

## STRENGTH AND DURABILITY OF SELF CONSOLIDATING CONCRETE CONTAINING RECYCLED MATERIALS

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*Submission date: 30 Sept 2018*

*Accepted date: 30 Dec 2018*

*Published date: 30 Jan 2019*

### Abstract

Self-Consolidating Concrete (SCC) is developing class of concrete materials that offers great potential to improved ease of positioning and cost through reduced time and labor. Generally, amount of Construction and Demolition Wastes (C&DW) are increased daily. Therefore, it is beneficial to final usage of coarse recycled concrete aggregate that produced from crushed concrete waste as a new construction solution. Researchers have found that waste materials have unique properties that could help in improving the quality of self-consolidating concrete produced. Therefore, reuse of RCA generated as the supplemental material for the replacement of aggregate are significant in reducing the environmental impact. This research was focused on the strength characteristic and the chloride permeability level of SCC containing RCA. The influence of RCA content in the range from 0% to 100% of Natural Aggregate (NA) to the strength characteristic and the chloride permeability level of SCC was identified and compared with SCC containing normal mixes. In this research, three (3) series of concrete specimens were cast with different water cement ratios (0.53, 0.49 and 0.45). The concrete specimens were subjected to strength at the age of 3, 7, 14, 21, 28, 56 and 90 days and durability at the age of 28, 56 and 90 days. The result shown that the compressive strength and chloride permeability of SCC containing 100% RCA replacement give better performance than the 0% RCA replacement. Based on the finding, SCC containing 100% RCA replacement can be categorized similar to conventional concrete hence it can be utilized for construction purposes. RCA can also acts as an alternative replacement in concrete for replacing the NA.

**Keywords:** Strength Properties; Rapid Chloride Permeability Test; Self Consolidating Concrete; Recycled Concrete Aggregate

### 1.0 INTRODUCTION

The terms Self-compacting concrete (SCC) is not a new technology to the construction industry and becoming progressively used in civil engineering due to its ability. In addition, SCC is known as a concrete

that has high performance, which has no requirement towards vibration or compaction effort due to its flowability and capability in filling and achieving full compaction in reinforcement (Hamzah et al, 2016; Kushwaha et al., 2013). The workability of SCC is achieved with the increases of the fine aggregates and filler, also an adequate amount of superplasticizer, hence it can completely fill the formwork by their own weight (Helincks, Boel, De Corte, De Schutter, & Desnerck, 2013). All of SCC behaviors lead to the reduction of construction cost and time. Reductions of the permeability and improving the durability of concrete are some of the others improvement to the concrete other than facilitating constructability and ensuring good structural performance (Shi, Wu, Lv, & Wu, 2015).

The SCC is firstly developed in Japan at University of Tokyo during the late 1980s in collaboration with leading contractors (Naik & Kumar, 2001; Shameen & Naveedul, 2015). This statement also being supported which it is said that SCC first developed in 1988 in Japan for having a higher durability of concrete (Mohan, Salim, and Survesh, 2013). Apart from that, Mohan et. al. (2013) indicates that the first paper had been published in 1992 by Ozawa et al. from University of Tokyo about modern SCC. It is also been found that Kochi University of Technology, Japan had held the first significant international workshop in August 1998 devoted to the material. This technology has been introduced since Japan having the problem of lack of skilled labor (Naik & Kumar, 2001). The SCC helps in solving this problem with their ability to place without the use of compactor or a vibrator. Mohan et. al. (2013) identified that Sweden had begun the development and research at the 1990s and now the technology is spreading to all of other countries.

SCC is a strongly dependent on the composition, a sensitive mix and the characteristics of its constituents. It has to possess the incompatible properties of high segregation resistance together with high flowability. SCC consists of the same ingredients as conventional concrete such as cement, aggregates, water, additives and admixtures with regard to its composition.

The quality and properties of aggregate are the major factors to produce concrete. The use of construction and demolition waste as a source of aggregate for the production of new concrete has become more common. The increasing charges for landfill, on the one hand, and the scarcity of natural resources of aggregate, on the other hand, encourages the use of waste from construction sites as a source for aggregates. Aggregate is an important component material used to produce concrete whereby about 75% of concrete mixtures consist of aggregates (Kothai & Malathy, 2014). The Freedonia Group (2009) reported that the worldwide demand for coarse and fine aggregates is forecasted to increase 2.9 percent annually through 2013 to 28.7 billion metric tons, valued at \$128 billion. The demand for the natural aggregates has caused an increase in the exploitation of aggregate sources that eventually lead to their scarcity (Ridzuan, Fauzi & Kassim, 2011). Thus, the need for preserving the natural resources from exhaustion and finding the proper way to reuse the construction waste material.

The disposal of demolished concrete from old structures and other sources of concrete wastes in landfill is currently a bad strategy because of the declining availability of disposal space and other environmental concern. An effective way to reduce the shortage of aggregates is to reuse concrete waste as recycled aggregate for the production of Recycled Concrete Aggregate (RCA).

This paper presents the investigation of SCC in fresh and hardened states containing coarse RCA. The aim of this research was to evaluate the effects of RCA on workability, compressive strength and rapid chloride permeability of SCC.

## 2.0 MATERIALS AND METHOD

### 2.1 Material Selection

Cement, fine and coarse natural aggregate (NA), coarse RCA, Superplasticizer and water were used in this research to produce the SCC.

Ordinary Portland Cement (OPC) was used as a binder. OPC used is in compliance with BS EN 197-1:2000 because it has a medium rate of hardening and is suitable for most type of work. The physical properties and chemical composition using X-ray Fluorescence (XRF) test of cement used in the present research are shown in Table 1 and Table 2 respectively.

Table 1: Physical properties of OPC used

Physical Properties	
Relative Density	2.25
Surface Area	13000 cm <sup>2</sup> /g
Ph	11-12
Colour	Grey
Particle Size, D90	11 µm

Table 2: Chemical composition of OPC used

Oxide	Percentage
SiO <sub>2</sub>	15.05
CaO	72.17
Al <sub>2</sub> O <sub>3</sub>	2.56
Fe <sub>2</sub> O <sub>3</sub>	4.00
MgO	1.27
MnO	0.06
Na <sub>2</sub> O	0.08
K <sub>2</sub> O	0.41
SO <sub>3</sub>	2.90
P <sub>2</sub> O <sub>5</sub>	0.06
TiO <sub>2</sub>	0.12
LOI	1.33

River sand was used as fine aggregate. Fine aggregate which in properly graded is essential to successful execution of the work. Fine aggregate that was used is in maximum size of 5 mm.

Coarse aggregates was crushed mining aggregate. The maximum size of aggregate is 20 mm. The size of the aggregate selected was according to BS EN 933-1:2012. The coarse aggregate content in SCC is kept either equal to or less than that of the fine aggregate content (EFNARC, 2005).

The coarse RCA was obtained from the batching plant at Global Prefab System Sdn. Bhd., Cyberjaya, Selangor. The jaw crusher was used to get recycled aggregate, and then, the RCA was graded to the size required by using the grading machine. The coarse RCA was compliance to BS 8500-1:2006+A1: 2012. Maximum size of recycled concrete aggregate is usually 20 mm. RCA obtained was from normal concrete which is of grade 40 N/mm<sup>2</sup>, to ensure the consistency of the source.

Tap water was used to mix the concrete as it is considered being cleaned and free from dirt and organic matter. The quality of water is according to the Public Work Department of Malaysia, adopted from BS EN 1008:2002, for concrete work specifications.

The type of superplasticizer (Sp) used in this research is GLENIUM ACE 388, also known as Poly Carboxylic Ether (PCE). For all batches, 1.0 Liter (of 100 kg of cementitious weight) of Sp was added to concrete mixture. This amount of Sp is based on the cementitious weight that been used for that batch.

## 2.2 Experimental Methods

This research was carried out to identify the compressive strength properties and durability of SCC containing different percentages of coarse RCA replacement which are 0%, 30%, 50%, 70% and 100% of NA coarse aggregate for water cement ratio is 0.53, 0.49 and 0.45 of concrete. The SCC properties covered in this study include properties for the fresh and hardened state of the SCC. For this research, the dimension size of the specimen was 100mm x 100mm x 100mm for compressive strength and 50mm x 100mm (diameter) for rapid chloride permeability. The effect of adding coarse RCA on compressive strength and rapid chloride permeability of SCC was determined at the age 3, 7, 14, 28, 56 and 90 days.

## 2.3 Design of Mix Proportion

The basic components for mixed composition of SCC are similar with mix that was used in conventional concrete. The concrete mix for this study was designed in two stages. The SCC mix for this study was designed based on the British method Department of Environment revised in 1988 (Aginam, Umenwaliri & Nwakire, 2013) to determine the indicative quantity by weight of the cement content, free water and total aggregates. The mix proportions for water cement ratio (w/c) of 0.45, 0.49 and 0.53 are as shown in Table 3.

Table 3: Mix proportion used in this research

W/C Ratio	RCA Coarse Replacement (%)	Cement (kg)	Water (kg)	Sand (kg)	Mix Proportion (kg/m <sup>3</sup> )				Superplasticizer (liter)
					Coarse Aggregate (kg)		Coarse RCA (kg)		
					10 mm	20 mm	10 mm	20 mm	
0.53	0	390	205	890	300	590	0	0	3.9
	30				210	413	90	177	
	50				150	295	150	295	
	70				90	177	210	413	
	100				0	0	300	590	
0.49	0	420	205	875	290	580	0	0	4.2
	30				203	174	87	174	
	50				145	290	145	290	
	70				87	174	203	174	
	100				0	0	290	58	
0.45	0	455	205	855	285	570	0	0	4.55
	30				199	399	86	171	
	50				143	285	142	285	
	70				86	171	199	399	
	100				0	0	285	570	

## 2.4 Casting and Curing

The process of casting is where the concrete mix is poured into steel mould. The specimens were produced in the cube and cylinder shape. The dimension for the cube is 100mm x 100mm x 100mm and the cylinder is 100mm (diameter) x 50mm.

The specimens were demoulded after 24 hours casting and cured in water until the testing date. The method of curing was according to BS EN 12390-2:2009. The concrete specimens were subjected to strength at the age of 3, 7, 14, 21, 28, 56 and 90 days and durability at the age of 28, 56 and 90 days.

## 2.5 Test Procedures

There are two type of test procedures were carried out which are fresh concrete procedures and hardened concrete procedures.

The fresh concrete tests conducted for this research were slump flow test for measuring flowability and L-box test for measuring passing ability. The test method is based on the conventional slump test as in accordance to British Standard BS EN 206-9:2010. The diameter of the concrete circle is a measure for the flowability of the concrete. The L-box test was conducted in accordance to BS EN 12350-10:2010. This test consists of L-shaped boxed in which the vertical and horizontal ends are separated by a sliding door. The ratio of the vertical section ( $h_1$ ) and at the end of the horizontal section ( $h_2$ ) is an indication of the passing ability of the concrete.

After curing, the specimens of SCC were tested for compression and rapid chloride permeability test. The compressive strength was tested as accordance to BS EN 12390-3:2009. The rapid chloride permeability was tested in accordance to ASTM C1202-12.

## 3.0 RESULT AND DISCUSSION

### 3.1 Fresh Properties of SCC

Fresh concrete produced in this study were tested for flowability and passing ability to satisfy the requirement for self-consolidating concrete before the concrete specimens were casted. The results of the slump flow test and the L-box test of the concrete are shown in Table 4.

Table 4: Slump flow and passing ability of SCC

W/C	Mixes	Slump Flow (mm)	Passing Ability
0.53	NAM1	693	0.89
	RCA 1 – C30	660	0.83
	RCA 1 – C50	655	0.86
	RCA 1 – C70	640	0.91
	RCA 1 – C100	620	0.82
0.49	NAM2	680	0.92
	RCA 2 – C30	665	0.87
	RCA 2 – C50	640	0.83
	RCA 2 – C70	620	0.82
	RCA 2 – C100	615	0.82
0.45	NAM3	690	0.92
	RCA 3 – C30	675	0.88
	RCA 3 – C50	650	0.90
	RCA 3 – C70	620	0.86
	RCA 3 – C100	580	0.84

Slump flow value describes the flowability of a fresh mix in the unconfined conditions. In this research, the slump flow diameter of all specimens tested lies between 580mm and 693mm. The acceptable range for SCC is from 550 mm to 800 mm (BS EN 206- 9:2010). The results indicated that increasing percentage of RCA replacement content in the fresh concrete resulted in detrimental effect of the fresh SCC flowability even though more free water would be absorbed by increased RCA content which has high water absorption rate.

The Passing Ability (PA) of the fresh concrete for this study was ranged between 0.80 and 0.92. The acceptance criterion for SCC by EFNARC (2005) with regard to passing ability is between 0.8 and 1.0. Therefore all specimens for this study satisfied the acceptance criteria by EFNARC (2005) for SCC.

The specimen mix with RCA has an acceptable range on workability for both of the tests conducted as the values obtained satisfied the criteria for SCC by EFNARC (2005). The 0% replacement of RCA acts as a control sample. The other samples which show other percentage replacement of RCA indicated lower flow as compared to control sample. The composition of RCA containing angular shape and roughness of aggregates improves the workability of SCC mixes. The normal SCC mixes showed a higher slump on slump flow and higher ratio on L-box. This is because of the NA in the SCC mixes that present in concrete mixes are of round shapes therefore perform higher workability. Meanwhile, the slump flow and L-box for the replacement of RCA in SCC mix is lower than normal SCC due to high water absorption of RCA which is adjusted by water cement ratio range. All the results of the slump flow test and L-Box test are comparable and can be accepted due to the workability term.

### 3.2 Compressive Strength of SCC

The compressive strength is one of the most important properties in evaluating the performance and quality of the concrete. Compressive strength development of SCC containing RCA and normal SCC is shown in Figure 1 (a-c). As for each mix of SCC, strength development of SCC containing RCA is the similar to normal SCC. Hence with the same design strength, SCC containing recycled concrete mix showed higher compressive strength compared to normal SCC mixes. Figure 1 (a-c) show the value of in compressive strength of SCC containing coarse RCA (RCA-C30, RCA-C50, RCA-C70 and RCA-C100) with normal SCC for every water cement ratio series.

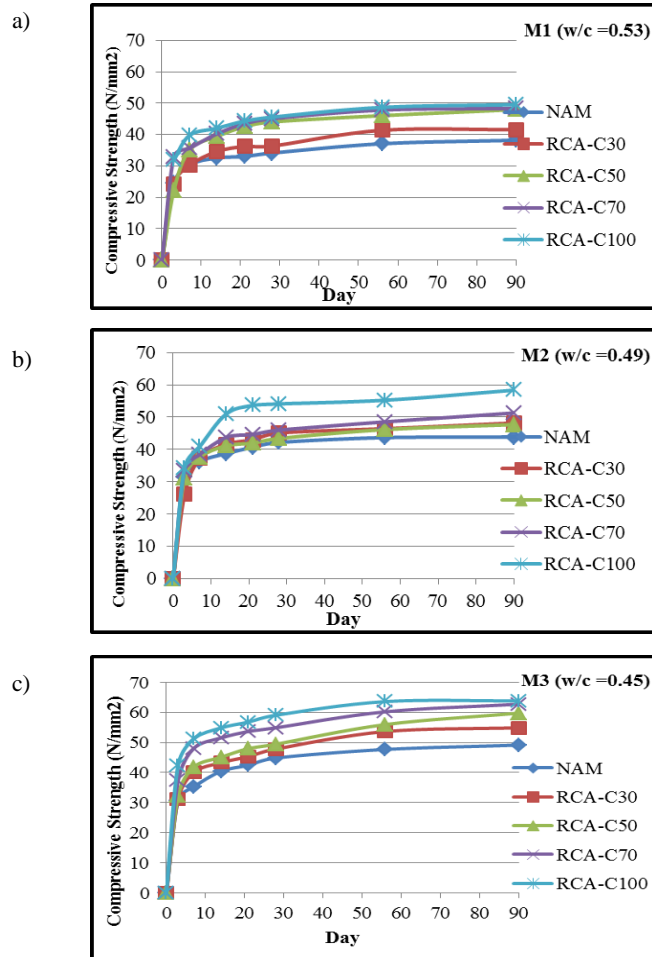


Figure 1 (a-c): Compressive strength development of SCC containing coarse RCA and normal SCC

The compressive strength difference is increased day by day. This trend is similar with another series of RCA SCC. Against the SCC mixture RCA-C30, RCA-C50, RCA-C70 and RCA-C100, it was found that the SCC with 100% of RCA (RCA-C100) is of higher strength than other SCC mixtures. The SCC containing 100% of RCA (RCA-C100) may be attributed due to high water absorption of RCA which reduce water content effectiveness, hence water cement ratio of the RCA mix resulting in higher compressive strength than the corresponding NA mix, shape of the RA which are more angular with rough texture provided better bonding to concrete matrix compared to natural aggregates.

The highest value of compressive strength of the SCC is achieved by RCA against normal SCC may be due to two main factors which likely caused by shape and texture of aggregate recycling and high water absorption by RCA from natural granite stone aggregate. The angular shape and rough texture were to create a better bonding strength than NA. In addition, higher water absorption by coarse RCA resulted in more porous texture as it contains old mortar attached. In general, effective water cement ratio mixture of SCC-RCA is reducing compared to normal SCC. The result is due to more cement particles that promote faster hydration process and production of cement gel. Therefore, higher compressive strength is obtained and accelerated at an early age concrete.

### 3.3 Rapid Chloride Permeability of SCC

Figure 2 (a-c) shows the result for the rapid chloride permeability test for SCC containing RCA and normal SCC cured in water. This figure showed the charge passed in coulomb of rapid chloride permeability of SCC containing RCA compared normal SCC versus day.

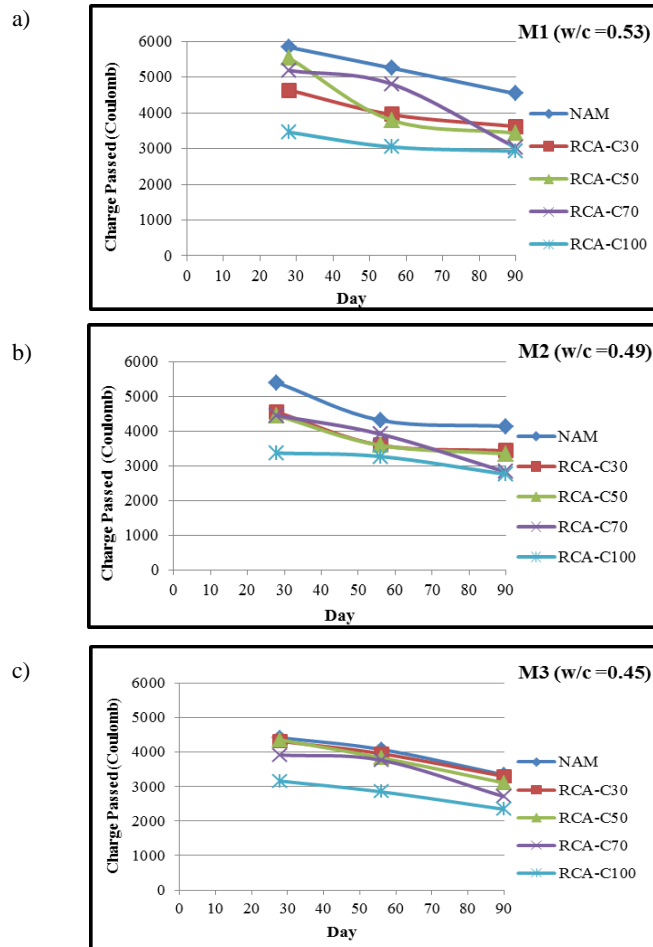


Figure 2 (a-c): Rapid chloride permeability of SCC containing coarse RCA and normal SCC

From the rapid chloride permeability result, all SCC samples of rapid chloride permeability can be evaluating categorized as high and moderate at the age of 28-day and 90-day respectively. Each mix of SCC, rapid chloride permeability development of SCC containing RCA is similar to normal SCC. This is because the chloride permeability of concrete surface produced high charge passed if the concrete contain many pores.

Figure 2 (a-c) shows that the trend of charge passed in normal SCC under rapid chloride permeability is slightly decreasing. This trend is similar with another series of RCA SCC. Again it was found that the SCC with 100% of RCA (RCA-C100) is lower in term of charge passed (coulomb) than other SCC mixtures (RCA-C30, RCA-C50, RCA-C70 and RCA-C100).



The rapid chloride permeability of RCA-C100 is better than normal SCC. A similar situation is shown by concrete RCA-C30, RCA-C50 and RCA-C70 for each series where rapid chloride permeability of RCA-SCC is better than normal SCC.

The difference in the rapid chloride permeability of SCC mix (RCA-C30, RCA-C50, RCA-C70 and RCA-C100) was that it has better charge passed at the oldest age of 90 days, compared to 28 days. This indicated that the hydration process of cement and waste paper sludge ash in RCA SCC slowly reduced and the decreased rate in chloride permeability is less than normal SCC. Hameed (2009) stated the more permeable the concrete, the higher the coulombs and the less permeable the concrete, the lower the coulombs.

### 3.4 Relationship between Compressive Strength and Rapid Chloride Permeability of SCC

Figure 3 shows the relationship between rapid chloride permeability with compressive strength of SCC containing coarse RCA and normal SCC at the age 90 days.

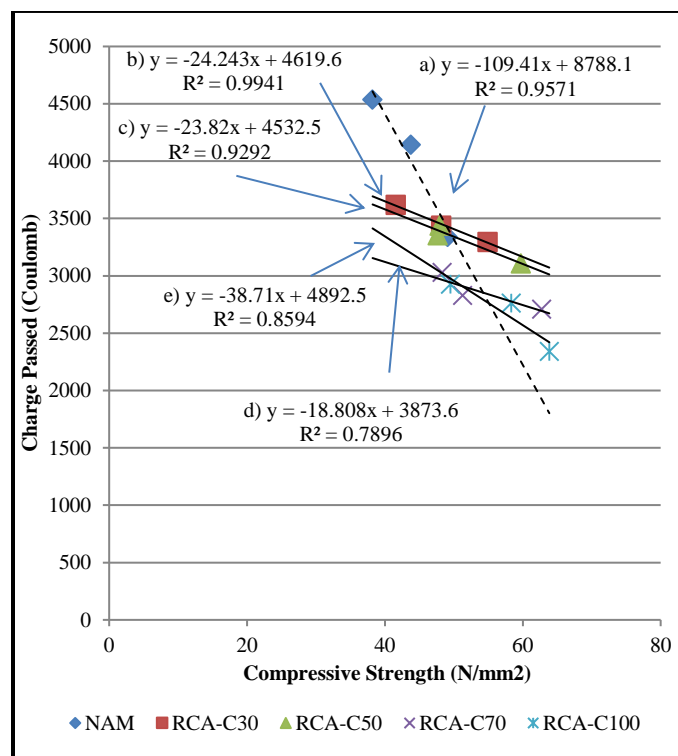


Figure 3: Relationship between RCPT with compressive strength of SCC containing coarse RCA and normal SCC (90 day)

From figure 3 shows that rapid chloride permeability and compressive strength of SCC containing RCA for 90 days compared to normal SCC is equal for all replacements of RCA. This relationship shows that rapid chloride permeability of SCC containing RCA and normal SCC decreased when compressive strength is increased for 90 days. This indicated that rapid chloride permeability property of SCC containing RCA is similar with normal SCC.

Based on the regression analysis, the relationship equations between rapid chloride permeability tests with compressive strength were obtained in the following form;

$C_p = -109.41C_s + 8788.1$	For Normal SCC	(7.1)
$C_p = -24.243C_s + 4619.6$	For RCA-C30 SCC	(7.2)
$C_p = -23.82C_s + 4532.5$	For RCA-C50 SCC	(7.3)
$C_p = -18.808C_s + 3873.6$	For RCA-C70 SCC	(7.4)
$C_p = -38.71C_s + 4892.5$	For RCA-C100 SCC	(7.5)

Where;  $C_p$  is charge passed (Coulomb) for rapid chloride permeability (cylinder) and  $C_s$  is compressive strength (cube).

From the regression analysis, the best regression equation for the relationship between rapid chloride permeability and compressive strength is available in the form of inverse linear function as follow;

$$C_p = -AC_s + B \quad (7.6)$$

Where  $C_p$ , is charge passed (coulomb) for rapid chloride permeability at 90 day and  $C_s$ , is compressive strength (cube) at 90 day.

This figure exhibits a good correlation relationship between rapid chloride permeability and compressive strength, which coefficient of determination ( $R^2$ ) for all SCC containing RCA and normal SCC has a value close to 1. According to Wee, Suryavanshi & Tin, (2000), the charge passed was shown to be related to compressive strength of SF and GGBFS concrete; compressive strength increases linearly with the charge passed decreasing. According to research by Kartini, Mahmud & Hamidah (2010) stated that the correlation suggested the presence of an inverse type of relationship between compressive strength and w/c ratio; the lower the charge passed through the concrete mixture, the higher the compressive strength, i.e. the compressive strength increases linearly with a decreasing charge passing through the concrete.

#### 4.0 CONCLUSION

The following conclusions can be drawn from the experimental works carried out in this research:

1. The RCA used in this research is suitable to be used as a concrete aggregate.
2. The compressive strength of SCC containing RCA can achieved the target strength. The compressive strength of SCC containing 100% of RCA is comparable to SCC using normal aggregate for all the three water cement ratios of 0.53, 0.49 and 0.45.
3. The compressive strength of SCC containing RCA increases as the percentage of RCA replacement increases.
4. The SCC containing RCA shows lower charge passed of rapid chloride permeability compared to normal SCC, therefore it has better resistance to the penetration of chloride ions.
5. The relationship between compressive strength of SCC containing RCA and charge passed of rapid chloride permeability gave a inverse linear correlation in which rapid chloride permeability of SCC containing RCA and normal SCC decreased when compressive strength increased.

#### Acknowledgement

The author would like to acknowledge the Research Management Institute for providing the “Geran Inisiatif Penyelidikan” (GIP) (600-IRMI/GIP 5/3 (0004/2016)) and Faculty of Civil Engineering, Universiti Teknologi MARA for providing the facilities to accomplish the experimental work for this research.

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