Experimental Investigation on Greener Self-Compacting Concrete With Inclusion of Rice Husk Ash

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***Abstract*— Self-compacting concrete (SCC) has become more popular than conventional concrete owing to its advantages, such as a high level of consistency, finishability, and flow rate with the least possible water-cement ratio. So far, researchers have conducted their research on self-compacting concrete based on various factors that may affect the compressive strength and fresh properties of SCC. Only a few SCC mix designs consider the impact of minerals such as rice husk ash (RHA), silica dust and fly ash. Therefore, this paper looks forward to assessing the effect of the addition of RHA on the compressive strength of self-compacting concrete with various mixing designs. To conduct this research, 5 to 14 mm size aggregates were employed in this research study. After developing seven SCC mixes, cement was partially replaced with locally collected RHA at 5, 10, 15 and 20%, respectively. In addition, data analysis was conducted, and experimental results were carefully monitored using graphical methods and SPSS software by checking the variation of compressive strength against different factors such as RHA percentage, curing period and water-cement ratio. According to the results, a higher strength was encountered with 5% white-ash RHA, which contained more amorphous silica than carbon.**

Keywords*— *Self-compacting concrete, Rise Husk Ash (RHA), Slump flow, Compressive strength, Low-Carbon, High-Carbon

I. INTRODUCTION

Among different concrete types, self-compacting concrete (SCC), also referred to as self-consolidated concrete, is mainly gaining popularity over conventional concrete due to its behaviour and benefits. As the name implies, the self-compacting concrete fills the formworks due to its self-weight (filling ability), passing through reinforcement bars without any additional forces (passing ability) and has segregation resistance. Self-compacting concrete portrays advantages such as less energy consumption, less vibration, higher productivity and less noise than conventional concrete due to its abilities as mentioned above [1]. In addition to conventional concrete ingredients such as cement, sand, coarse aggregate and water, the admixture is essential for self-compacting concrete to achieve fresh workability properties compared to conventional concrete. However, the use of superplasticizers increases the production cost of SCC relative to conventional concrete, which is a significant disadvantage incorporated with SCC.

Cement occupies approximately 20% of concrete and plays a crucial role in deciding concrete behaviour in fresh and hardened properties. Carbon dioxide emissions during cement manufacturing created a severe environmental problem and should be reduced. Further environmental pollution is increasing due to ineffective disposal methods for agricultural waste materials. Nevertheless, some of these materials can be a solution to the scarcity of cement. Therefore, cement is currently partially substituted by waste minerals such as silica fume, rice husk ash, and fly ash to minimize production cost, thereby making the SCC greener.

Rice husk ash (RHA) is a paddy waste product that can increase SCC's compressive capacity. Because RHA has a high reactive amorphous silica, consisting of a higher proportion of silica oxide, it can be used as a partial substitute for cement. Also, replacing less costly RHA as partial cement replacement reduces environmental pollution and production costs and improves SCC's sustainability [2]. As a result, the cost of SCC production will be reduced, making concrete greener. Despite the RHA inclusion to help in SCC properties, it may result in some strength reduction after a certain increment percentage. Therefore, an optimal percentage of RHA is required as a partial replacement for cement.

Therefore, this research study examines the impact of high and low carbon RHA directly taken from a rice mill to ensure the economy of concrete production rather than utilizing a sophisticated combustion process. This experimental program was conducted to investigate the difference in RHA percentage's compressive strength as a partial cement substitute.

II. LITERATURE REVIEW

As a solution for the environmental issues, many research studies have been performed with natural pozzolans for green concrete, high-performance concrete, lightweight concrete and self-compacting concrete [3,4]. The by-products such as rice husk ash, fly ash, silica fume, metakaolin, and blast furnace slag have been effectively utilized by replacing the cement in self-compacting concrete to enhance compression strengths [4-6]. Due to large amounts of utilizing cementitious materials, apparent shrinkage and cracks can be induced on the concrete structures [7].

Rice Husks from rice mills are regularly discarded directly in the environment or often burned outdoors, paving the way for environmental contamination, particularly in wet conditions [8]. Replacement of RHA offers a viable environmental solution [9] and reduces concrete manufacturing costs with RHA's inclusion [5]. Nevertheless, the RHA amount of silica content varies according to RHA type, combustion time, and method [6, 10]. Venkatanarayanan & Rangaraju (2015) [11] states that ground RHA's inclusion significantly improved reactivity and concrete strength.

Sandhu & Siddique (2017) [5] reported that minerals such as rice husk ash, fly ash, metakaolin, silica fume can be reduced heat of hydration, improve strength, reduce permeability, increase chloride and sulphate resistance cost reduction of minerals and reduce CO2 emission. Also, Omrane et al. (2017) [4] have stated that using waste materials shows constructive effects such as good production of an environmentally friendly SCC and lower cost concrete production.

Alex et al. (2016) [12] have studied the effect by the grinding time of rice husk ash, which has characterized as unground RHA, RHA with 15 min and 60 min grinding time, on the compressive strength of SCC. Alex et al. (2016) [12] have stated that the average particle size decreases, and the specific surface is increased while increasing grinding time. Also, 60 minutes of grinding time have shown high bulk density and high compressive strength development. Also, this research study resulted that the replacement of 10% of RHA, which exhibits high amorphous silica, shows higher compressive strength. Also, Alex et al. (2016) [12] mentioned that RHA's use as supplementary cementitious material is the better option for sustainable concrete development, which helps to solve some negative impacts of cement, such as CO2 emission resource deficiency and high cost.

As discussed above, most of the research has been performed to find the effect of waste products such as RHA, fly-ash, metakaolin and silica fume on the self-compacting concrete properties. However, the investigation has not been performed separately for the effect of RHA as a partial replacement for the SCC. Therefore, this research study looks forward to examine the effect of RHA in the SCC fresh and harden properties.

III. METHODOLOGY

Ordinary Portland Cement (OPC) belongs to the 42.5N strength class, manufactured according to the SLS conformation; river sand (fine aggregates) and natural coarse aggregates have been used in this experimental analysis. The river sand was sieved through a 4.75 mm sieve net to eliminate any foreign particles larger than 4.75 mm. Based on EFNARC (2002) [13] guidelines, coarse aggregates can be used in the range of 5 to 20 mm in self-compacting concrete to achieve fresh properties. However, if large aggregates are used, the flowability and passing ability of the SCC will be reduced due to the weight and size of the coarse aggregates. Hence it will detriment the

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fresh properties of SCC. Therefore, this study only used coarse aggregate sizes ranging from 5 to 14 mm. In this research study, the admixture CHRYSO®Optima SL 186, a high-range water-reducing admixture, was employed to enhance self-compacting concrete's workability. Further, it confirms the standards ASTM C 494 (2019) Type-A, F and G [14] and BS EN 934-2 [15].

Moreover, Rice husk ash was directly collected from a local mill, Kilinochchi town, Northern Province, Sri Lanka, and used in this study. After that, the collected RHA's physical properties and chemical composition were analyzed before being used in the experiment. There are mainly two types of RHA employed, type A and type B (both were collected directly from the local mill), which means that type A RHA contains lower carbon than type B RHA, as shown in Fig. 1(a) and Fig. 1(b), where less carbon RHA is grey while high carbon RHA is black.

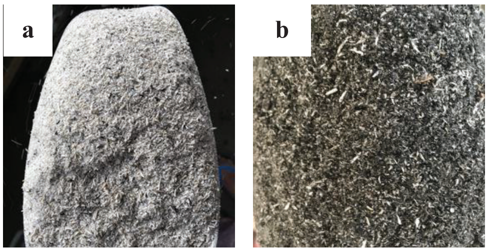

Fig. 1. Rice Husk Ash (a) Low-Carbon RHA (b) High-Carbon RHA

The primary objective of this research study is to examine the effects of RHA on SCC behaviour. An experimental study was performed to achieve this objective. Moreover, the mixing procedure of SCC profoundly affects the properties of SCC. Thus, the mixing procedure was kept consistent throughout the research study. Moreover, in this research study, seven different research control mixes where referred to as RC1 to RC7 have been used with varying cement, aggregate, water-cement ratio and admixture percentage. After successfully developing seven SCC mixes, RHA replaced cement in the mixes as 5, 10, 15, and 20%. SCC should satisfy all fresh property tests such as slump flow, U-box, V-funnel, and J-ring, representing flowing, passing, filling, and passing filling abilities, and these tests were performed based on the guidelines such as ASTM C1611/C1611M – 14 (2014) [16] and EFNARC (2002) [13]. Furthermore, research control mix 1-7 (RC1-RC4) contains type B RHA (as per Fig. 1(b)); whereas other mixes contain type A RHA (as per Fig. 1(a)).

A. *Slump flow test*

A freshly mixed SCC sample was poured without any external vibration in the inverted slump cone. Then the slump cone was lifted carefully, and the concrete has been allowed to spread, as shown in Fig. 2(a). After the spreading, two slump flow diameters were measured in perpendicular directions with the nearest 5 mm and the average slump flow diameter was calculated.

B. *U-box test*

A freshly mixed SCC sample was poured into one of the U-box compartments. Then the sliding gate was lifted and allowed to flow out to the other compartment via a series of reinforcement bars, as shown in Fig.2(b). After that, the height difference between concrete in both compartments was measured.

C. *J-ring test*

The slump cone was kept in an inverted position in the J-ring apparatus centre, and the freshly mixed SCC sample was poured into the slump cone. Then the slump cone was lifted carefully, and the concrete was allowed to spread, as shown in Fig. 2(c). After that, the height difference between the concrete just inside the bars and just outside the bars has been measured in three different locations, and the average has been calculated.

D. *V-funnel test*

This test method is used to find the filling ability of SCC. A freshly mixed SCC sample was poured completely into the V-funnel without any external vibration. Then, the bottom trap door was opened, and the concrete was allowed to flow with that own weight, as shown in Fig. 2(d). The bottom trap door was opened when the stopwatch started, and the time was recorded until concrete discharged completely through V-funnel.

The fresh concrete mixture was then filled into 150mm × 150mm ×150 mm moulds without any external vibration from the height of approximately one foot. After 24 hours, the dry concrete samples were removed from the mould and stored in the curing tank to cure the concrete specimens. Finally, 7, 28, and 56-day compressive strength testing was performed under BS EN 12350-3 (2000) [17].

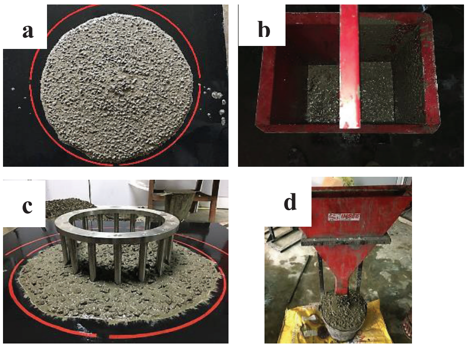

Fig. 2. Fresh property tests (a) Slump flow test (b) U-box test (c) J-ring test (d) V-funnel

IV. RESULTS AND DISCUSSION

In the graphical analysis, the relationship between the independent design variables and dependent variables was investigated using experimental data based on the seven control mix designs. Moreover, the graphical relationships were developed based on each fresh and hardened property test result's mean value. The SCC slump flow depends on the water-cement ratio and depends on the RHA and admixture percentage.

Fig. 3 illustrates the average slump flow variation against the RHA percentage, and it clearly shows that the slump flow reduced concerning an increment of RHA percentage. This pattern indicates that the plastic viscosity of SCC increased with an increase in the RHA percentage because the presence of amorphous silica in the RHA behaves as a viscous agent [18]. In the SCC, although admixture helps to decrease the water-cement ratio and increase the flow, sometimes it leads to segregation in the concrete due to the cause decrease in plastic viscosity of SCC. Also, the SCC flow rate will increase during pumping due to lower plastic viscosity, leading to dispersing concrete particles [19]. Therefore, RHA inclusion will help maintain the plastic viscosity at an optimum level with the required slump flow as shown in Fig. 3 and inclusion of 5 and 10% of RHA resulting in better plastic viscosity.

This experiment's primary purpose was to evaluate the variation in compressive strength of SCC for different mix designs with RHA's influence. Therefore, the analysis was done based on the 630 cube strength results.

Fig. 4 shows seven SCC mix design's 28-day compressive strength variation with varying RHA percentages (0 to 20%). The strength capacity increment was expected due to amorphous silica in RHA, but compressive strength capacity was reduced with an increasing RHA percentage in the experimental study. This may be due to the presence of carbon in RHA, which was directly taken from a local mill and increased the RHA percentage's water-cement ratio. Mix design RC3 indicates the highest strength in five RHA percentages compared to other sets of mix designs. In the mix design of RC3, white ash colour RHA, which has a higher amount of amorphous silica and lower carbon, was used. This caused an increase in the early strength of concrete from 0% to 5% RHA addition. Nevertheless, the white-ash-colour RHA, which contains a higher amount of amorphous silica and a lesser amount of carbon, was used in the mix designs of RC5, RC6, and RC7. Also, in these mix designs, a higher per cent of admixture was used, thus reducing the water demand in the concrete and enhancing the compressive strength at the stage of 5% and 10% of RHA.

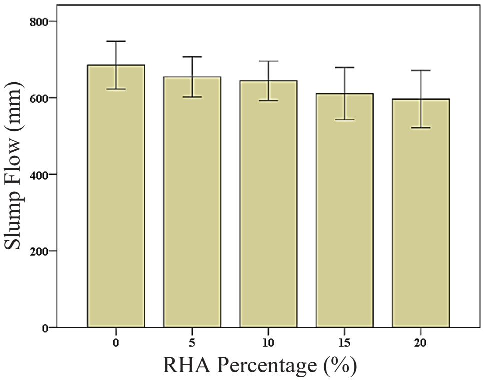

Fig. 3. Slump flow variation with RHA percentage

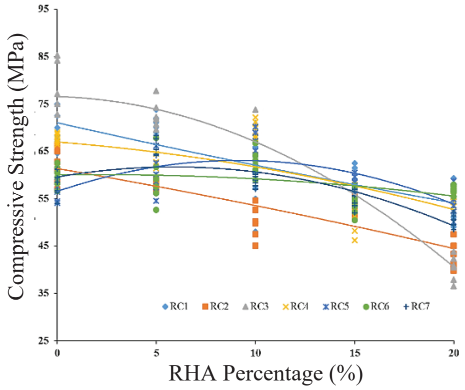

Fig. 4. Compressive strength variation for each mix designs with respect to RHA percentage at 28-days

Fig. 5 illustrates the variation of compressive strength to the curing period for different RHA percentages, such as 0%, 5%, 10%, 15%, and 20%. The graph indicates that the SCC with 5% RHA mix has higher concrete strength than other

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concrete mixes with respect to curing period. Even though the inclusion of 5% RHA enhanced the strength comparatively higher than the inclusion of 10%, 15% and 20% RHA, little lower compressive strength has been observed during the curing period of 28-days when compared control cube, which contained 0% RHA. However, there is a substantial development in 56-days compared to 28-days, as shown in Fig. 5. Therefore, RHA enhances the compressive strength of concrete after 28-days due to the chemical reaction of amorphous silica.

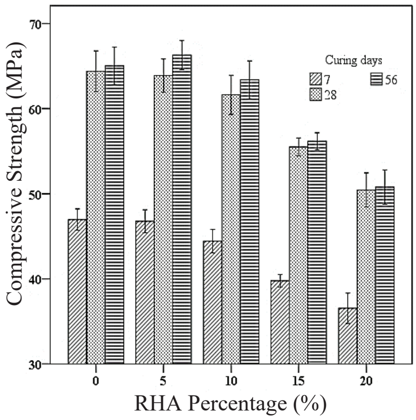

Fig. 5. Compressive strength variation with respect to different curing period

Fig. 6 indicates that the RHA percentage increment leads to an increase in the water demand in the concrete and reduced concrete strength. Nevertheless, the white-ash-colour RHA, which contains a higher amount of amorphous silica and a lesser amount of carbon, was used in the mix designs of RC5, RC6, and RC7. Also, in these mix designs, a higher per cent of admixture was used, thus reducing the water demand in the concrete and enhancing the compressive strength at the stage of 5% of RHA.

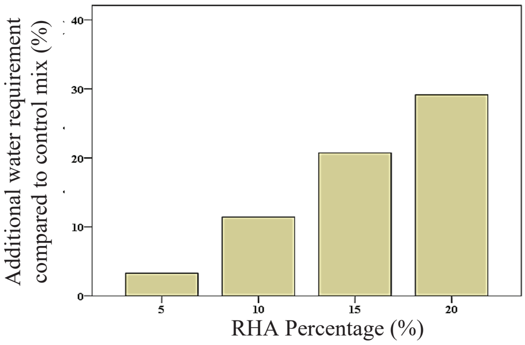

Fig. 6. Water requirement variation with respect to RHA percentage

V. COST ANALYSIS

The cost of concrete depends on many factors such as concrete ingredients, production cost, and labour cost during concreting. For the cost analysis, mainly cost (costs were calculated based on Sri Lanka's market value in rupees) and strength factors were considered. The cost of concrete ingredients was calculated for different concrete mixes. The concrete's production cost (excluding the cost of ingredients) is considered the same for conventional concrete and self-compacting concrete. It clearly states that SCC with 5% and 10% RHA have lower cost/strength factor when compared to SCC without RHA as shown in Fig. 7. However, this is only the cost of ingredients but, for conventional concrete, the labour cost is higher because of the usage of the vibrator during concreting and levelling. In the self-compacting concrete, it has its compacting ability and self-levelling ability. Thus, it helps to reduce the cost of concrete. In addition, when RHA is employed in the SCC, it will help make the environmental greener compared to conventional concrete.

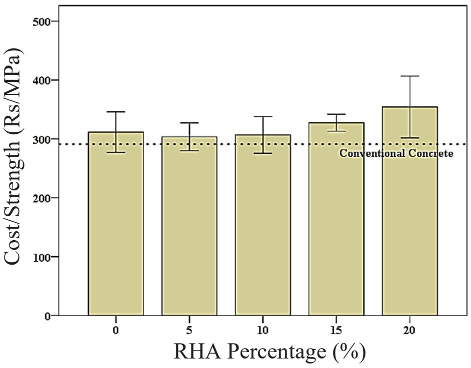

Fig. 7. Cost variation for different

Therefore, it can be concluded that the usage of SCC with RHA gives more enormous benefits than conventional such as lower cost, environmental friendliness, ease of use. Further, RHA replacement for cement reduces ozone depletion, human toxicity, freshwater ecotoxicity and fossil depletion [20].

VI. CONCLUSION

The following findings can be summarized based on the experimental analysis in this research study:

1. The compressive strength of SCC increases with an increase in the percentage of white-ash rice husk ash, which contains a higher amount of amorphous silica, up to 5% of replacement for cement for different mix designs;

2. The compressive strength of concrete highly developed after 28-days, which can be obtained at 56-days strength because of the reactive amorphous silica content;

3. The filling ability of self-compacting concrete was not affected by the percentage of RHA increment;

4. The water demand decreases for ground rice husk ash compared to unground rice husk ash.

5. Cost/Strength factor shows the lower value for the 5 to 10% of RHA replacement.

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