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Self-Compacting Concrete with incorporation of Recycled Concrete Aggregates

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Abstract: At the present the natural resources of aggregates are decreasing day by day due to usage of aggregates in construction industry rises. To overcome this problem, Self-Compacting Concrete (SCC) consisting recycled concrete aggregate (RCA) has the potential to save the natural resources of aggregate and reduces the solid waste generation. In this research, natural aggregates were replaced using RCA at different percentages ranging from 0% to 100% with an increment of 25%. The mechanical properties like filling ability, passing ability, segregation resistance, compressive and tensile strength of M30 grade SCC were examined at 7 and 28 days water curing regimes. Based upon the results it was observed that the slump flow decreased when RCA was incorporated. Furthermore, similar trend was observed in the compressive and tensile strength of SCC containing RCA where 4% to 6% loss in strength was observed compared to control sample.

Keywords: Sustainable concrete, recycled concrete aggregates (RCA), self-compacting concrete (SSC), natural aggregates conservation

1. Introduction

The rapid influx of people to metropolitan and other urbanized areas has allowed many countries to achieve economic growth [1]. This growth has significantly boosted the construction activities including the repairing or maintenance of existing infrastructures. The construction industry is regarded as the backbone of any country and contributes significantly in its social and financial growth [2], [3]. But with the raising demand for infrastructures, due to scarcity of land, a trend has begun in which old existing infrastructures and buildings are demolished in order to construct new ones. This trend has started to contribute significantly in generating more and more construction and demolition (C&D) wastes across the world.

Though Malaysia is one of the developing countries, it has seen rapid urbanization over the years. The construction sector contributes to approximately 10.1% to Malaysia's Gross Domestic Products (GDP) [4]. Taking into consideration, the significant contribution to GDP by the construction industry, increase in generation constructional waste such as C&D is expected. This gradual increase in C&D waste generation is not only becoming a severe issue for

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Malaysia but same is being faced across the world with increasing constructional activities, rapid economic development and growing populations.

Due to this, researchers have attempted to utilize C&D waste to reduce environmental issues and contribute to sustainability aspect in construction industry. The recycling or reusing of concrete as aggregates, commonly known as recycled concrete aggregates (RCA), among the various C&D wastes generated, has opened a whole new and wide range of possibilities for re-utilizing materials in construction due to its great environment effect [5]. Maximum utilizing of waste materials, which have the potential to be recycled or reused, in concrete as a component will contribute significantly in reducing the cost of construction as well as towards sustainable construction. It is a fact that in a typical concrete, the aggregates amount to 80% of concrete [6], therefore the replacement of aggregates by recycled materials such as RCA can really help in transforming traditional concrete into sustainable material.

It has been estimated that approximately 40% of total worldwide construction aggregate production is consumed by the construction industry, but the use of recycled aggregate stands at minimal 3% [5]. Previous studies have suggested that Asia and Pacific countries consumption the highest natural aggregates for constructional purposes as shown in Fig. 1, worldwide the increasing demand of construction aggregate to reach 48.3 billion metric tons by the year 2015 [7].

The gradual depletion of natural resources, CO_2 emissions has forced the construction industry towards developing sustainable concrete [9]. Therefore, has increased research into the utilization of RCA and its possible application in the construction industry.

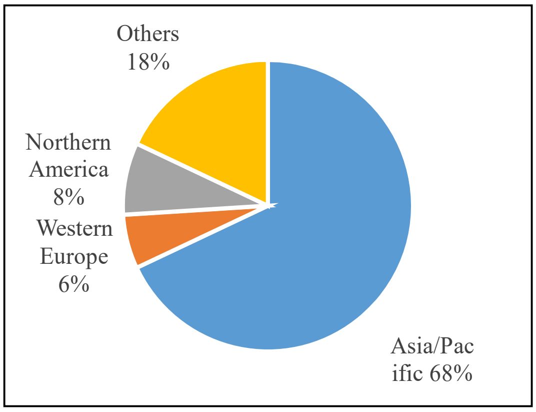

Fig. 1 - Worldwide demand for construction aggregates in 2015 [8]

The utilization of RCA in the production of concrete is a slightly complicated due to the difference in properties from natural aggregates and fluctuating the quality of RCA. The RCA consist of not only the original natural aggregates but also mortar (cement paste) adhering to the surface of the RCA as seen in Fig. 2. The existence of mortar in RCA is the foremost reason for deterioration in its quality, this is because the adhered mortar is characterized as porous and prone to micro cracking. Therefore, the water absorption of RCA is relatively higher than natural aggregates, RCA achieves lower density as well as lower mechanical strength. Considering these characteristics of RCA, it is expected that the utilization of RCA in concrete may have adverse effect on interfacial bond between RCA and cement paste [5].

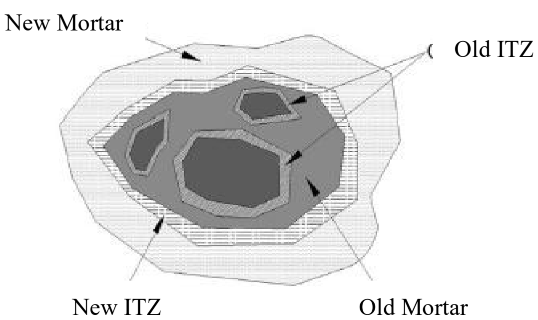

Fig. 2 - Structure of recycled coarse aggregate [10]

But considering the gradual depletion of natural aggregates due to increasing consumption in construction, the utilization of RCA could have significant impact in reducing the consumption of natural aggregates in construction, and thus ensuring sustainability in construction industry. This experimental work was done to determine the effects on the mechanical strength of self-compacting concrete when RCA is incorporated as coarse aggregate replacement. The natural aggregates were replaced 0% to 100% with an increment of 25%.

2.0 Literature Review

SCC is the twenty first century invented concrete and is known as high performance and high strength concrete, which has tendency to flow by its own weight and fill the entire frame work without any external sources due to that SCC is more parable to normal concrete now days [11-13]. Like conventional concrete SCC also possesses the coarse aggregates, which occupies the 28 to 35% volume of total SCC because of that great number of natural resources of stone decreased day by day. To save the natural resources of aggregates the alternative source is to use the RCA which resolve the reduction in natural resource as well as save the environment from concrete waste [14-17]. In this research the RCA were replaced with natural aggregates at different percentages such as 0%, 25%, 50%, 75% and 100 %. The slump flow, segregation resistance, compressive and tensile strength were examined. The compressive and tensile strength were analyzed at 7- and 28-days water curing.

Many previous studies were conducted to analyze the fresh and hardened properties of SCC by replacing the coarse aggregate with recyclable concrete aggregate. [18] examined the physical properties such as density, water absorption and porosity, fresh properties like filling ability, passing ability and segregation resistance and hardened properties includes compressive, tensile and flexural strength, ultrasonic pulse velocity, stiffness, and both dynamic and static modulus of SCC consisting the RCA and compared the results with conventional concrete. The RCA were replaced at different percentages like 0%, 20%, 50% and 100%. The hardened properties were analyzed at the 7- and 28-days water curing. The results demonstrated that the flowability and passing ability were decreased when RCA percentage increase compared to conventional concrete. The segregation resistance was also low in context of conventional concrete. The physical properties like density decreased when SCC consisting the RCA, the water absorption and porosity were increased when RCA added to SCC compared to conventional concrete. The hardened properties were 10% to 15% lower than the conventional concrete.

Reddy [19] analyzed the M20, M40 and M60 grade SCC consisting the RCA. The compressive strength, acid resistance and water sorption were examined when 0%, 25%, 50%, 75% and 100% at 7- and 28-days water curing. The outcomes explain that the acid resistance and water absorption were rapidly increased when RCA was added, the water absorption of SCC contain RCA was almost double compared to conventional concrete. The compressive strength of SCC contain RCA was slightly decreased compared to control sample and 25% replacement of RCA was optimum compared to all mixes which consist RCA. Modani [10] also investigated the strength performance, permeability, resistance to acid attack, chloride penetration and alkalinity when RCA were replaced by natural aggregates with 0% - 100% with an increment of 20%. The compressive strength was analyzed at 3-, 7-, 28- and 90- days water curing. The results described that permeability, resistance to acid attack, chloride penetration and alkalinity were significantly increase while replacement of RCA with normal aggregate and the compressive strength was 5% to 7% decreased in context of control sample.

A study was conducted to determine the effect of fine and coarse aggregate replacement on the properties of various grades of concrete [20]. The fine aggregates were replaced using River Indus Sand while coarse aggregates were replaced using RCA. The results indicated that there was a decrease in flexural and tensile strengths ranging from 5% to 15% and 1% to 1.8% respectively.

There has been an attempt to develop concrete which could be used for structural applications, incorporating RCA. In a study conducted by Malešev [21], the concrete waste from laboratory testing of cubes and precast concrete columns was crushed into RCA. 50% and 100% coarse aggregate replacement was done with RCA and compared with a control sample with no replacement. It was found that irrespective of replacement percentage, the reinforced beams consisting RCA showed satisfactory performance, not much of difference was observed compared to the control specimens.

A study to produce sustainable concrete incorporating RCA was conducted on concrete to meet the durability and strength requirements [7]. A 100% coarse aggregates replacement was done, the experimental work focused on the evaluating of the physical and mechanical properties of concrete incorporating RCA over a period of 6 months and compared to control sample. Based upon the results obtained, it was observed that concrete with acceptable strength and durability could be produced if high packing density is achieved.

RCA when finely grinded have higher water absorption than coarse RCA [22-24]. Therefore, the higher water absorption leads significant impact on the workability of SCC. Therefore, the effect of finely grinded RCA on the rheology of SCC over time was studied by [6]. The fine RCA was used to replace natural aggregates, replacement varied (0%, 20% 50% and 100%). It was found that the higher (50% and 100%) RCA incorporation in SCC lead to loss of SCC characteristics whereas lower (20%) was successful in maintaining the filling and passing abilities of SCC. It was further observed that the increase in RCA content significantly decreased the compressive strength of SCC.

However, according to study on the long-term properties of SCC incorporating RCA conducted by Malnzi [25], it suggested that up to 40% RCA utilized in SCC is still able to maintain the SCC characteristics. It was also observed that the pores size distributions were highly influenced by the content and assortment of RCA.

3 Methodology

3.1 Materials and Mix Design

The cement (Ordinary Portland Cement) name as Tasek was utilized as binding material (Grade 53) which has similar specification given in MS EN 197-1:2007. The river sand was utilized as fine aggregate and crushed natural aggregates were utilized as coarse aggregates having maximum size was 12mm. The RCA was obtained from the waste of concrete and sieved from 12mm sieve. The water absorption of sand, natural aggregates and RCA were analyzed using BS 1881-122:2011 [26] method and specific gravity was also examined by utilizing the BS EN 1097-3:1998[27]. The physical properties of sand, natural aggregate and RCA are presented in Table 1.

Table 1 - Physical properties of aggregates

Property	Sand	C.A	RCA
Specific Gravity	2.5	2.5	2.2
Water Absorption	1.0	1.2	4.3
Bulk Density	167	162	141
Fineness Modulus	3.1	4.1	5.9

From Table 1, it can be seen that the RCA has high water absorption compared to sand and natural aggregates and the specific gravity and bulk density are less compared to sand and the natural aggregates.

The M30 grade SCC was designed for this research with design ratio 1:2.5:2 (cement, sand, aggregate). The EFNARC (European Guideline) [28] were followed. After the designing of ratio, the fresh properties (filling ability, passing ability and segregation resistance) were investigated either satisfied the EFNARC specification or not. The water-cement ratio used in this research was 0.45.

For the purpose of the experiment five types of concrete mixes were made. In each mix natural coarse aggregate was replaced by recycled coarse aggregate in the ratio of 0%, 25 %, 50%, 75% and 100% by volume as shown in Table 2. The preliminary mix design was carried out using method prescribed for target strength of 30 MPa. The quantity of components required for making 1 m^3 of concrete was constant, with the exception of small variations in the quantity of superplasticizer for the purpose of achieving equal consistency for all the mixes.

Table 2 - Mix designation with respect to replacement percentage

Mix Designation	Coarse Aggregates	RCA
M0	100%	0%
M1	75%	25%
M2	50%	50%
M3	25%	75%
M4	0%	100%

3.2 Testing Methods

The testing was divided into two parts, one was the fresh properties testing and other was hardened properties.

3.2.1 Fresh-State Properties

The SCC is considered by its flowing ability, passing capability and resistance to segregation. The concrete to be considered as SCC it must satisfied the conditions shown in Table 3 recommended by EFNARC guidelines.

Table 3 - SCC recommendations by EFNARC guidelines

Meth	Un	Mi	Ma
Slump Flow	m	55	75
J-ring Test	m	0	1
Segregation	%	90	10

The slump flow test and t500 test aim at investigating the flow ability and the flow rate of SCC in the absence of obstructions. The filling ability of the concrete is studied by filling the concrete onto slump cone without any external compacting action such as vibrating. Fig. 3 shows the flow spread of SCC.

Fig. 3 - Flow spread of SCC

Fig. 4 shows the J-ring test aims to simulate a flow through reinforcement in an unconfined condition. It can also be used to investigate the resistance of SCC to segregation by comparing test results from two different portions of sample. The J-Ring flow spread indicates the restricted deformability of SCC due to blocking effect of reinforcement bars.

Fig. 4 - J-ring test

The sieve segregation resistance is used to assess the resistance of self-compacting concrete to segregation. The test aims at investigating the resistance of SCC to segregation by measuring the portion of the fresh SCC sample passing through a 5 mm sieve according to BS EN 12350-11:2010.

3.2.2 Hardened-State Properties

The compressive and splitting tensile strength of SCC containing the RCA were investigated by utilizing the British standards BS EN 12390-3:2009 [29] and BS EN 12390-6:2009 [30] respectively. The three samples of cubes having size 100mm x 100mm x 100mm and cylinders having diameter 100mm and 200mm height were tested for compressive and tensile strength for each sample at 7 and 28 days water curing regimes.

4 Results and Discussion

4.1 Fresh-State Properties

The fresh properties tests of SCC had been conducted during the casting process of the SCC specimen included the filling ability, passing ability and segregation resistance. The slump flow test, J-ring test and sieve segregation test were conducted respectively to determine the workability on every different design mix proportion of SCC specimen before placed into the mould. The design mix proportions were adjusted if the specimens were not passed any three workability tests of SCC.

The fresh properties result of SCC consisting the RCA are presented in Table 4. The slump flow test was conducted to examine the filling ability of SCC as shown in Fig.5 and Fig.6. All mixes show the slump flow in the limit of 610- 650, which showed that all considered mixtures are in the SF1 and SF2 class as per EFNARC guidelines which is widely utilizable class in civil engineering construction industry.

Table 4 - Fresh properties of SCC containing the RCA

Mix	Slump Flow	J-Ring Test	Segregation Resistance (%) <
M0	6	3	5
M1	6	5	5
M2	6	7	4
M3	6	7	3
M4	6	8	3

For filling ability of SCC, the EFNARC requirement for J-ring is ranging from 0 to 10 mm is counted adequate. The J-ring outcomes for all mixes are 0 to 7mm which encounter the requirement of passing ability and indicate that all mixes good passing ability even in the presence of dense reinforcement. The sieve segregation resistance is utilized to measure the resistance of self-compacting concrete to segregation.

The purpose of segregation resistance test is to analyze adhesion of SCC mix sample passing from 5mm sieve. The influence of RCA on the segregation resistance in illustrated in Fig.7.

If the SCC mix has low segregation resistance, the cement pastes easily pass from sieve. Therefore, the portion which passed from sieve indicated that either SCC mix is stable or not. In this research the segregation resistance was within the range from 4% to 8% which predicted that, SCC has high adhesion power which make the high segregation resistance to bleeding.

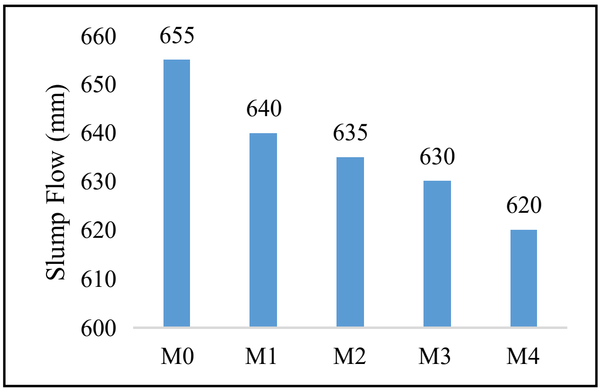

Fig. 5 - Percentage of RCA and its effect on slump flow SCC

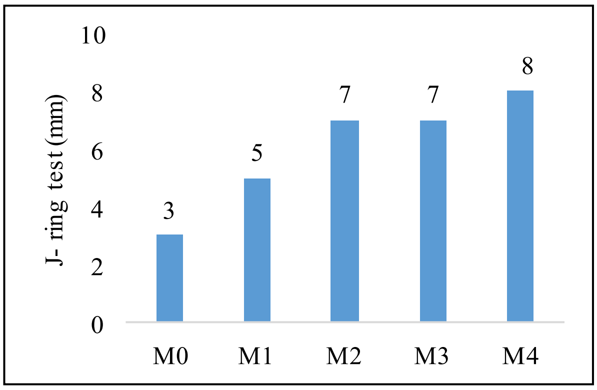

Fig. 6 - Percentage of RCA and its effect on J-ring flow of SCC

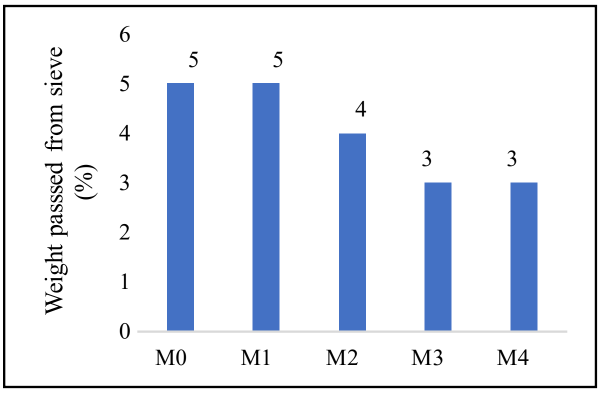

Fig. 7 - Effect of RCA on Segregation resistance of

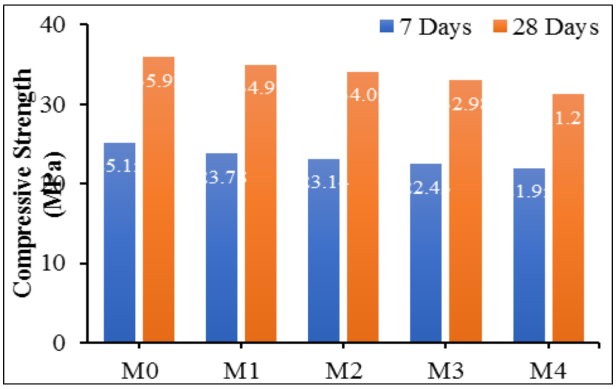

Fig. 8 - Compressive strength of SCC incorporating

From Fig. 5, Fig. 6 and Fig. 7 it is observed that slump flow decreased with the increment of RCA contain because the RCA water absorption is higher than the natural aggregate. The passing ability of SCC were significantly decreased when SCC consists the RCA. The segregation resistance increased with the addition of RCA in SCC.

4.2 Mechanical Properties

The compressive and splitting tensile strength were investigated at 7 and 28 days water curing.

4.2.1 Compressive Strength

The compressive strength outcomes of all specimen are presented in Table 5 and Fig. 8. From results it can be seen that all mixes achieved the target mean strength. The outcomes show that the compressive strength is significantly decreased with the addition of RCA in SCC. The decrement in strength because addition of RCA makes the poor adhesion bond which cause poor packing between particles.

Table 5 - Average compressive strength of SCC incorporating various percentage of RCA

Mix	Compressive Strength	
	7 Days	28 Days
M0	25.15	35.92
M1	23.78	34.97
M2	23.14	34.09
M3	22.43	32.98
M4	21.95	31.21

The compressive strength was decreased 4% to 6 % with the addition of RCA in SCC. The optimum percentage of RCA replacement was 25% which has almost same compressive strength to control sample.

4.2.2 Splitting Tensile Strength

The splitting tensile strength of all mixes is shown in Table 6 and Fig. 9. The outcomes demonstrate that splitting tensile strength of SCC was decreased with the addition of SCC. The splitting tensile strength decreased because the bond between the particles was not strong and the RCA were highly brittle compared to natural aggregates.

Table 6 - Average splitting tensile strength of RCA based SCC

Mix	Splitting Tensile Strength	
	7 Days	28 Days
M0	2.01	2.87
M1	1.90	2.79
M2	1.85	2.72
M3	1.79	2.63
M4	1.75	2.50

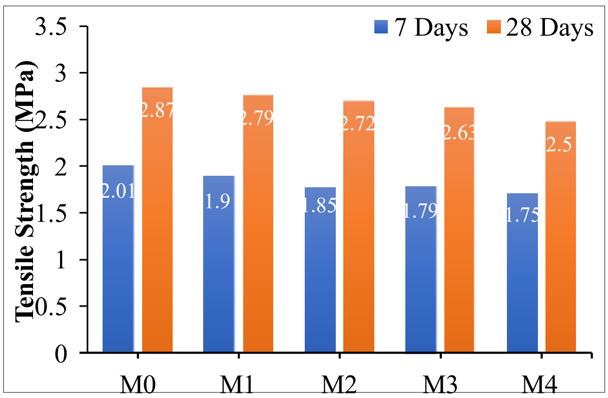

Fig. 9 - Splitting tensile strength of SCC incorporating RCA

4.2.3 Correlation between compressive and splitting tensile strength of SCC

The correlation between the two mechanical strength for SCC incorporating RCA was derived for 7 days and 28 days testing as shown in Fig. 10 and Fig. 11 respectively.

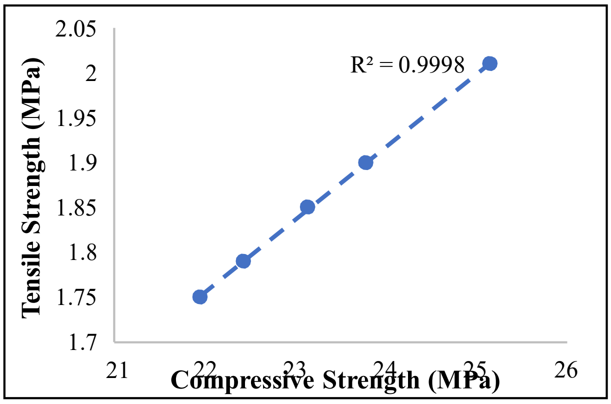

Fig. 10 - Correlation between 7 days compressive and splitting tensile strength of SCC incorporating RCA

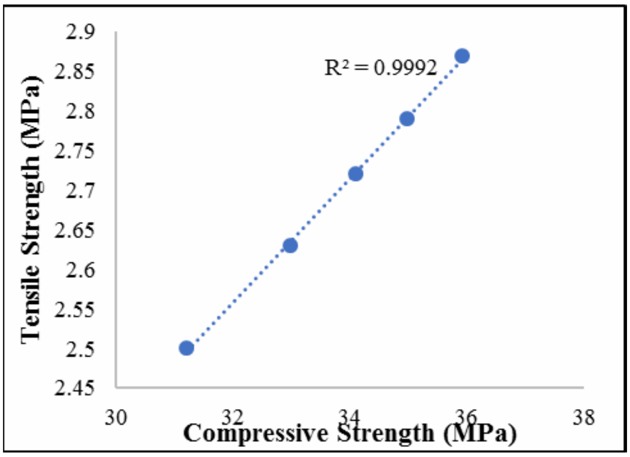

Fig. 11 - Correlation between 28 days compressive and splitting tensile strength of SCC incorporating RCA.

In statistical analysis, R-squared is a measure of how close the data are to the fitted regression line. The values of R-squared range from 0 and 1, where values closer to 0 indicate a poor fit while values closer to 1 indicate a perfect fit. From the correlations between the compressive and splitting tensile strength of SCC incorporating RCA, it can be observed that the R-square value is relatively high, indicating a near-perfect model, and decrease in compressive strength results in simultaneous decrease in splitting tensile strength of SCC.

5. Summary

Based upon the results obtained, it can be concluded that:

- The potential utilization of RCA in SCC is an appropriate solution for green and sustainable development in construction sector.
- The SCC retained its characteristics irrespective of the amount of RCA used to replace coarse aggregates in SCC.
- Self-compacting concrete consisting the RCA were obtained the target mean strength and satisfied the fresh characteristics required for SCC according to European Guidelines (EFNARC: 2005).
- The compressive and splitting tensile strength analysis presents that strength decrease slowly with the addition of RCA, as the amount of RCA increase the hardened and fresh properties behaves inversely because the interlocking between the concrete mix became poor.

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