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Self compacting concrete from uncontrolled burning of rice husk and blended fine aggregate

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ABSTRACT

This paper presents an experimental study on the development of normal strength Self compacting concrete (SCC) from uncontrolled burning of rice husk ash (RHA) as a partial replacement to cement and blended fine aggregate whilst maintaining satisfactory properties of SCC. Experiments on the fresh and hardened state properties have been carried out on RHA based SCC from uncontrolled burning. The dosages of RHA are limited to 0%, 20%, 30% and 40% by mass of the total cementitious material in the concrete. The experiments on fresh state properties investigate the filling ability, the passing ability and the segregation resistance of concrete. The experiments on hardened state properties investigate the compressive and the splitting tensile strengths. The water absorption level of the concrete with changing RHA levels has also been monitored. The experimental studies indicate that RHA based SCC developed from uncontrolled burning has a significant potential for use when normal strength is desired.

1. Introduction

Concrete is one of the most important materials for a very wide range of construction work. Generally, concrete is compacted by a vibrator or a steel bar after placing it inside the formwork to remove the entrapped air and it becomes a dense and homogeneous material. Compaction is very important to produce good concrete with desired strength and durability.

Self compacting concrete (SCC) is competent to flow, fill all areas and corners of the formwork even in the presence of congested reinforcement. It compacts under its own weight without segregation and bleeding and does not require any type of internal or external vibrator. Self compacting concrete must satisfy three fresh concrete properties related to the filling ability, the passing ability and the adequate segregation resistance [1–3].

The prototype of SCC was first developed in Japan in 1988 in order to make sure durable and safe concrete structures by changing the concept of concrete production and construction process. Significant research and development work into SCC are now being conducted nearly all over the world [4–6]. SCC seems to have a number of benefits in terms of economical, environmental, mechanical strength and durability aspects over Normally Vibrated Concrete (NVC) construction. As SCC does not require internal or external compaction, it reduces the segregation of coarse aggregate from cement paste leading to less porous zones between aggregate and cement paste. This reduction in porous zones may be related to durability properties [3,4].

SCC requires a significant decrease of coarse aggregate and an increase of cement content to maintain its fresh state properties and homogeneity. High cement content generally increases overall concrete production cost and also generates high heat during the chemical reactions as well as increasing creep and shrinkage problems. Consequently, significant quantities of pozzolanic material including Fly Ash (FA), rice husk ash (RHA), silica fume, Ground Granulated Blastfurnace Slag (GGBS), etc. are frequently used to replace cement to improve the fresh state properties of concrete, to control the generation of heat and to reduce the creep and shrinkage problems [4,5].

An increasing focus of the society towards sustainability has led to a significant increase in the use of different types of waste materials including RHA, tires, Oil Palm Shell (OPS) and FA. Intelligent reuse of materials is directly related to the necessity arising from the environmental effects of waste. The reuse of waste materials in concrete is an attempt to address a part of these problems by introducing sustainable materials in the construction industry. Concrete is the second most used material in the construction industry after water. As a result, the environmental impact, including the carbon footprint of concrete, is severe.

RHA, a by-product of paddy, can be abundantly found over a very large region of the world and is a contributor to air, river,

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sea and groundwater pollution. Reuse of RHA in concrete attempts to address a part of the environmental problems. To establish the credibility of the use of such materials, experimental studies are important to demonstrate the efficiency of RHA blended concrete in terms of a number of traditional performance measures of standard concrete in terms of construction usage. Consequently, it is very important to study the physical and chemical properties of RHA and fresh state properties and hardened state properties of RHA based self compacting concrete extensively.

Diverse studies have been carried out on high strength conventional SCC and FA based SCC in both fresh and hardened states and a limited number of studies also exist on RHA based normal strength SCC. Fresh state properties of RHA based SCC along with cost analysis have been carried out before [3] where the dosage of RHA was limited to 5–10% by mass of the total cementitious material. RHA based SCC was observed to be more cost effective than Ordinary Portland Cement (OPC) based SCC. Mechanical properties of RHA based SCC have also been investigated [2] where the dosage of RHA was limited to 10–20% by mass of the total cementitious material. It was found that the RHA based SCC yielded higher results than the OPC based self compacted concrete in terms of strength at an age of 60 days. Durability performance of SCC has been investigated by researchers as well [7] and it has been reported that the porosity of SCC is generally lower than that of normal concrete and hence improved resistance to corrosion, freeze thaw cycles and sulphate attack. Hardened state properties of RHA based SCC have been studied [8] where the dosage of RHA is limited to 0–30% by mass of the total cementitious material. It was found that the hardened state properties improved with the increasing of RHA content. Some investigations have been reported relating to the increase of strength and durability properties of concrete through the use of RHA [9–14].

The availability of a significant amount of RHA is through uncontrolled burning. Considering the fact that a very significant amount of concrete construction in the developing regions around the world is associated with the use of normal strength concrete, there seems to be a potential of using RHA from uncontrolled burning to produce normal strength concrete with adequate fresh and hardened state properties. There does not seem to be extensive research work present on RHA based normal strength SCC from uncontrolled burning. A significant amount of RHA from uncontrolled burning is generated every year in many developing countries. Such RHA contains around 90% SiO_2 and due to this high percentage of SiO_2 in RHA, it works as a pozzolanic material. Therefore it is very important to utilize in concrete and also to study RHA based normal strength self compacting concrete by examining its hardened state properties. The uses of normal strength concrete in Malaysia and in many developing nations associate with a very high share of all of the concrete construction. The application of uncontrolled burning RHA as pozzolanic material in normal strength SCC in Malaysian construction industry and similar developing nations is not usual and there is a general lack of technical knowledge and guidance in this regard.

These paper present experimental studies on RHA based normal strength SCC from uncontrolled burning with blended fine aggregates in relation to the adequacy of achieving fresh and hardened state properties. Filling ability, passing ability and segregation resistance were tested for fresh state while the compressive and the splitting tensile strength were tested for hardened state. Additionally, a water absorption test and a comparison with FA based SCC are carried out in this paper with respect to RHA based SCC from uncontrolled burning. The study demonstrates the possibility of use of RHA based SCC from uncontrolled burning as a sustainable building method for the development of normal strength concrete.

2. Details on materials for testing

2.1. Cement

Ordinary Portland Cement (OPC) grade 42.5 based on ASTM: C150/C150 M-12 was used in the concrete as cementitious material. The density of the cement is 2950 kg/m^3.

2.2. RHA

RHA obtained through uncontrolled burning was used in this study. The RHA was collected from a village (Kota-Kinabalo) in Sabah, Malaysia. The RHA was sieved by a 75 μm sieve to remove large particles and was then grinded to obtain fine powder. The chemical composition of the RHA was determined using XRF (X-ray Fluorescence). The results of the chemical composition of cement are presented in Table 1. The amount of SiO_2 in the RHA is observed to be 94.8%.

2.3. Coarse aggregate

10 mm nominal size crushed quartzite was used as the coarse aggregate in this research. The coarse aggregate was composed of particles within the range of 5 –10 mm. Sieve analysis of a 2000 g sample indicated that the entire sample (100%) passed through a 9.5 mm sieve while only 5% passed a 4.75 mm sieve (i.e. 95% retained on 4.75 mm sieve). This conforms with the 10 mm single sized aggregate requirements in AS: 2758.1 [15]. The gradation of coarse aggregate is presented in Table 2.

2.4. Fine aggregate

AS: 2758.1 [15] categorize aggregates with particles finer than 4.75 mm as fine aggregates (FA) for concrete mix design. In this research programme two categories of fine aggregates was used. One category was chosen such that nominal size was 4.75 mm while all the particles were coarser than 600 μm (crushed quartzite). The other category had a nominal size of 600 μm (uncrushed river sand) while sieve analysis indicated the presence of even microfines to a small extent (particles of size less than 75 μm). The gradations of the two categories chosen as fine aggregates of both types are presented in Table 3 and Table 4 respectively.

The fineness modulus of river sand is rather small (1.32), indicating a very fine overall particle size. Very often, the desired value for fine aggregates is 2.5 or above. Hence it is necessary to use a coarser fine aggregate in the mix. The fineness modulus of crushed quartzite is 4.29. The aggregate characteristics summary is presented in Table 5.

2.5. Admixture

The super-plasticizer used in this research was supplied by Sika Kimia Sdn Bhd. The trade name of the high range water reducing

Table 1
Chemical composition of cement, RHA.

Compound	Cement (%)	RHA (%)
SiO_2	20	94.8
CaO	63.2	1.41
Fe_2O_3	3.3	1.61
K_2O	N.A	1.33
TiO_2	N.A	0.17
MnO	N.A	0.28
CuO	N.A	0.04

Table 2
Coarse aggregate (CA) gradation.

Sieve size (mm)	% Finer	AS 2758.1 requirements
9.5	100	85–100
4.75	5	0–20
2.36	0	0–5

Table 3
River sand gradation.

Sieve size (μm)	% Finer	AS 2758.1 requirements
600	100	15–100
300	58	5–50
150	10	0–20

Table 4
Crushed quartzite gradation.

Sieve size	% Finer	AS 2758.1 requirements
4.75 mm	99	90–100
2.36 mm	50	60–100
1.18 mm	20	30–100
600 μm	2	15–80

(up to 30% depending on dosage) admixture is Sikament®-NN and conforms to the requirements of ASTM C494/C494 M-13 while the chemical base of the dark brown liquid is Naphthalene Formaldehyde Sulphonate. The use of admixture is advocated along with the application of the use of RHA from uncontrolled burning to enhance the workability and the reduction of water requirement. Such admixtures used during normal production of concrete and consequently the use of RHA can be effective in reducing the cost.

3. Details of experimentation

3.1. Mix proportions

Four concrete mixes were designed and the dosage of RHA are limited to 0%, 20%, 30% and 40% respectively by the mass of the total cementitious material. Crushed quartzite was mixed with river sand to increase the fineness modulus of fine aggregates. The fineness modulus of river sand was 1.32 and the maximum size of the coarse aggregate was limited to 10 mm. The mix proportions of RHA based SCC are summarized in Table 6.

3.2. Sample preparation

The mixer used was a 0.5 m^3 capacity forced action cylindrical pan mixer with a vertical axis of rotation. For optimal mixing outcomes a specific procedure was chosen from a number of different methods of mixing. The procedure most suited to the experiments involved putting all the aggregates into the pan and running the mixer for around 1 min. Following this run, RHA powder was added and the mixer was run for approximately another 1 min. Next, about 60% of the required water was added slowly (poured towards, but not too close to the outer wall of the pan) and mixer was run again for around 1–1.5 min. Once this mixing was carried out, 30% of the water and 90% of the super-plasticizer was mixed in a bucket and then added slowly to the pan before running it for about 3–3.5 min. The super-plasticizer was found out to be most effective when added with water. The consistency and the flow of the resulting mixes were observed and the remaining 10% of water and 10% of super-plasticizer (mixed together) were used to adjust the mix. This step was found out to be especially helpful due to the changes in water and super plasticizer demand as RHA content was increased. The step took about 40–50 s. The resulting mixture was then allowed to rest for not less than 2.5 min (for air dissipation), and remixed for 20–30 s, after which all the fresh state tests were carried out. With increasing the RHA content in the mix, the need to follow this procedure was obvious since the mixture tended to be more viscous and sudden addition of water lead to complete failures in terms of achieving the desired SCC.

3.3. Testing of samples

3.3.1. Fresh state properties

SCC must satisfy three fresh concrete properties including the filling ability, the passing ability and the adequate segregation resistance. For determining the filling ability, slump flow and V-funnel tests were carried out. The passing ability was determined through J-ring test while the segregation resistance was determined through sieve segregation tests. The performance criteria for fresh state concrete properties of SCC are presented in Table 7 [4,5,8].

The slump flow indicates the ability to completely fill all areas and corners of the formwork into which it is placed. It measures the average diameter from two perpendicular directions of the mass of the concrete after taking out the standard slump cone.

Table 5
Aggregate characteristics summary.

	Material type	Size range	Fineness modulus	Water absorption (%)	Specific gravity
Fine aggregate	Uncrushed river sand	0.0–600 μm	1.32 (low)	1.10	2.64
	Crushed quartzite	600 μm to 5.0 mm	4.29 (high)	1.30	2.67
Coarse aggregate	Crushed quartzite	5.0–10.0 mm		1.40	2.62

Table 6
Mix proportions of RHA based SCC.

Materials	Cement (kg/m^3)	RHA (kg/m^3)	Water (kg/m^3)	w/p	sp%	River sand (kg/m^3)	Crushed quartzite (kg/m^3)	Coarse aggregate (kg/m^3)
Mix 1	540	0	205	0.38	1.8	230	630	690
Mix 2	400	100	250	0.5	3.5	150	700	700
Mix 3	350	150	250	0.5	3.5	150	700	700
Mix 4	300	200	250	0.5	3.5	94	756	700

Table 7
Performance criteria for fresh state SCC [4,5,8].

Test method	Property	Criterion
Slump flow	Filling ability	550–850 mm
V-funnel	Filling ability	6–12 s
J-ring	Passing ability	0–10 mm
Sieve segregation	Segregation resistance	⩽18%

Fig. 1. J-Ring sample.

V-funnel test was carried out to determine the stability of SCC mixes which determine the flow time. J-ring test (Fig. 1) was carried out to determine passing ability of the SCC through congested reinforcement without separation of the constituents or blocking. This test measures the difference in height between the concrete inside the bars and that just outside the bars. Sieve segregation test was carried out to determine the resistance to segregation of SCC to retain the coarse components of the mix in suspension in order to maintain a homogeneous material.

3.3.2. Hardened state properties

The hardened state properties of the concrete include strengths in compression and tension properties. Cylindrical specimens were tested to failure to determine hardened state properties like compressive strength and splitting tensile strength at 3, 7, and 28 days respectively using Universal Testing Machine. Adequate strength in compression and tension establishes the uses of RHA based SCC from uncontrolled burning for the production of normal strength concrete.

4. Results and discussions

4.1. Fresh state properties

The results of the slump flow, V-funnel, J-ring and Sieve segregation test for the fresh state properties of RHA based self compacting concrete are presented in Table 8. For Mix 1, the slump flow diameter is 630 mm, V-funnel flow time is 5.9 s, the difference in height in J-ring is 5.2 m and the segregation ratio is 8.2%. For Mix 2, the slump flow diameter is 660 mm, V-funnel flow time is 6.6 s, the difference in height in J-ring is 3.7 mm and the segregation ratio is 0.04%.

Table 8
Fresh state properties of rha based SCC.

Test method	Mix 1	Mix 2	Mix 3	Mix 4
Slump flow (mm)	630	660	670	580
V-funnel (s)	5.9	6.6	6.3	7
J-ring (mm)	5.2	3.7	3.5	4.4
Sieve segregation (%)	8.2	0.04	0.09	0.2

For Mix 3, the slump flow diameter is 670 mm, V-funnel flow time is 6.3 s, the difference in height in J-ring is 3.5 mm and the segregation ratio is 0.09%. For Mix 4, the slump flow diameter is 580 mm, V-funnel flow time is 7.0 s, the difference in height in J-ring is 4.4 mm and the segregation ratio is 0.2%.

Slump flow test was carried out to investigate the filling ability of normal strength SCC. The standard range of slump flow diameter is 550–850 mm. If the slump flow (SF) value is higher than 750 mm, the viscosity will be lower and the greater its ability to fill formwork under its own weight however concrete might segregate. If the slump flow (SF) value is lower than 500 mm, the viscosity will be higher and greater its chance to make blockage in congested reinforcement. All the results from this study fall within the middle range, which indicates an excellent filling ability of normal strength SCC.

V-funnel test was also carried out in addition to the slump flow test to investigate the filling ability of normal strength SCC. The standard range of V-funnel flow time is 6–12 s as per EFNARC [4]. This test measures the ease of flow of the concrete. The longer flow times indicate lower flowability and shorter flow times indicate greater flowability. The results from this study are higher than the minimum standard value of 6 s and lower than the maximum standard value of 10 s.

J-ring test was carried out to investigate passing ability of the normal strength SCC. This test measures the difference in height between the concrete inside the bars and that just outside the bars. The standard range of difference in concrete height between the concrete inside and outside the bars is 0–10 mm. The greater the difference in height, the passing ability of the concrete is low and the lower the difference in height; the passing ability of the concrete is high. All the results from this research work are less than 10, which indicate a good passing ability of RHA based normal strength SCC.

The sieve segregation resistance test was carried out to investigate the resistance of normal strength self-compacting concrete to segregation. The standard limiting value for sieve segregation resistance test is less than 18%. As per EFNAC, if the result is higher than 15%, the viscosity will be lower, the concrete might segregate. The results from this research work are less than 15%, which indicate that RHA based normal strength SCC is a good resistance to segregation [4,5].

It is noted from these experiments on the fresh state properties that the RHA based SCC from uncontrolled burning satisfies all the criteria of the fresh state properties of SCC including filling ability, passing ability and segregation resistance. Consequently, the material has good potential as a cement replacement in the production of SCC.

4.2. Hardened state properties

4.2.1. Compressive strength

The compressive strength of RHA based SCC are evaluated at 3, 7 and 28 days and the results are presented in Table 9. The percentage of RHA content in the Mix1, Mix2, Mix3 and Mix4 are 0, 20, 30 and 40 respectively. It can be seen from the Table 9 that the compressive strength decreased with increasing of RHA content. Previous studies [2,9,16] showed that the 28 days compressive strength decreased with increasing of RHA content. It is due to the fact that the amount of RHA present in the mix is higher than the amount required and due to the leached out extra silica. This extra silica replaces part of the cementitious material and does not contribute to

Table 9
Compressive strength of SCC.

Compressive strength (MPa) RHA based SCC				
Days	Mix 1	Mix 2	Mix 3	Mix 4
3	28.2	26.1	23.4	20.9
7	32.8	37.2	35.1	28.1
28	48.5	42.9	40.9	33.5

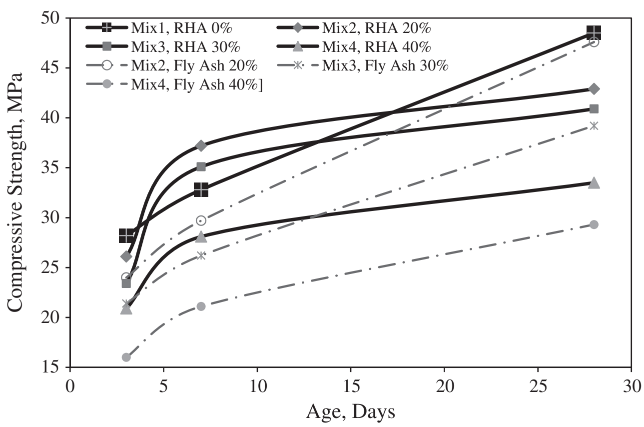

Fig. 2. Compressive strength of SCC mixes.

compressive strength [16]. Compressive strength of RHA based SCC along with the results obtained from similar studies carried out on fly ash based SCC are presented in Fig. 2. It can also be observed from Fig. 2 that the compressive strength decreased with increasing of fly ash content. Studies [17] also showed that the compressive strength decreased with increasing of FA content. At an early stage, the rate of gain of strength of RHA based SCC was higher due to presence of higher percentage of silica in RHA. The higher percentage of silica helps the pozzolanic reactions occur at early ages [18]. However, the rate of gain of strength was lower after 7 days. In general RHA based SCC yielded higher strength than similar studies carried out on FA results. However, the 28 day strengths of Mix2 (Fly Ash) are higher than RHA based SCC, an obvious reason of which is not apparent. Generally, the strength gain of RHA is consistently more rapid than the FA based SCC and the maximum compressive strength is reached quite early.

4.2.2. Splitting tensile strength

The splitting tensile strength test results of RHA based SCC are presented in Table 10. The percentage of RHA content in the Mix1, Mix2, Mix3 and Mix4 are 0, 20, 30 and 40 respectively. It can be seen from Table 10 that the splitting tensile strength decreased the same as the compressive strength with the increasing of RHA content. This relationship between the compressive strength and the splitting tensile strength of RHA based SCC is presented in Fig. 3. The findings correspond to some previous studies [19–22]. The correlation between the splitting tensile strength and compressive strength are presented in Table 11. It can be seen from Fig. 3 that the splitting tensile strength increases with increasing the compressive strength. The splitting tensile strength of SCC based on RHA was 8–12% of compressive strength. It can also be observed in Fig. 3 that the splitting tensile strength of SCC are higher than the normal vibrating concrete due to uniform compaction of SCC under its own weight without any types of internal and external vibrator and without segregation and bleeding. Felekoglu et al. [19] also found that the splitting tensile strength of SCC is higher than the normal vibrating concrete.

Table 10
Splitting tensile strength of SCC.

Splitting tensile strength (MPa) RHA based SCC				
Days	Mix 1	Mix 2	Mix 3	Mix 4
28	5.1	5.1	4.3	2.8

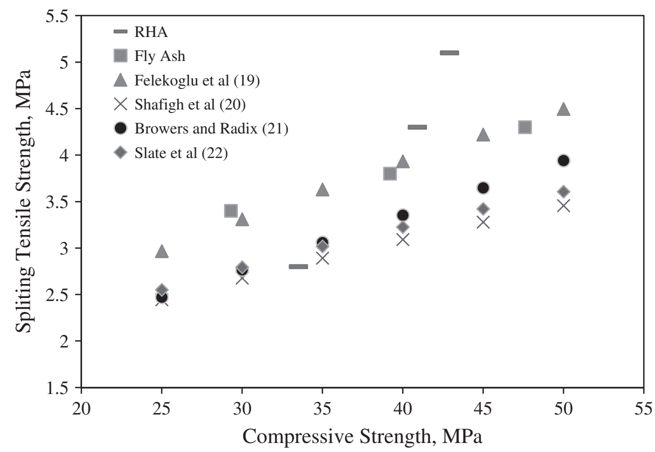

Fig. 3. Relationship between 28-days compressive and splitting tensile strength.

Table 11
Equations for splitting tensile strength.

RHA based SCC [experimental]	$0.0007(f_c)^{2.3437}$
Studies based on FA	$0.676(f_c)^{0.4759}$
Felekoglu et al. model [21]	$0.4887(f_c)^{0.5}$
Shafigh et al. model [22]	$0.43(f_c)^{0..6}$
NEN 6722 model [23]	$1\ N/mm^2 + 0.05\ f_c$
Slate et al. model [24]	$0.51(f_c)^{0..5}$

4.2.3. Water absorption test

The water absorption test results of RHA based SCC are presented in Table 12. The percentage of RHA content in the Mix1, Mix2, Mix3 and Mix4 are 0, 20, 30 and 40 respectively. It can be seen from Table 12 that the water absorption of the SCC increased with the increasing of the content of RHA. Previous studies [23] showed that the water absorption level increased with increasing of RHA content in concrete. RHA is finer than cement. The total binder surface area increased with increasing the RHA content in SCC and thus the water absorption level of concrete also increased [23].

4.3. Materials and carbon footprint

Significant amounts of virgin materials including limestone and clay besides energy are consumed to produce cement and 1.5 ton of virgin materials are needed to produce one ton of cement [24]. Cement production industries are liable for more or less 7% of the world's carbon dioxide discharge and to produce one tone of cement approximately one ton of CO_2 is released in the atmosphere [24,25]. RHA is a by-product of paddy which can be abundantly found over a very large region of the world and is a

Table 12
Water absorption (%).

RHA based SCC				
Days	Mix 1	Mix 2	Mix 3	Mix 4
28	6.2	7.7	8.9	10.5

contributor to air, river, sea and groundwater pollution. This study shows that RHA has good potential as a cement replacement up to 40% in normal strength self compacting concrete production. Every year significant amount RHA from uncontrolled burning is produced by villagers in developing countries. The reuse of waste materials in concrete is an attempt to address a part of these problems by introducing sustainable materials in the construction industry and consequently reduce carbon footprint.

4.4. Discussion on durability aspects

Care should be taken in relation to proper curing of this concrete since poor curing affects durability more significantly than an Ordinary Portland Cement (OPC) concrete of similar strength. The water permeability of concrete with RHA will eventually be lower than an equivalent OPC due to continued hydration beyond 28 days. The porosity will also be lower for correctly manufactured concrete due to precipitation of gel products in pores and this will be more effective for elevated curing temperatures. Resistance to chloride ingress will be increased with increased RHA content in concrete. This reduction in the average pore diameter of cement paste caused by the incorporation of rice husk ash in the mix effectively reduces the pore sizes, permeability and diffusivity of chloride ions in concrete [11]. The carbonation of concrete with RHA is expected to be eventually at the same level as of OPC concrete, although the early rate of carbonation can be higher for concrete with RHA. Higher levels of RHA can also aid in sulphate resistance. Performance against freeze–thaw effect can be inferior to OPC but this may be improved through air entrainment and good curing.

5. Conclusions

In general, RHA has good potential as a cement replacement in normal strength self compacting concrete production and can even be used for construction of low-cost housing project. Simultaneously, the use of RHA also reduces waste materials. The following observations and conclusions can be made on the basis of the current experimental results:

- Concrete blended with RHA obtained from uncontrolled burning is able to produce normal strength self compacting concrete with incorporating up to 40% RHA as supplementary of cementing material and blended fine aggregate without compromising the fresh state properties.
- The ranges of slump flow diameter for all the mixes are 580 to 670 mm indicating an excellent filling ability of SCC.
- The V-funnel flow time ranges are 6.3 to 7 s indicating also an excellent filling ability of SCC.
- The ranges of difference in height between the concrete inside the bars and that just outside the bars are 3.5 to 4.4 mm indicating a good passing ability of SCC.
- The sieve segregation resistance value falls in the range of 0.04 to 0.2% indicating a good resistance to segregation of SCC.
- Compressive strength and splitting tensile strength decreased with increasing of RHA content. It is due to the fact that the amount of RHA present in the mix is higher than the amount required and due to the leached out extra silica. This extra silica replaces part of the cementitious material and does not contribute to compressive strength.
- With increasing the RHA content in the mix, the mixture tended to be more viscous and especially sudden addition of water lead to complete failures in terms of achieving the desired SCC.
- The splitting tensile strength of SCC based on RHA was 8–12% of compressive strength respectively which satisfies the correlation between tensile strength and compressive strength of concrete.
- The splitting tensile strength of SCC is higher than the normal vibrating concrete due to better homogeneous mixture of SCC.
- The water absorption level increased with increasing of RHA content as it is hygroscopic in nature.

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