete debris was obtained from concrete test cubes that were used in compressive strength tests in IIUM Civil Engineering laboratory. The concrete cubes were crushed using a hammer to smaller sizes and the Los Angeles Abrasion machine was used to get the fine particles from the concrete waste. These aggregates were then sieved in accordance to BS 410 to get the appropriate size for coarse and fine aggregate replacement. Figure 1 shows the methodology flowchart for this project.

2.2 Aggregate Properties

The aggregates collected from the concrete debris as well as the natural aggregates underwent three aggregate tests, i.e. flakiness index, specific gravity and absorption of course aggregate test and sieving. The flakiness index test is done in accordance with BS 812-105.1:1989. This test is required to analyze the mass of flaky particles expressed as a percentage of the mass of the sample. The specific gravity and absorption of course aggregate test is done in accordance with ASTM C127. Sieve test on the hand is being done in accordance with BS 812-103.1:1985. This test is basically to access the particle size distribution (also called as aggregate gradation) by allowing the material to pass through a series of sieves of progressively smaller mesh size weighing the amount of material that is stopped by each sieve as a fraction of the whole mass.

2.3 Concrete Mixes

The production of Grade 30 of control and green concrete mixes were in accordance with BS 1881-125: 1986. Water-cement ratio for the mixes was at 0.55% by weight and the slump required was set at 30–60 mm and 210 kg/m^3 of free water content is required in order to obtain the specified slump. The mixing process needed about 382 kg/m^3 of cement, 633 kg/m^3 of fine aggregate and 1175 kg/m^3 of coarse aggregate in order to achieve the target strength. The proportion for fine aggregate is 0.35% of the total aggregate content. The ratio between 10 and 20 mm size of coarse aggregate used in this research was 1:2.

In this research, the properties of concrete made by FAACP and CAACP have been investigated. Various percentages of concrete mixes containing 10, 20 and 30% of coarse aggregate and fine aggregate replacement were prepared accordingly as shown in Table 1. Several tests on fresh and hardened concrete such as slump test, compacting factor test, and compressive strength were conducted to evaluate the properties of green concrete. Concrete is tested during its fresh state to guarantee that the concrete mix satisfies the specification of works. Fresh concrete tests are performed once the mixing process is done and before the concrete set.

Slump test was conducted in accordance with BS EN 12350-2 and it was done to evaluate the workability of the designed concrete. Compacting factor test on the other hand, was done in accordance with BS 1881-103. This is test is also conducted to evaluate the concrete workability and to confirm the results achieved from the slump test.

The compressive strength test is conducted in accordance with BS 1881-116:1983. Standard steel cube mould 150 × 150 × 150 mm was required for the tests at three various ages of concrete which were at 3, 7 and 28 days. Besides, the vibrator machine is also needed to compact the concrete and to eliminate air bubbles in fresh concrete. The maximum load was recorded to the nearest 0.5 N/mm^2. Table 1 shows the mix proportion planned for this research with Mix No. 1 as the controlled sample.

Table 1 Mix proportions of concrete

Concrete mix grade 30 N/mm^2			
Mix no.	Coarse aggregate replacement (%)	Fine aggregate replacement (%)	Water-cement ratio (%)
M1 (0%)	0	0	0.55
M2 (C10%)	10	0	0.55
M3 (C20%)	20	0	0.55
M4 (C30%)	30	0	0.55
M5 (F10%)	0	10	0.55
M6 (F20%)	0	20	0.55
M7 (F30%)	0	30	0.55

3 Results and Discussion

3.1 Aggregate Properties

Gradation curve from Figs. 2 and 3 elucidates that the coarse and fine aggregates from concrete debris fell below the minimum limit set by the code. This can be concluded that the aggregate sizes retrieved from the concrete debris were gap-graded aggregates whereby most of the samples had the same sizes and lack of intermediate sizes to fill the void between aggregates. This is possibly due to the crushing process of the concrete debris itself. Hammer was used during the process and obviously could not control the production of aggregate sizes. As agreed by Nikolic et al [6], aggregate characteristics such as shape, surface texture, mineralogy, size, and grading (particle size distribution) can influence and affect the strength of concrete in varying degrees.

The particles shape of aggregate is determined by the percentage of flaky particles. Flakiness index is the mass of flaky particles expressed as a percentage of the mass of the sample. The flaky aggregate has a direct effect on the strength of concrete due to the higher water demand than the rounded aggregate. Furthermore, concrete with flaky particles will have lower workability thus requiring more water in order to maintain given workability.

In this research, the flakiness index test for natural coarse aggregate and coarse aggregate from the concrete debris have been conducted to compare its flakiness and their effect on the properties of green concrete. Tables 2 and 3 show the flakiness index for natural coarse aggregate and coarse aggregate from the concrete debris.

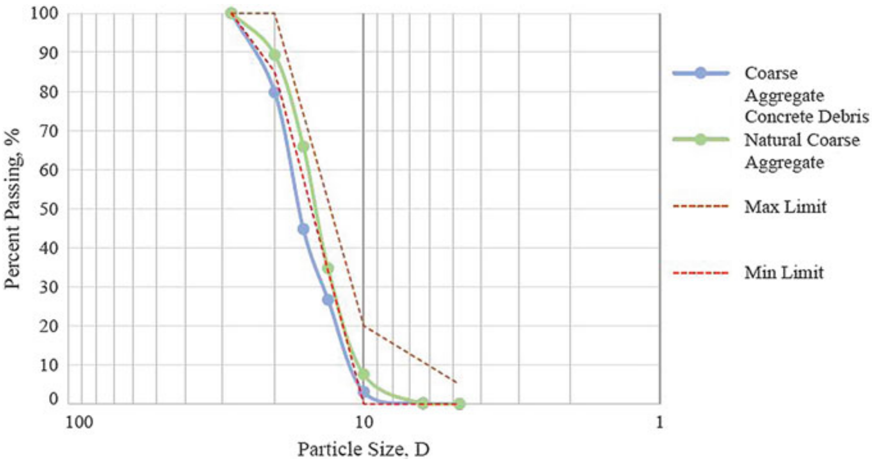

Fig. 2 Grading curve for natural coarse and coarse aggregate from concrete debris

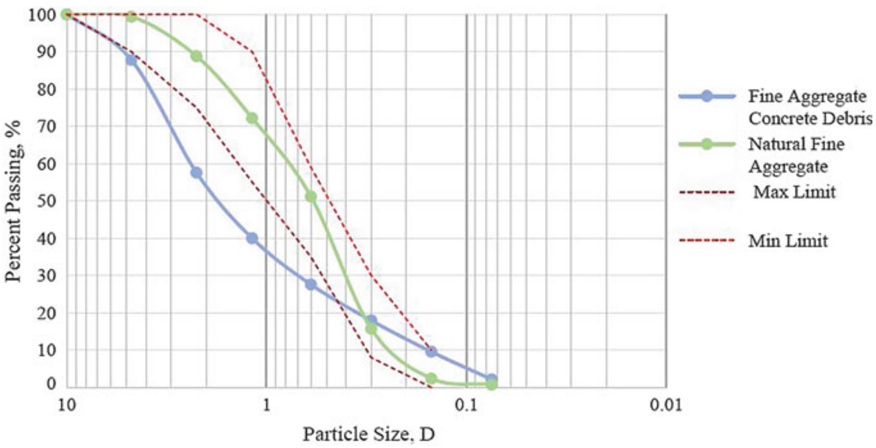

Fig. 3 Grading curve for natural fine and fine aggregate from concrete debris

Table 2 Flakiness index for natural coarse aggregates

Sieve size		Weight retained (g)	Percentage retained (%)	Weight of flaky particles (g)	Individual flakiness index (%)
Passing (mm)	Retained (mm)				
28.0	20.0	214.0	10.7	55.0	25.7
20.0	14.0	1092.0	54.6	169.0	15.5
14.0	10.0	543.0	27.2	50.0	9.2
10.0	6.3	150.0	7.5	6.0	4.0
Total		1999.0		280.0	
Flakiness index (%)					14.0

Table 3 Flakiness index for coarse aggregates from the concrete debris

Sieve size		Weight retained (g)	Percentage retained (%)	Weight of flaky particles (g)	Individual flakiness index (%)
Passing (mm)	Retained (mm)				
28.0	20.0	405.0	20.3	66.0	16.3
20.0	14.0	1062.0	53.2	180.0	16.9
14.0	10.0	472.0	23.6	69.0	14.6
10.0	6.3	57.0	2.9	3.0	5.3
Total		1996.0		318.0	
Flakiness index (%)					15.9

Coarse aggregate from the concrete debris shows higher flakiness index than natural coarse aggregate which is 15.9 and 14% respectively. These data are still below the limit set by British Standard 882:1992 which limits the coarse aggregate flakiness index to 50 for natural gravel and to 40 for crushed or partially crushed aggregate. Higher flakiness index for concrete debris is due to the crushing process on the concrete cube. Hammer is the only tool used in the crushing process that makes the sample flaky and not in the rounded and uniform shape. Furthermore, Neville [7] stated that, flakiness of coarse aggregate has a considerable effect on the workability of concrete. Higher flakiness index and angularity could reduce the workability of fresh concrete.

3.2 Fresh Concrete

It is essential that concrete should have a workability feature. For this particular reason, a fresh concrete experiment was carried out and as explained prior to this, the results of a slump test is presented in Table 4. Slump test was conducted to study the effect of aggregates from concrete debris to the workability of green concrete. In concrete with CAACP or FAACP replacement, a decreasing trend was shown whereby mixes with higher aggregate replacement shows a possible lower slump. This is probably due to the high water absorption rates from aggregates of concrete debris that influences the slump and workability of concrete. The cement mortar that is attached to the aggregates from the concrete debris contributed to most of the water absorption in the mix. Higher absorption rates will reduce the water content in the concrete mix and eventually will lead to a lower slump and workability. It can be concluded that, as the percentage of coarse aggregate replacement increases, so thus the diminution in workability of the green concrete.

This result is supported by Etxeberria et al [2]. The authors claimed that due to the high absorption rate of coarse aggregate from the concrete debris, green concrete made with recycled coarse aggregates and natural sand generally needs 5% more water than conventional concrete in order to get the same workability. If recycled aggregates are employed in dry conditions, the concrete's workability is extremely reduced due to their absorption capacity.

Another possible factor that may influence the diminution in workability is the difference in aggregate preparation for control and green concrete mix. The natural aggregates in the control sample were employed in wet condition and were washed

Table 4 Slump test results

Mix no	Slump (cm)
M 1 (0%)	4.1
M 2 (C10%)	8 6
M 3 (C20%)	6.2
M 4 (C30%)	3.0
M 5 (F10%)	2.8
M 6 (F20%)	3.0
M 7 (F30%)	5.5

before the mixing process take place. Therefore, specific gravity in saturated surface dry condition (SSD) for natural coarse aggregate is higher than coarse aggregate from the concrete debris. Thus, when aggregate is presented with higher specific gravity, it gives a much lower absorption capacity.

Compacting factor test has been conducted in order to support the results of the slump test achieved. Table 5 shows the compacting factor test results for all 7 concrete mixes. For coarse aggregate replacement, Mix 2 indicates the highest compacting factor with 0.966 while the least compacting factor was shown by Mix 4 with 0.844. These results are in line with slump test results. Both tests show the decreasing trend and Mix 4 have the lowest workability. The lower value of compacting factor indicates the low workability of the fresh concrete.

The compacting factor for fine aggregate replacement on the other hand, indicates almost the same trend as the slump test results. Mix 5 has the lowest compacting factor with 0.816 while Mix 7 has the highest compacting factor with 0.927. 30% fine aggregate replacement shows the nearest value of compacting factor with the control mix. This indicates that 30% replacement of fine aggregates is an acceptable quantity of aggregate replacement in green concrete in terms of concrete workability. Besides, this trend also shows the same relationship as a slump test for fine aggregate replacement.

3.3 *Hardened Concrete*

Compressive strength was conducted to evaluate the properties of hardened concrete. This test was conducted for day 3, 7 and 28 of curing time. This test is important in order to study the effect of concrete debris on the strength of concrete.

Referring to Table 6, Mix 4 with 30% of coarse aggregate replacement obtained the highest strength on the 28th day. It achieved 8% higher strength than the control sample due to the higher quantity of concrete debris used in the production of green concrete. According to Etxeberria et al [2], increases in the compressive strength of recycled concrete is due to the rough texture and absorption capacity of the adhered mortar in concrete debris that provides stronger bonding and interlocking between the cement paste and the concrete debris themselves compared with those of conventional concrete.

Table 5 Compacting factor test results

Mix no	W (kg)	W_1 (kg)	W_2 (kg)	C.F
M 1 (0%)	2.35	13.10	13.85	0.935
M 2 (C10%)	2.60	13.90	14.30	0.966
M 3 (C20%)	2.60	13.80	14.30	0.957
M 4 (C30%)	2.60	12.35	14.15	0.844
M 5 (F10%)	2.60	12.15	14.30	0.816
M 6 (F20%)	2.60	12.85	14.25	0.880
M 7 (F30%)	2.60	13.45	14.30	0.927

Table 6 Compressive strength of concrete

Mix no	Compressive strength (MPa)		
	3 days	7 days	28 days
M 1 (0%)	24.28	31.20	41.89
M 2 (C10%)	24.45	30.58	38.96
M 3 (C20%)	24.72	29.80	39.67
M 4 (C30%)	22.92	31.04	45.34
M 5 (F10%)	26.09	34.76	47.57
M 6 (F20%)	25.03	30.30	43.49
M 7 (F30%)	24.35	32.94	43.93

For fine aggregate replacement, on the other hand, Mix 5 gained the highest strength with 47.57 MPa at 28 days. This can be attributed to the presence of cement particles in fine aggregate concrete debris. Additional non-hydrated cement in concrete debris increases the strength of green concrete. Khatib [4] explained that the increase of strength in green concrete could be due to further cementing action of non-hydrated cement particles in recycled fine aggregate. This fact is also supported by Evangelista and de Brito [3] whereby they author claimed that fine aggregates from the concrete debris contain high levels of hydrated and non-hydrated cement that can increase the total amount of cement in the mix. The higher the cement quantity that adhered mortars in the concrete debris, the higher the strength of the green concrete.

4 Conclusions

Behavior of fresh and hardened concrete can be evaluated in order to determine the suitability of concrete debris as aggregate replacement in green concrete. The workability of concrete decreases as the coarse aggregate replacement increases. This is an attribute to the higher absorption rate of coarse aggregate from the concrete debris that influences the effective water-cement ratio in the mixture. Fine aggregate replacement indicates almost opposite behavior to coarse aggregate replacement. More test needs to be done for the fine aggregate replacement with concrete debris.

Higher compressive strength was shown by 30% of coarse aggregate replacement. 10% of aggregate replacement for fine aggregate replacement, on the other hand, shows the satisfying strength which exceeded the control sample strength. Some factor that may influence the strength of concrete at 28 day may include the flakiness index of aggregates as well as the specific gravity and absorption rate of aggregates. In order to maintain and preserve the strength of green concrete, optimum replacement of aggregate is recommended up to 30% for coarse aggregate or at 10% fine aggregate. It can finally be concluded that green concrete can be produced by FAACP or CAACP and possibly to produce higher strength compared to the conventional concrete strength.

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