HIGH EARLY STRENGTH OF SELF-CONSOLIDATING CONCRETE INCORPORATING QUA-SI-RHA

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ABSTRACT

Self-consolidating concrete (SCC) is an innovative construction material that can be placed into forms without mechanical vibration and able to flow and consolidate under its own weight, and completely fill the formwork even in the presence of dense reinforcement. Self-consolidating concrete, a latest innovation in concrete technology is being regarded as one of the most promising developments in the construction industry due to numerous advantages of it over conventional concrete. The use of mineral additives in SCC was also found to produce other advantages such as enhancement of SCC properties in fresh and hardened states, reuse of industrial and agricultural by products in concrete production and reduction of greenhouse gases into the atmosphere. Thus, the incorporation of Qua-Si-RHA which are the combination of Quarry Dust (Qua), Silica Fume (Si) and Rice Husk Ash (RHA) as supplementary cementitious material and fine aggregate replacement in SCC was investigated. The high-range superplasticizer, water reducer was used as the chemical admixtures which can enhance the rheological properties of concrete.This study presents the results of a laboratory investigation of conventional vibrated concrete and SCC with eco-friendly and sustainable materials. The workability test and compressive strength test were conducted to determine properties of fresh and hardened conventional concrete and SCC. The early strength of conventional and SCC concrete cubes were tested after 24 hours of casting. As expected, the innovation material incorporating Qua-Si-RHA in SCC resulted in high workability performance and high early strength self-consolidating in concrete.

Keywords:
High Early Strength, Self - Consolidating Concrete (SCC), Quarry dust (Qua), Silica Fume (Si), Rice Husk Ash (RHA).

1.0 INTRODUCTION

Self - consolidating concrete (SCC) also known as self-compacting concrete was first developed in 1988 by Professor Okamura to achieve durable concrete structures that do not require any vibration for placing and compaction in concrete (Okamura & Ouchi, 2003). SCC is defined as concrete that is able to flow and consolidate under its own weight, completely filling formwork even in the presence of congested reinforcement (Kushwaha *et al.*, 2013).

SCC consists of the same components as conventional vibrated concrete which are cement, water, fine and coarse aggregates with the addition of different proportions of chemical and mineral admixtures. The high-range water reducers (superplasticizers) and viscositymodifying agents (VMA) can be used as the chemical admixtures which can change the rheological properties of concrete (Kushwaha *et al.*, 2013).

Silica fume is the mineral admixture while quarry dust and rice husk ash are the industrial and agricultural by products in concrete production. Due to the depletion of natural sand, quarry dust can be used as partial fine aggregate replacement and silica fume and rice husk ash can be used as partial cement replacement in order to reduce the use of cement in a high paste concrete. The use of mineral additives and reusing of industrial and agricultural by products in SCC can enhance the properties in fresh and hardened concrete and at the same time reduce the amount of greenhous gases into the atmosphere (Atan & Awang, 2011). Furthermore, Malaysia Quarries Association reported that there were 322 quarries throughout the country which manufactures granite and limestone (Malaysia Quarries Association, 2004). Thus, by replacing the fine aggregates with quarry dust in concrete, it is hoped that it can reduce the environmental impact and economic problem. The disposal of rice husks into landfill create environmental problem that leads to the alternative idea of substituting rice husk ash in concrete production The content of silica in the rice husk ash is reported about 92-97% (Kartini, 2011). Other than that, by adding a large volume of powdered material can eliminate segregation in concrete (Aggarwal *et al.*, 2008).

Strength performance of concrete is among the problem that had been raised up nowadays. Sufficient compaction and vibration by skilled workers are required in order to enhance the durability performance of concrete. SCC has been used in wide world for placement in congested reinforcement concrete structures where casting conditions are difficult and where pump ability properties are required especially in high rise building. The uniformity of SCC mixtures reduces the permeability which can enhance and increase the performance of concrete. Therefore, the development of SCC enhances the concrete lifespan compared to conventional vibrated concrete (Singh *et al.*, 2013).

Kartini (2011) reported the increased of rice husk ash in the mix resulted in a dry and unworkable mixtures unless Sp is added. Thus, by including the superplasticizer in concrete while maintaining the w/b ratio, the slump and cohesiveness of the concrete will be improved. Rai *et al.* (2016) studied the different percentages replacement of river sand by quarry waste, 0%, 10%, 20%, 30%, 40%, 50%, 70%, and 100% to determine the flowability characteristics of SCC. According to their research study, it can be concluded that at 30% replacement of fine aggregate by quarry waste, the slump flow was observed to be consistent. Thus, river sand replacement of 30% with quarry waste is recommended.

Johnsirani *et al.* (2013) investigated on self-compacting concrete (SCC) with sand replacement of a quarry dust with different percentages of 0%, 25%, 50%, 75%, 100%. The addition of mineral admixtures like fly ash and silica fume and chemical admixtures like super plasticizers had been used. It was reported that, by replacing fine aggregate to quarry dust the strength values decreases gradually after 25% of replacement of quarry dust and in the case of 100% replacement, the compressive strength will highly decrease.

Nowadays, the development of SCC is a desirable achievement in construction industry in order to overcome the problems related with cast-in-place concrete as there is no additional inner or outer vibration needed for the compaction (Kushwaha et al., 2013). The SCC that has been adopted by a large number of precast operations that eliminates the need for vibration and also reduces the labour requirement for SCC placement. Therefore, the energy consumption associated with vibration can also be removed. Thus, the formwork used is no longer subjected to stresses of vibration which reduces the initial cost and maintenance cost of formwork. Other benefit by eliminating vibration in concrete is the noise reduction that increase the worker productivity by reducing noise-induced and vibration-induced illnesses and at the same time improves the working environment and safety (Ahmadi *et al.*, 2007).

Therefore, this study presents the results of a laboratory investigation of conventional vibrated concrete and SCC containing eco-friendly and sustainable materials. Slump flow test was conducted to compare the concrete workability and compressive strength test was conducted to determine the early strength of conventional vibrated concrete and SCC incorporating Qua-Si-RHA.

The early strength of conventional vibrated concrete and SCC concrete cubes were tested after 24 hours of casting. The result of workability test, compressive strength test and the relationship between workability test and compressive test of conventional vibrated concrete and different mixture designation of Qua-Si-RHA in SCC was investigated in this study. Thus, the early strength of self-consolidating concrete incorporating Qua-Si-RHA was investigated in this study which the Qua-Si-RHA are the combination of Quarry Dust (Qua), Silica Fume (Si) and Rice HuskAash (RHA). Quarry dust had been use as partial fine aggregate replacement while silica fume and rice husk ash had been used as supplementary cementitious material in SCC. High-range superplasticizer, water reducer was used as the chemical admixtures which can enhance the rheological properties of concrete.

2.0 EXPERIMENTAL PROGRAMME

2.1 Material Preparation

The material used in this study were Ordinary Portland Cement, water, sand, gravel, quarry dust, silica fume, rice husk ash and superplasticizer. The rice husk and rice husk ash was obtained from Seri Tiram Jaya Mill in Kuala Selangor, Malaysia. The rice husk was burnt in a ferrocement furnace to produce rice husk ash and were grinded and sieved with maximum size 150µm. Sand and quarry dust with maximum passing size 5 mm sieve, coarse aggregates from crush granite gravel with maximum size 10 mm sieve while silica fume was sieved with maximum size 150µm were used. Quarry dust, silica fume and superplasticizer are shown in Figure 2, Figure 3 and Figure 4 while Figure 5 shows the rice husk ash preparation as SCC admixtures used in this study.

Figure 2: Quarry dust

Figure 3: Silica Fume

Figure 4: Superplasticizer

(a) (b) (c)

Figure 5: Rice husk ash preparation: (a) Rice husk, (b) Rice husk ash before sieving, (c) Rice husk ash passing 150 µm sieve, ≤150 µm

2.2 Mix Design Proportion

The conventional vibrated concrete or also known as control specimen of concrete grade 40 N/mm² and concrete mix with water cement ratio of 0.45 was designed using DOE method (DOE, 1988). Different mixture designation of QuaSiRHA10, QuaSiRHA20, QuaSiRHA30 with different percentages consist of 10%, 20% and 30% of quarry dust (Qua) to replace sand as partial fine aggregate replacement with constant 5% of silica fume (Si) and 5% of rice husk ash (RHA) of total cement as supplementary cementitious material. The superplasticizer of 2.5% was added as water reducer in SCC. The proportion of partial fine aggregate replacement and supplementary cementitious material were designed based on volume replacement. Summary of concrete mix design for control mix and different proportion of triple blended Qua-Si-RHA in SCC is shown in Table 1.

Table 1: Concrete Mix Proportion

Mixture Designation	**Concrete Mix Proportion (kg/m³)**							
	Cement	**Water**	**Sand**	**Gravel**	**Qua**	**Si (5%)**	**RHA (5%)**	**Sp (2.5%)**
Control	440	198	840	840	-	-	-	-
QuaSiRHA10	406.8	198.0	750.1	840.0	89.9	16.9	16.3	11.3
QuaSiRHA20	406.8	198.0	660.2	840.0	179.8	16.9	16.3	11.3
QuaSiRHA30	406.8	198.0	570.4	840.0	269.6	16.9	16.3	11.3

*Qua=Quarry dust, Si= Silica fume, RHA= Rice husk ash, Sp = Superplasticizer

2.3 Specimens Preparation

The constituent materials need to be thoroughly mix together to produce a uniform color and consistence in the concrete batch. Method for mixing complies with BS 1881: Pt. 125: 1986. Size of rectangular concrete specimens measuring of 150mm x 150mm x 150mm were casted as shown in Figure 6. All concrete specimens for control, QuaSiRHA10, QuaSiRHA20, QuaSiRHA30 were demoulded and tested in concrete laboratory after 24 hours.

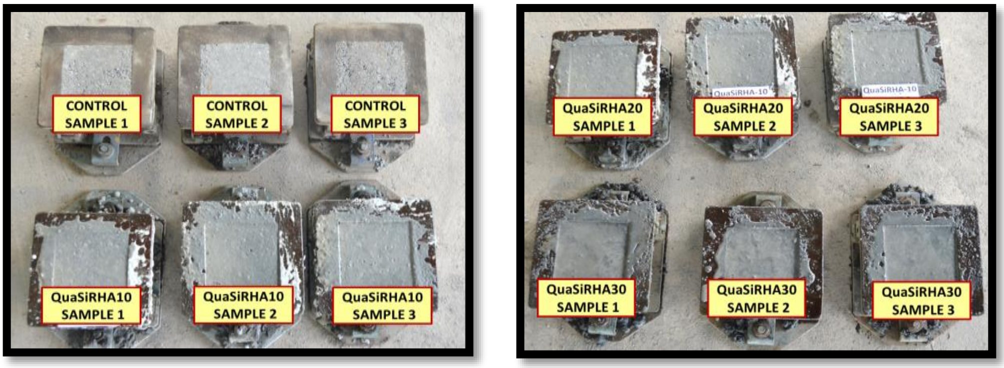

Figure 6: Concrete specimens for control, QuaSiRHA10, QuaSiRHA20, QuaSiRHA30

2.4 Test Methods

2.4.1 Slump Flow Test

Slump flow test was conducted in accordance to BS EN 12350-8:2010 to determine the workability of concrete as shown in Figure 7. The cone is lifted and the diameter of the concrete after the flow has stopped is measured. The average diameter of the concrete circle is a measure for the filling ability of the concrete. The slump flow test measures the capability of concrete to deform under its own weight against the friction on the surface of the base plate with no other external resistance present.

Measurement of slump-flow indicates the flowability of self- consolidating concrete and determines the consistency and cohesiveness of the concrete. Slump flow ranging from 500 to 700 mm (20 to 28 inches) is considered as a proper slump required for a concrete to qualify for self-consolidating concrete. The slump flow diameter less than 500 mm indicates the concrete is considered to have insufficient flow to pass through congested reinforcement while slump flow diameter more than 700 mm indicates the segregation of concrete might occur.

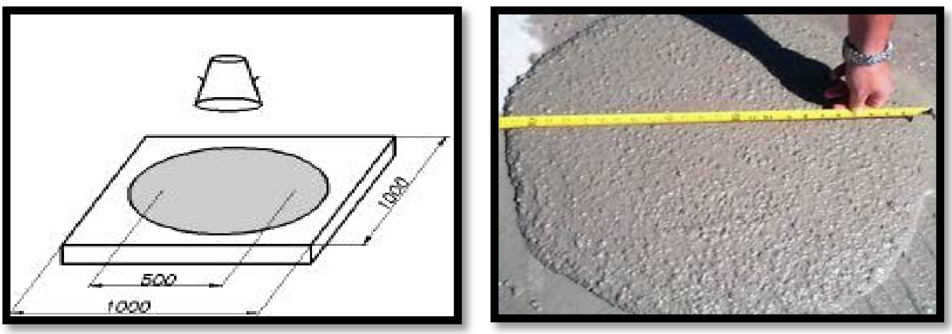

Figure 7: Slump Flow Test (BS EN 12350-8:2010)

2.4.2 Compressive Strength Test

Compressive strength test was conducted in accordance to BS EN 12390 – 3: 2009 to determine the early strength of hardened concrete as shown in Figure 8. Size of rectangular concrete specimens measuring of 150mm x 150mm x 150mm were casted. All concrete specimens were demoulded and tested in concrete laboratory after 24 hours. The specimens were dried before tested. The load was applied on the smooth sides without shock and increased continuously until the failure of the specimen.

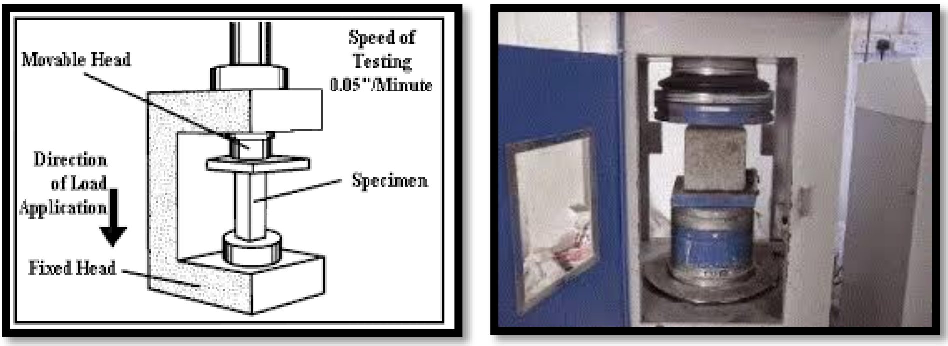

Figure 8: Compressive Strength (BS EN 12390 – 3: 2009)

3.0 DATA AND ANALYSIS

3.1 Workability Test Result

The graph result of slump flow diameter for control concrete and SCC with different mixture designation of triple blended Qua-Si-RHA for this research study is shown in Figure 9. The slump flow diameter of the SCC mixes with different designation QuaSiRHA10, QuaSiRHA20, and QuaSiRHA30 in SCC increased with the increase of quarry dust consist of 10% to 30% as fine aggregate replacement, constant 5% silica fume and 5% rice husk ash as cement replacement which are 515 mm, 525 mm and 555 mm. The slump flow diameter for QuaSiRHA10, QuaSiRHA20, and QuaSiRHA30 in SCC are more than 500 mm and it can be considered as a proper slump required for a concrete to qualify for self-consolidating concrete.

The workability of SCC increased with the increase percentages of quarry dust due to it physical properties and classified as less water absorbent material than sand. Additionally the usage of superplasticizer in SCC increases the workability exponentially even though the water cement ratio for control and SCC with triple blended QuaSiRHA are the same.

The replacement of rice husk ash in the mix resulted in a dry and unworkable mixtures unless superplasticizer is added. The inclusion of superplasticizer in concrete while maintaining the water cement ratio increased the workability and improved the cohesiveness of the concrete (Kartini, 2011). The addition 2.5% of superplasticizer in SCC absorbed into the cement particles, and imparts a strong negative charge, which helps to lower the surface tension of the surrounding water considerably and thus, greatly enhances the fluidity of the mixes. Therefore, the increases of slump flow diameter with the increase of quarry dust percentages and additional of superplasticizer improve the workability of SCC than conventional vibrated concrete. It indicates the optimum slump flow diameter for this research study is QuaSiRHA30 in SCC.

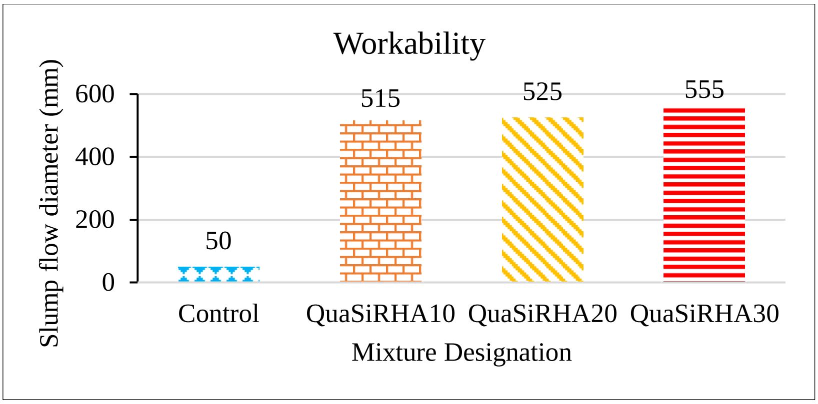

Figure 9: Workability of Concrete Mixture Design

3.2 Early Compressive Strength Test Result

The graph result of early compressive strength for control concrete and SCC with different mixture designation of triple blended Qua-Si-RHA for this research study is shown in Figure 10. Early compressive strength test was conducted after 24 hours after concrete mix casting. The result for the early compressive strength test for control, QuaSiRHA10, QuaSiRHA20, and QuaSiRHA30 are 8.22 N/mm^2, 6.68 N/mm^2, 7.36 N/mm^2 and 9.12 N/mm^2. It is observed that the compressive strength of triple blended of Qua-Si-RHA in SCC increased with the increase percentages of quarry dust as partial fine aggregate replacement.

The early compressive strength result for QuaSiRHA10 and QuaSiRHA20 are lower than control concrete. However, the early compressive strength result for QuaSiRHA30 is higher than control concrete and it indicates the QuaSiRHA30 in SCC as the optimum result in this research study. QuaSiRHA30 has the highest early strength between all design mixes, with an increase of 10.9% than control mix. In order to increase the workability of concrete, higher water to cement ratio is needed thus decreasing the strength of concrete. However, by introducing the QuaSiRHA and the use of superplasticizer, higher early strength can be achieved with the constant water cement ratio for all mixes.

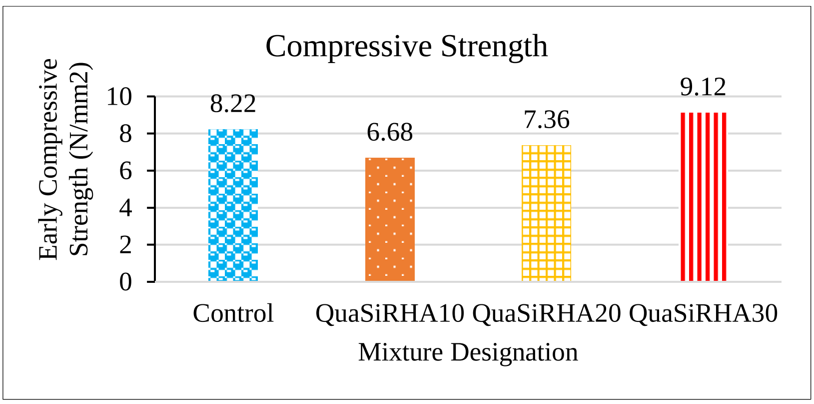

Figure 10: Compressive Strength of Concrete Mixture Design

3.3 Relationship between Workability Test Result and Early Compressive Strength Test Result

The graph of relationship between workability and early compressive strength for SCC with different mixture designation of triple blended Qua-Si-RHA for this research study is shown in Figure 11. Based on the result of workability and early compressive strength plotted in the graph, equation of exponential trendline was used according to the coefficient of determination value. Furthermore, the coefficient of determination value by using exponential trendline equation is 0.9271 which is nearest to 1.

Thus, the higher the percentage of quarry dust as fine aggregate replacement at constant percentages of silica fume and rice husk ash as partial cement replacement, the higher the workability and the higher the early compressive strength of QuaSiRHA in SCC.

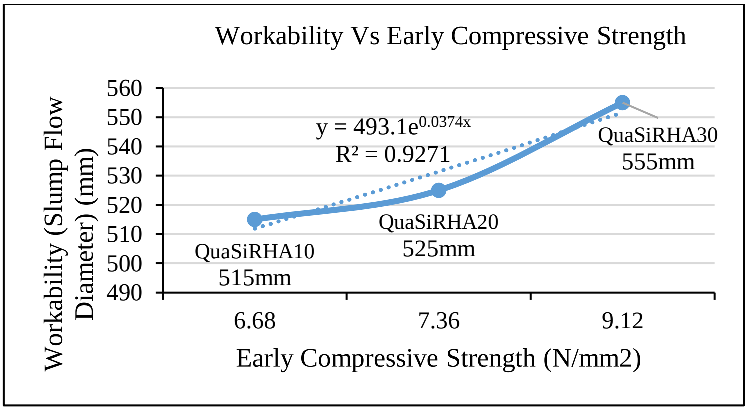

Figure 11: Workability vs Strength of Concrete Mixture Design

4.0 CONCLUSION

In conclusion, the workability of SCC increased with the increase percentages of quarry dust due to it physical properties and classified as less water absorbent material than sand. Additionally the usage of superplasticizer in SCC increases the workability exponentially even though the water cement ratio for control and SCC incorporating QuaSiRHA are the same. The early compressive strength result for QuaSiRHA30 is higher than control concrete and it indicates the QuaSiRHA30 in SCC as the optimum result for this research study. QuaSiRHA30 has the highest early strength between all design mixes, with an increase of 10.9% than control mix. Based on the relationship between the workability and early compressive strength result, the higher the percentages of quarry dust as fine aggregate replacement at constant percentages of silica fume and rice husk ash as partial cement replacement, the higher the workability and the higher the early compressive strength of QuaSiRHA in SCC. As expected, the concrete innovation incorporating Qua-Si-RHA as eco-friendly and sustainable materials resulted in high workability performance and high early strength self-consolidating in concrete. Therefore, SCC performance with the innovation of Qua-Si-RHA was improved and higher than conventional vibrated concrete.

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