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A Review: Mechanical Properties of Recycled Aggregate Concrete and its Optimum Content in Concrete

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Abstract: Recycled aggregate concrete as structural materials can avoid the depletion in natural resources because major natural resources such as cement and virgin aggregates are needed in huge amount in manufacturing concrete in building construction. The aim of this study is to investigate the optimum content of recycled aggregates that used in concrete. Compressive strength, splitting tensile strength and modulus of elasticity of recycled aggregate concrete were analysed from previous studies. The mechanical test was carried out on the 28 days of concrete casting under relevant standard either ASTM or BS EN using 25%,50%,75% and 100% of recycled aggregates. It was found that as percentage of recycled aggregates increases, the compressive strength and modulus of elasticity will decrease about 30% but there are some slightly increases for tensile strength at low percentages such as 25%. A substitution of about 25% of recycled aggregates have insignificant influence on its mechanical properties of recycled aggregate concrete.

Keywords: Recycled Aggregate Concrete, Mechanical Properties, Optimum Content

1. Introduction

Concrete is a composite material made up of aggregates, water and cement paste with high durability and flexibility. It is commonly used as building and structural material in construction site [1]. Construction industry demand for sand and natural aggregates continues to grow from year to year resulting in resource depletion since sand and aggregate are natural resources which are non-renewable. Nowadays, the high demand for natural resources as construction material to meet today's requirements has created immense opportunities for the reuse and recycle of waste materials in the field of construction. Green concrete is concrete fabricated from recycled waste which gives the concept to

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concrete with those additional measures is taken in the mix design and application to promote safe and sustainable construction strategies. As the global carbon dioxide emission for the past 10 years due to construction is getting increased more than 20% had stimulated the growth of green concrete [2].

Recycled aggregate concrete (RAC) which uses the concept of green concrete can minimize the waste stream that created in landfills, but also able to reduce the consumption of major natural resources such as aggregate and gravel at about 20%. Therefore, RAC able to conserve the environment and fulfil the requirements in construction field as well. In construction field, concrete incorporating recycled aggregate has been widely used to avoid depletion of natural resources [3]. This practice is becoming popular which are proven by statistic with regard to actual construction and demolition wastes that have been processed for RA which was about 50%. This represents high recovery rate from construction and demolition waste generation. Besides, incorporating 15% of recycled aggregates into new asphalt mixtures could reduce the total cumulative energy requirement as well as utilization of fossil fuels by 13 to 14% [4]. Recycled aggregates can be view as crushed aggregates processing from construction waste and demolition. The recycled aggregate concrete has high potential to be used as concrete structure when the strength is compromised without modifications to water-cement ratio in concrete mixture [5]. Nevertheless, the optimum content of recycled aggregates used in concrete should be taken into considerations as substitution at high percentages may lead to unsatisfactory properties of concrete.

The aim of this review is to compare concrete compressive strength, splitting tensile strength and modulus of elasticity from previous researcher works. From that, optimum content of RAC can be determined as well. It is possible to substitute the natural aggregates using recycled aggregates at optimum content. The compressive strength of recycled aggregate concrete will be influenced by the percentages of recycled coarse aggregates as replacement, water-cement ratio and the quantity of attached mortar on surface of aggregates. The higher percentages of recycled aggregates will affect tensile splitting strength when concerns about water absorption level as recycled aggregates concrete has greater ability on water absorption compared with normal concrete [6]. However, RAC even have better tensile strength in certain condition. Generally, recycled aggregate concrete has a lower modulus of elasticity than natural aggregate concrete particularly when the other components of the mixture remain constant.

2. Materials and Methods

The materials used in previous experimental work to determine the mechanical properties of RCA concrete include Ordinary Portland Cement (OPC), natural fine aggregates and coarse aggregates, recycled coarse aggregate, superplasticizer and water. Basically, the percentages of recycled aggregates used as substitutes are 0%,25%,50% and 75% and 100%. The research methodology used in this review study is separated into two stages which are collecting all the data and information obtained from the previous experimental work and analyzing the data collected. In this review, the parameters for mechanical properties of RAC include compressive strength, tensile strength and modulus of elasticity. Besides, the optimum content of recycled aggregate in a concrete mixture are evaluated through this section. These result data on these mechanical properties studied from the previous research were tabulated then comparison and analysis were conducted.

The concrete was determined to be at a sufficient strength by a series of compression test on cylinder concrete specimen or cube concrete specimen as shown in Figure 1 and Figure 2. The compressive strength test was carried out in compliance with relevant standards on the 28th days after concrete casting. The test machine must meet the standard specifications for the specific compressive force range. The maximum applied load to the cylinder specimen is recorded as indicated by the testing machine. The compressive strength of the cylinder specimen is calculated by dividing the maximum force applied to the cylinder by the cross-sectional area.

$$C, Compressive\ strength\ = P/A \qquad Eq.(1)$$

Where, P = Maximum load in kN

A = Cross-sectional area in mm2

The result of compressive strength was taken to be closest to 0.5 N/mm2.

Figure 1: Cylinder concrete specimen

Figure 2: Cube concrete specimen

The splitting tensile strength test used on cylinder concrete samples which split across the vertical diameter. The test was carried out on the 28 days of concrete casting under relevant standard either ASTM or BS EN. Testing machines should adhere to specifications for appropriate loading ranges. The steel testing jig is needed to ensure that the cylinder specimen is centrally located on the lower platen of the testing machine, and the bearing strips positioned vertically and parallel to the axis of the specimen. Figure 3 show tensile split test perform on cylindrical concrete specimen. The maximum load applied to the specimen as indicated by the testing machine was recorded. The splitting tensile strength of the cylinder specimen is calculated as below.

$$Tensile\ strength\ = {}^{2000P}/_{\pi Ld} \qquad Eq.(2)$$

Where P = Maximum applied load by testing machine in kN

L = length of the cylinder in mm

d = diameter of the cylinder in mm)

The result of splitting tensile strength to nearest 0.1MPa.

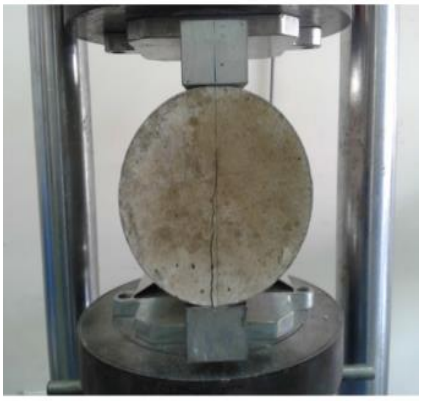

Figure 3: Split tensile strength test

The modulus of elasticity of the concrete are determined by compression tests conducted on cylinder specimens and were tested at 28 days. The loading was applied according to relevant ASTM standard. Based on the guideline, all samples should be tested under moist conditions and the modulus of elasticity was determined from compressive test. The compressor meter that used to test modulus of elasticity of cylinder concrete are shown in Figure 4.

Figure 4: Modulus of elasticity test

In experimental work of Azzawi [7], compressive strength of recycled aggregate concrete is determined by the compression test that performed on cylinder concrete specimen in accordance with ASTM-C39M [8], by using cylinder concrete specimen with 150mm of diameter and 300mm of height whereas for cubes specimen, dimension of 150mmx150mmx150mm is used according standard BS1881-116 [9] which conducted at 28 days. Tensile strength of concrete specimen is obtained by conducting splitting cylinder strength test following standard ASTMC496 [10] using two cylinders with 150mm of diameter and 300mm of height. Modulus of elasticity concrete was performed according ASTM-C469 [11] technique using concrete cylinders measuring 150 x 300mm tested in constant strain compression. Adnan et al. [12] had studied the compressive strength test follows the standard BS 1881: Part 108 to investigate the strength of RAC cube specimen with dimension 100mm x 100mm x 100mm. Rahman et al. [13] investigated the compression test is carried out using 75x150mm standard cylinder. The split cylinder test is performed to find the tensile strength of a cylinder concrete specimen. Besides, the compression strength tests of RAC were conducted by Exteberria et al. [14] using 150mmx150mm x150mm cube specimen, whereas tensile strength and modulus of elasticity conducted with cylinder specimen of 150mm x 300mm.

According to Mohamad et al. [15], compressive strength test is carried out according to BS 1881: Part 116 [16] by using cube specimen of 150 mm x 150 mm x 150 mm at 28 days. Splitting tensile strength is determined by split cylindrical test on cylinder specimen with 150mm of diameter and 300mm of height in accordance with BS 1881: Part 117 [17]. The modulus of elasticity was determined from the compression test on the concrete cylinder using the Universal Testing Machine in accordance with BS 1881: Part 121 [18]. According to Saleh et al. [19], compressive strength test is conducted by standard cubes 100mm x100mm x 100mm were used according to BS1881: part 116 [20] at 28 days. Modulus of elasticity of concrete tests conducted by following ASTM C469-02 [21] using cylinder specimen of 150mm of diameter and 300mm of height. In experimental work of Ozbakkaloglu et al. [22] axial compression test carried out in accordance with ASTM C39 by cylinder specimens with dimension 100mm x 200mm at 28 days while modulus of elasticity of the concrete determined by compression test following ASTM C469 by cylinder specimens with dimension 100mm x 200mm.

3. Results and Discussion

According to research conducted by Azzawi [7], when percentage of recycled aggregate increases, compressive strength of concrete decreases for both concrete cubes and cylinder at 28-day. Compressive strength of concrete reduced approximately from 6.7% to 30.9% when 25%,50%,75% and 100% of recycled aggregates were substituted respectively. Similarly, from the experimental work of Adnan et al. [12], when the water/cement ratio used in same, the compressive strength of recycled aggregate concrete was lower than that of natural aggregate concrete at 13.25% to 21.85%. These can be explained by recycled crushed aggregates are more porous and less dense than virgin coarse aggregates. As a result, coarse aggregates which have lower density which contributes majority of concrete mass will cause the recycled coarse aggregate has lower strength and thereby concrete with recycled aggregate will exhibit lower concrete strength. RCA concrete with up to 25% recycled aggregate show close but slightly inferior mechanical properties. However, there is a significant difference in compressive strength when the coarse aggregate in concrete is fully replaced by recycled coarse aggregates.

Salleh et al. [19] findings show that the percentage difference from reference concrete for S25, S50, S75 and S100 is in the range of 2.85% to 12.76%. Based on result that has shown, the compressive strength of concrete with 25% of replacement has slightly differences compared with conventional concrete which is reduced 2.85% only. According to Ozbakkaloglu et al. [22], compressive strength of concrete with recycled aggregates are slightly lower in comparison with natural aggregate concrete except for N-C-25-T. The findings indicate that concrete with 25% of recycled aggregate is optimum content to be used as it has satisfied compressive strength as it shows close but slightly inferior mechanical properties. The comparison of compressive strength of RAC between different experimental work are shown in Figure 5.

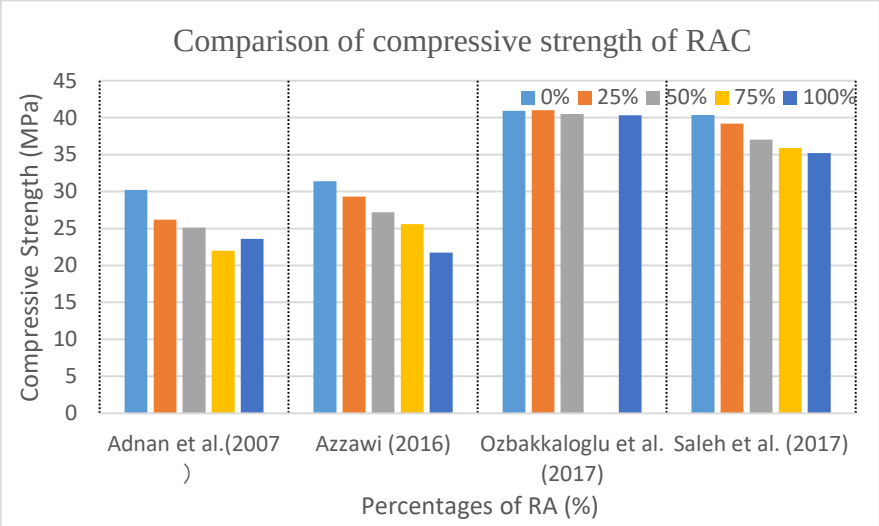

Figure 5: Compressive strength of RAC

The splitting tensile strength decreases as percentage of recycled aggregate increases according to Azzawi [7]. The splitting tensile strength of concrete decreased from 8.36% to 38.91%. However, there is only a small variation for splitting tensile strength in between NAC and RAC25. Therefore, it can be concluded that the effect of recycled aggregate on tensile strength can be considered negligible when low percentages of recycled aggregates used in concrete mixture. The reason of decline in splitting tensile strength may be due to the fact that recycled aggregates consist of high percentage of natural aggregate particles with a lower percentage of mortar attached to the aggregate particles, resulting in angular particles that only slightly improved interlocking and provided comparable strength.

According to research conducted by Mohamad et al. [15], the tensile split strength of the recycled aggregate concrete is found to be slightly greater than that of the conventional concrete. Similarly, from the experimental work by Rahman et al. [13] and Exteberria et al. [14], the splitting tensile strength was found to be slightly greater for concrete with 25% and 50% of recycled aggregate. This may attribute to the increased absorption of the mortar attached to the recycled aggregate, as well as stronger bond between the aggregates and the mortar matrix. This may attribute to the increased absorption of the mortar attached to the recycled aggregate, as well as stronger bond between the aggregates and the mortar matrix. The residual mortar in RAC creates a weakened region for compressive failure, it often improves tensile strength by smoothing the transfer between mortar and aggregate. However, there is only a small variation for splitting tensile strength in between NAC and RAC. The comparison of splitting tensile strength of RAC between different experimental work are shown in Figure 6.

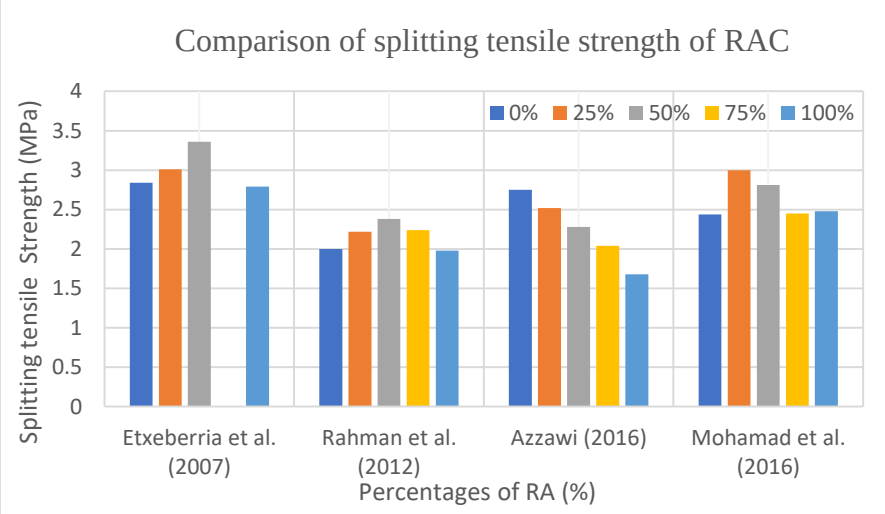

Figure 6: Splitting tensile strength of RAC

Based on the experimental work by Azzawi [7], the modulus of elasticity of recycled aggregate concrete decreases as the percentage of recycled aggregates increases. The modulus of elasticity of RAC was decreased from 9.1% to 31.97%. The modulus of elasticity of concrete is highly associated with its compressive strength, as well as volume fractions and properties of aggregates. The percentages of MOE value between NAC and RAC25 is considered insignificant. Exteberria et al. [14] findings show that 25% of recycled aggregates in concrete has highest modulus of elasticity but it will decreases as the percentages of RA increases.

In the experimental work of Mohamad et al. [15], the modulus of elasticity of RCA concrete will decreases with the increasing of percentage of recycled aggregates except for M-50. In general, the finding shows that the modulus of elasticity of recycled aggregate concrete is lower compared to conventional concrete. However, the value of MOE reduced varies significantly between studies. This is because the variation of modulus of elasticity is dominated by the characteristic of aggregates instead of the properties of the concrete itself and most likely this difference is caused by varying properties of the aggregate utilized in concrete. The modulus of elasticity of RAC is reduced about 1.1% to 13.05% for 25% to 100% of RA substitution, respectively in this study. However, it can be said that the difference between the value of modulus of elasticity for recycled aggregate concretes and natural aggregate concrete are comparatively small.

For the research conducted by Saleh et al. [19] when there is an increasing in recycled aggregates replacement ratio, the modulus of elasticity will decrease but is not significant. Modulus of elasticity of RCA is slightly lower due to higher proportion of hardened cement paste. Concrete mixes containing

recycled melted brick aggregate tend to have a smaller value of modulus of elasticity than gravel concrete at 28-day. The different in terms of modulus of elasticity between recycled aggregate concrete and conventional concrete is in the range of approximately 10 to 15%. Lastly, experimental result shown by Ozbakkaloglu et al. [22] found that recycled aggregate concrete with a lower percentage of recycled aggregate will have higher modulus of elasticity compared to other recycled aggregate concrete with a higher percentage of recycled aggregates when subjected to same compressive strength for all concrete. The lower MOE value is explained by mechanical properties of recycled aggregates which has a lower strength and stiffness compared to natural aggregate. The comparison of modulus of elasticity of RAC between different experimental work are shown in Figure 7.

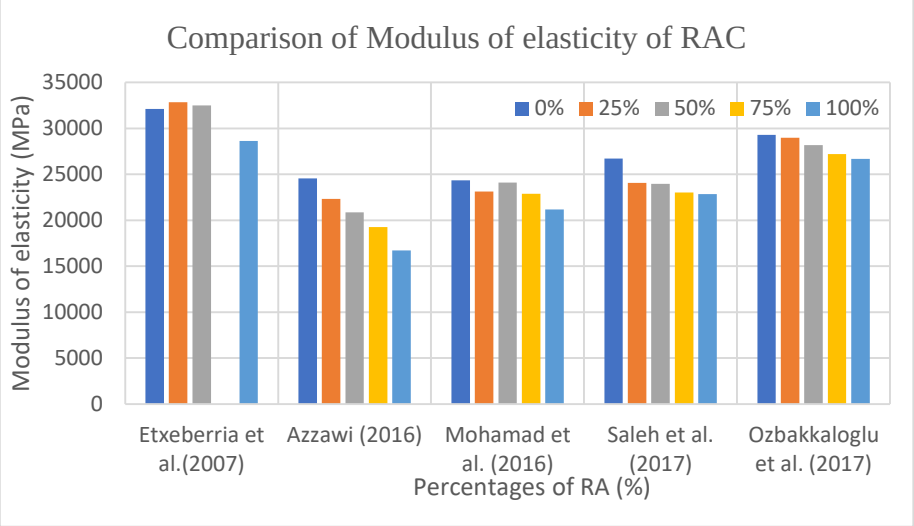

Figure 7: Modulus of elasticity of RAC

4. Conclusion

In conclusion, the compressive strength, tensile strength and modulus of elasticity of concrete will depend on the percentage of recycled aggregates replacement. Basically, as the percentage increases the compressive strength and modulus of elasticity of concrete will decrease. However, there are slightly increased in terms of splitting tensile strength when 25% to 50% of recycled aggregates are used in concrete. The optimum percentage of recycled aggregates to substitute normal coarse aggregates should be in 25% to 30%. It has been proved that compressive strength of recycled aggregate concrete is comparable to conventional concrete when the optimum content of recycled aggregate is used. The reduction of strength in concrete is negligible and able to resist compressive stress. A substitution of 25% will have minimal effect on tensile strength and elastic modulus as well. Therefore, it can be concluded that low percentages of recycled aggregates as substitute have satisfactory mechanical properties. However, excessive replacement of recycled aggregate up to 50% and above will lead to concrete structure exhibit inferior mechanical characteristics.

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