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Industrial Waste Materials as a Filler in Self Compacting Concrete

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Abstract – *Sri Lanka is currently facing a severe problem on solid waste management as it generates tons of waste per day. The currently adopted predominant method is open dumping mainly due to low cost and less processing involved. Therefore, it was intended in this study to examine the feasibility of using waste materials in self-compacting concrete to reduce their negative impacts on the environment. As such, this research aimed to evaluate the impact on the fresh state properties of self-compacting concrete by partially replacing the fine aggregate content with selected waste materials (rice husk ash, glass powder and asphalt dust waste) and to obtain an optimum percentage of the mix without loss in strength from each waste material. An optimum mix proportion was obtained by conducting performance-based tests such as slump flow test, T500 test, V funnel test, U box test and compressive strength test on the conventional self-compacting concrete mixes. Using the mix proportion obtained from the selected trial mix designs, fine aggregate content was replaced with selected industrial waste materials (rice husk ash, asphalt dust waste and glass powder) separately in percentages of 5%, 10%, 15%, 20% and 25%. Fresh state properties were checked separately for each Self-compacting concrete mix which replaced by waste materials. Hardened state properties too were checked for each mix using compressive strength tests conducted for 1 day, 7 day and 28 days. Next, the results were compared with controlled SCC mix and the optimum mix was obtained from each self-compacting concrete mix with waste materials. The results demonstrated that 5% replacement of rice husk ash (RHA), 15% replacement of glass powder (GP) and 15% replacement of asphalt dust waste (ADW) is the optimum percentages which satisfy and improves both fresh and hardened state properties of self-compacting concrete. Results obtained after 5% replacement of rice husk ash, 15% replacement of glass powder and asphalt dust waste have shown reduction in strength after 28 days. According to the cost analysis, the use of industrial waste materials (RHA, GP and ADW) to use as a filler in the production of self-compacting is profitable only marginally. Therefore, the study concludes that rice husk ash (RHA), glass powder (GP) and asphalt dust waste (ADW) are suitable as a filler in Self-compacting concrete as it improves the fresh state properties considerably without loss in strength.*

***Keywords**: Asphalt Dust Waste (ADW), Fillers, Glass Powder (GP), Rice Husk Ash (RHA), Self-Compacting Concrete (SCC)*

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1 INTRODUCTION

Environmental deposition of waste materials from industrial production is a significant problem that the world is facing today since deposition sites for those wastes are getting limited increasingly (Thongkamsuk et al., 2017). As a solution to this problem, researchers are focusing on using industrial waste materials as a raw material in concrete (Mohajerani et al., 2019). Self-compacting concrete (SCC) is a non-segregating, self-levelling and a highly flowable type concrete that is placed utilizing its weight (Han et al., 2017). The concept was first put forward by Okamura in the mid of 1980s (Esquinas *et al.*, 2018). By the mid-1990s, it was spreading around the world (Aggarwal *et al*, 2015). Since fresh SCC can flow under its weight over a long distance without segregation, bleeding and also without externally applied vibration to achieve compaction, it saves time, reduce overall cost and helps to improve the working environment (Elyamany *et al*, 2014).

Numerous applications of self-compacting concrete are available throughout the world. Some applications are the Anchorage block of the longest cable stays bridge; Akashi Kaikyo in Japan, Shin-Kiba Ohasi Bridge, Bandra Worli sea link project, the Burj Khalifa Dubai which is the tallest building in the world, La Maladiere football stadium at Switzerland and many more (Okamura and Ouchi, 2003). But, very limited applications of self- compacting concrete are available in Sri Lanka and one of the recent examples of SCC application is the silting chamber of the upper Kothmale dam (Sooriyaarachchi and Lasintha, 2016). In Sri Lanka, limited applications of SCC are available due to lack of awareness and high cost associated with its production.

To obtain enhanced quality, SCC should possess the following flow characteristics. They are the ability to flow under its own weight without vibration (filling ability), to retain homogeneity (passing ability) and segregation resistance ability (Kumar, 2015). To obtain fresh state properties, generally, SCC mixtures are adjusted by the aggregate content and by a combination of chemical and mineral admixtures (Da Silva and De Brito, 2015). Filler materials are often used to replace some of the aggregates and to modify the viscosity and also it results in sufficient segregation resistance, low yield stress and good filling ability (Angelin, Lintz and Barbosa, 2016). Chemicals used are often powerful superplasticizers and also a large number of powdered materials are too used as viscosity modifying mixtures (Guru Jawahar et al, 2013). There available several benefits of using powdered or filler materials such as to maintain sufficient stability or cohesion of the mixture so it helps in reducing bleeding, segregation and settlement (Elyamany *et al*, 2014). Self-Compacting Concrete differs from ordinary concrete mainly concerning the increase in the quantity of finer materials and reduction of coarse aggregates (Guerra, 2016). For any type of concrete, when we consider its constituents, their particle sizes and specific surface areas, and plot a graph, there is always a gap between fine aggregates and cement (Meddah et al., 2010). In the conventional concrete, this gap is filled via external compaction. As there is no compaction applied for SCC, additions of fillers are used to fill the gap (D. Han *et al*, 2017). Generally, fillers are used to obstruct pores and voids employing finer grains. In this study, Rice husk ash (RHA), Asphalt dust waste (ADW) and Glass powder (GP) which passes through 0.150mm size were used as filler materials for the partial replacement of fine aggregates.

The main byproduct of industrial processing of rice is rice husk. On average 20% of the weight of paddy is husk which sets the global estimate of the rice husk at 116 million tones (Memon et al., 2011). In Sri Lanka, rice husk is used as a fuel in brick kilns. During the burning process, 25% of the weight of this husk is converted into ash (Muntohar, 2002). In this study, rice husk ash directly put out from the industry was used. Miller (2007) has stated about 10.2 million tons of glasses are manufactured and out of them about 2.76 million tons are recycled and 8.2 million tons are discarded. According to Premachandra (2006), average composition of glass waste in Sri Lanka is 2.03. In this study, soda lime glass powder was considered which is the most prevalent type of glass. In recent past, asphalt pavement has become one of the materials commonly used for road constructions

(Ali Zangena, 2018). When producing asphalt concrete, the aggregates used are heated to a temperature of 180 ^{0}C. Next, during the cooling process, the finer particles that attached to the coarse particles get de-attached from the coarser particles. This is considered as asphalt dust waste. With the increase in demand for the asphalt concrete, there is an increase in asphalt dust waste as well as a decrease in availability of site for dumping.

When incorporating rice husk ash, glass powder and asphalt dust waste into self-compacting concrete, all three waste materials were considered as inert fillers. The impact from these three industrial waste materials on the fresh state properties of self-compacting concrete are investigated separately in this paper. Also, it attempts to determine the optimal level of fine aggregate replacement to attain satisfactory level of fresh state properties and compressive strength for self-compacting concrete.

2 METHODOLOGY

2.1 Sample Preparation

For sample preparation, rice husk ash was obtained directly from the brick kilns after fully burnt. Glass powder was prepared by grinding broken glass pieces using a ball mill. Asphalt dust waste was collected directly from a premix yard. All the materials were sieved through 0.150mm sieve.

The ranges of coarse aggregates used for the experiment were 25% from (10-20) mm range which passed through 20mm and retained on 10mm sieve sizes and 75% from (5-10) mm range that passed through 10mm and retained on 5mm sieve sizes were considered separately. M sand that pass-through 4.75mm sieve size were used for this experimental study. Chemical compositions of rice husk ash, asphalt dust waste and glass powder are shown in Table 1.

Table 1. Chemical composition of rice husk ash, glass powder and asphalt dust waste

Chemical Composition (% by mass)	**Rice husk ash (RHA)**	**Glass Powder (GP)**	**Asphalt Dust Waste (ADW)**
Calcium oxide (CaO)	5.24	9.6	2.90
Silica (SiO_2)	82.71	72.21	44.2
Alumina (Al_2O_3)	3.8	0.4	9.21
Iron oxide (Fe_2O_3)	1.152	0.2	4.25
Magnesium oxide (MgO)	0.89	-	0.62
Sulfur trioxide (SO_3)	0.05	-	-

2.2 Experimental Work

The present work aims to study the effect of filler types on fresh and hardened properties of SCC. Fresh and hardened properties such as slump flow, filling ability, passing ability, compressive strength *etc*. were considered.

2.2.1 Mix Design

Trial mix designs were carried out using design of experiments (DOE) method and a control mix design for high strength concrete of grade 60 was selected. A high strength concrete was selected as there available lots of on going projects relating to high rise buildings. As per the literature survey conducted, optimum results for the self compacting concrete with high strengths were shown by the mix proportions with the water-cement ratios in the range of 0.33 and 0.35. Therefore, water – cement ratio in the range of 0.33 – 0.35 was selected and several trial mix designs for conventianal self-compacting concrete of grade 60 was carried out. From the trial mix design for conventianal self- compacting concrete, mix design which provided the optimum test results for fresh and hardened state properties was selected and chosen as the controlled mix design. Then 5%, 10%, 15%, 20%, 25% from each waste materials (RHA, GP and ADW) which was taken as a percentage from cement content in order to circumvent possible errors due to the low specific gravities of the waste materials was replaced from the fine aggregate content of the controlled mix. Next, test results were obtained for fresh and hardened state properties. Table 2 shows the controlled mix design selected after conducting the trial mix designs.

Table 2. Mix design for controlled SCC mix

Cement (kg)	W/C ratio	Water (kg)	Total CA (kg)	CA (5-10) mm (kg)	CA (10-20) mm (kg)	FA (kg)	Super Plasticizer (Glenium sky 8233) (kg)
550	0.34	189.01	814.87	611.15	203.72	857.61	5.5

The detailed actual mix design ratio as preliminary data to produce self-compacting concrete by utilizing waste materials (rice husk ash, glass powder and asphalt dust waste) are shown in table 3.

Table 3. Mix design for self compacting concrete with fine aggregate replacement

Cement (kg)	Water cement ratio	Water (kg)	Waste material %	Waste material (kg)	CA (5-10) mm (kg)	CA (10-20) mm (kg)	FA (kg)	Super plasticizer (Glenium sky 8233) kg
550	0.34	189.1	0.05	27.5	611.15	203.72	830.86	5.5
550	0.34	189.2	0.1	55	611.15	203.72	802.96	5.5
550	0.34	189.29	0.15	82.5	611.15	203.72	775.12	5.5
550	0.34	189.38	0.2	110	611.15	203.72	747.28	5.5
550	0.34	189.48	0.25	137.5	611.15	203.72	719.44	5.5

2.2.2 Tests for Physical Properties of Aggregates

Sieve analysis tests were carried out for coarse aggregates and fine aggregates (M- sand) as per BS 882:1992 and for Rice husk ash, glass powder and asphalt dust waste too, to determine the particle size distribution of the materials. Specific gravity and water absorption for M-sand, rice husk ash, asphalt dust waste and glass powder were examined according to BS 1377-part 2:1990.

2.2.3 Determine Fresh State and Hardened State Properties of Self-Compacting Concrete

To determine fresh state properties, Slump flow test, t500 test, V funnel test and U box tests were carried out as per BS EN 206-9:2010. Compressive strength test was carried out to determine the hardened properties of self-compacting concrete. The test was conducted by applying a compressive strength until the specimen was failed according to BS EN 12390. A size of150mmX 150mmX 150mm moulds were used for the test of compressive strength of concrete. For each concrete mix, 9 cubes were cast to check compressive strengths after 1 day, 7 days and 28 days. For each testing day, 3 cubes were crushed and 1-day strength was determined immediately after demoulding without curing and others were cured.

3 RESULTS AND DISCUSSION

3.1 Physical Properties of Aggregates

Fig. 1 shows the sieve analysis test results obtained for M- sand. The lower and upper limits are specified as per the BS 882:1992. Results show the particle size distribution of M sand lies within the BS grading requirement.

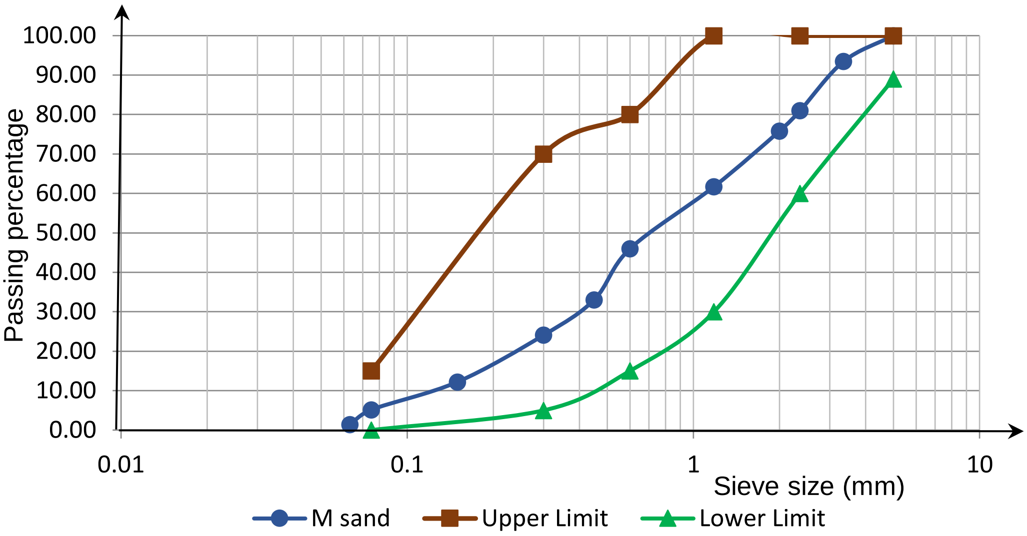

Fig. 1. Particle size distribution for M sand

The particle size distribution (PSD) curves of M sand, RHA, GP and ADW are shown in Fig. 2. Accordingly, particles of M sand, RHA, GP and ADW are well graded in their distributions.

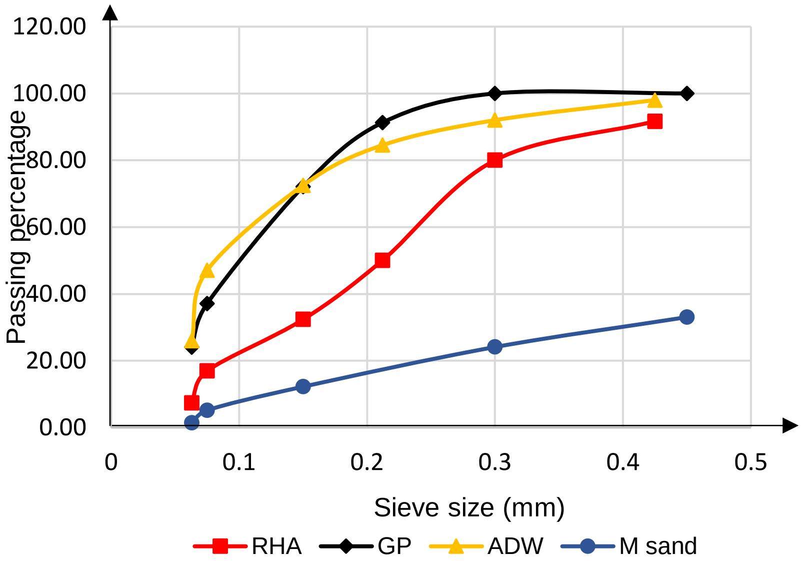

Fig. 2. Particle size distribution for M sand and waste materials

Specific gravity and water absorption for M-sand, rice husk ash, asphalt dust waste and glass powder were examined according to BS 1377-part 2:1990. Results obtained are shown in table 4 and table 5 respectively.

Table 4 – Specific gravity for constituent materials

Materials	Average specific gravity
M-Sand	2.68
Rice husk ash (R.H.A)	1.94
Asphalt dust waste (A.D.W)	2.69
Glass powder (G.P)	2.17

Results obtained for specific gravity of RHA show slight variation when compared with the results reported by Dolage *et al.,* 2011. This might be due to obtaining rice husk ash directly from the kiln and without grinding for our experiment. Results for glass powder are compatible with the results reported by Vanjare and Mahure, 2012.

Table 5. Water absorption for constituent materials

Materials	Water absorption (%)
M-Sand	0.90
Rice husk ash (R.H.A)	1.98
Asphalt dust waste (A.D.W)	1.90
Glass powder (G.P)	1.16

A larger amount of water has absorbed by rice husk ash. This may be due to the amorphous form of silica which presents highly in rice husk ash. RHA in amorphous form shows pozzolanic properties (Habeeb and Mahmud, 2010). The next highest water absorption was observed in asphalt dust waste. This might be due to its higher surface area. Accordingly, most of the results obtained for the physical properties of M-sand and waste materials (*i.e.*, rice husk ash, asphalt dust waste and glass powder) show similarities.

3.2 Fresh State Properties of Self-Compacting Concrete

A self- compacting concrete at fresh state must be stable to achieve homogeneity of the mechanical strength of the structure. Slump flow, V funnel and U box tests are carried out to understand the workability of self- compacting concrete. Criteria required for the fresh state properties of SCC according to BS EN 206-9:2010 are as shown in table 6.

Table 6. Criteria for self-compacting concrete according to BS EN 206-9: 2010

Test method	Properties	Range of values
Slump Flow	Filling ability	660-750 mm
T50	Viscosity	2-7 s
V-Funnel	Viscosity	6-15 s
U-box	passing ability	0-30 mm

Results obtained for fresh state properties obtained for the control mix obtained from trial mixes, RHA-SCC mixes, GP-SCC mixes and ADW- SCC mixes are shown in table 7. Fresh state property results obtained for the selected conventional trial mix satisfied all the requirements of EN 206-9: 2010.

Table 7. Fresh state properties obtained for control mix, RHA-SCC, GP-SCC and ADW-SCC mixes

	Mix Design	Slump Flow (mm)		Average Flow (mm)	S.F. T500 (s)	V Funnel (s)	U- Box (mm)		
		D1	D2				H1	H2	H1 – H2
Control Mix	TM-5	740	750	745	4.81	10.57	282	282	0
RHA-SCC MIX	RHA 5%	720	730	725	5.93	13.01	282	282	0
	RHA 10%	715	705	710	7.26	14.25	285	269	16
	RHA 15%	685	685	685	7.65	9.64	278	278	0
	RHA 20%	590	600	600	8.43	9.17	294	275	19
	RHA 25%	490	490	490	0	6.54	302	279	23
GP – SCC MIX	GP 5%	745	755	750	6.18	13.58	280	270	10
	GP 10%	715	725	720	5.56	14.65	285	273	12
	GP 15%	720	715	717.5	6.44	14.78	285	285	0
	GP 20%	720	710	715	6.72	15.04	280	280	0
	GP 25%	695	695	695	7.21	14.28	288	280	8
ADW – SCC MIX	ADW 5%	735	735	735	4.05	11.28	284	284	0
	ADW 10%	710	700	705	6.58	13.64	288	276	12
	ADW 15%	705	695	700	6.32	12.36	295	275	20
	ADW 20%	695	695	695	6.00	13.95	295	274	21
	ADW 25%	690	700	695	6.07	14.98	288	271	17

As shown in Fig. 3, the results of slump flow test were obtained between 660 and 750 mm for the mixtures containing rice husk ash up to 15%, glass powder and asphalt dust waste up to 25%. Slump flow of 5% replacement of glass powder has reached to upper limit because of low viscosity. However, replacement of rice husk ash after 15% have decreased from 685mm to 4900mm due to increase in viscosity and thixotropy. Higher water absorption of rice husk ash might be the reason to low slump flow. In similar studies done by Samantaray *et al.* (2016) and Chopra *et al.* (2015), results of the fresh state properties shown up by 15% replacement of RHA tally with the results of this study. According to Safawi *et al.* (2005), there available four parts of the slump flow; between 400 and 500mm, 500 and 600mm, 600 and 700 mm and 700 and 800mm. Generally, highly viscous mixtures have slump flows less than and around 500mm. The viscosity of the mixture would be expected to be optimum at slump flows at 600mm and it would flow easily by virtue of its own weight. Slump flows between 700mm and 800mm would be prone to segregation easily.

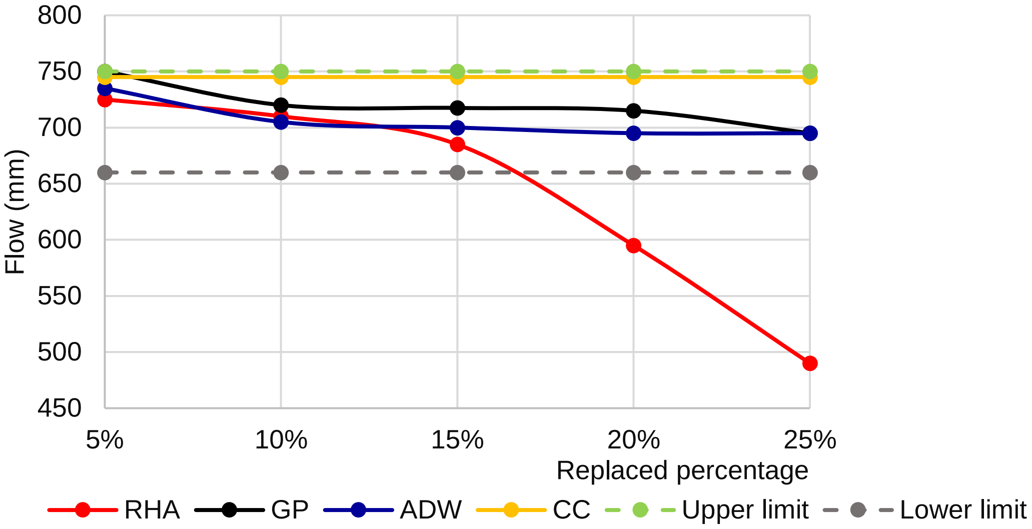

Fig. 3. Slump flow test results

Results obtained for V funnel are shown in fig. 4.

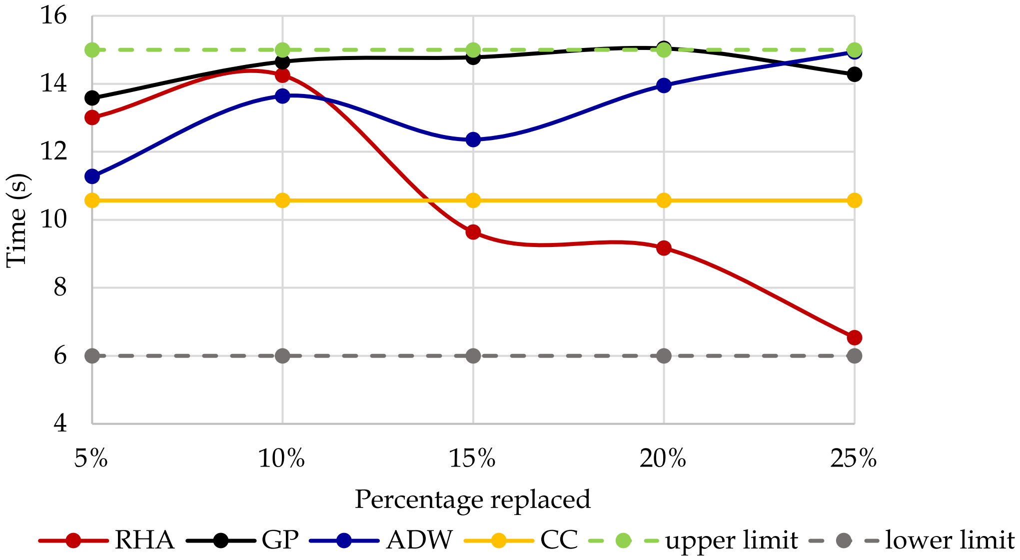

Fig. 4. V funnel test results

15%, 20% and 25% replacement of RHA has shown lower results than that for the results obtained for the conventional concrete mix. Which in turn means good flowability. Except 20% replacement of glass powder, all the other results obtained for each mix were within the limit specified by BS EN 206-9: 2010 which means mixes with good viscosities and segregation resistances. The viscosity of self-compacting concrete with glass powder was very high and therefore V funnel flow time was closer to 15s which is the upper limit. Reasons for decrease in flow resistance might be due to the increase in packing density of the fresh mix resulting due to various parameters like the reactivity of fillers, the volume of fine particles required to fill the total volume of voids in the mix, water cement ratios and etc.

Fig. 5 indicates the results related to U box and it indicates the filling and passing ability of SCC. U box test is more sensitive to blocking.

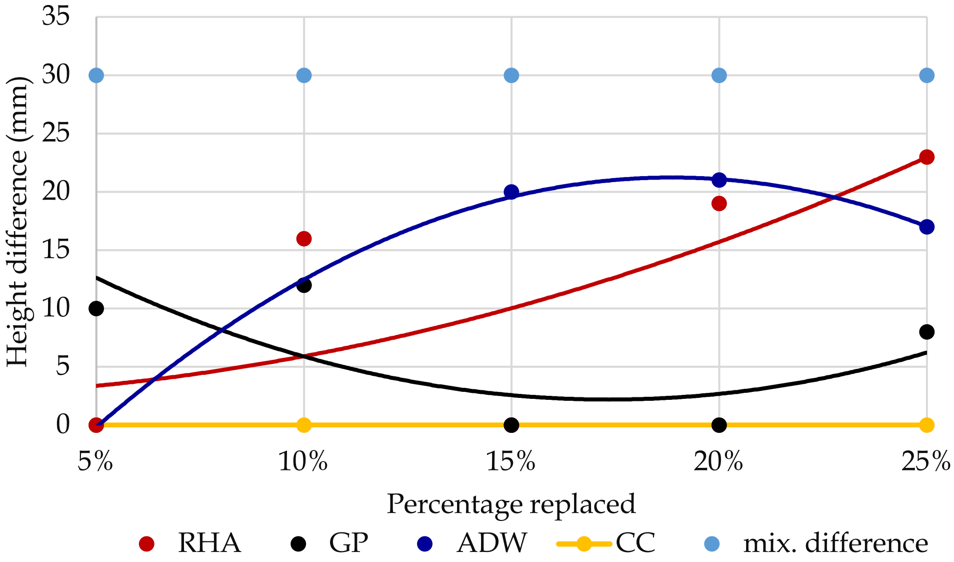

Fig. 5. U box test results

Results obtained for U box test of each mixes were in target range. According to Nguyen et al, (2006), if the standard procedure is followed to carry out the testing and the U box gate is quickly lifted, the flow is controlled by inertia effects, depending on the lifting speed of the gate and thus, depending on the operator. Once the gate is slowly lifted, the kinetic energy is spread over the gate lifting duration. Then the flow moves slowly towards the other side. These can be considered as the reasons for the variations of the results obtained for each percentage.

According to the results obtained for the fresh state properties, 5% and 10% replacement of rice husk ash, 5%, 10%, 15% and 20% replacement of glass powder and 5%, 10% and 15% of asphalt dust waste has shown best performance according to the BS EN 12350-8: 2009.

3.3 Hardened State Properties of Self-Compacting Concrete

Compressive strength of crushed concrete cubes was determined by dividing failure load by surface area of the cube (*i.e.*, 0.0225m^2). Fig. 6 illustrates the results obtained for 28 days compressive strength test results.

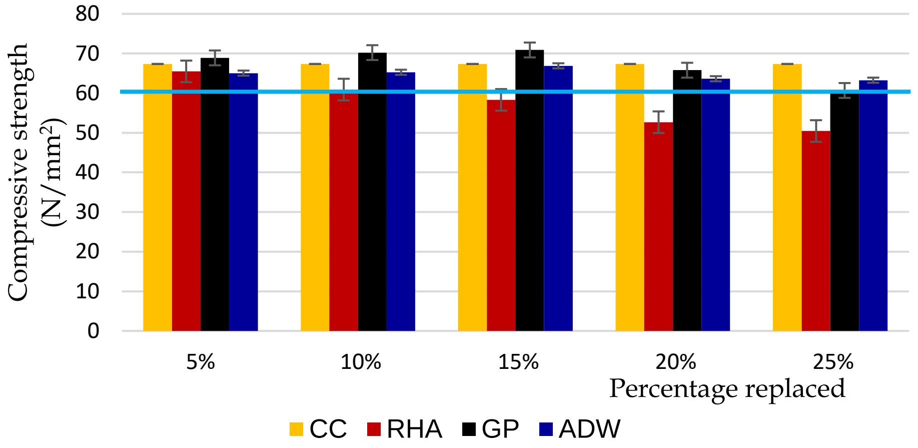

Fig. 6. 28 days compressive strength results

Addition of RHA has a noticeable effect on the compressive strength of the hardened SCC. This may be due to the lightweight of the rice husk ash and higher water absorption. As can be seen from the results obtained for the compressive strengths, 5% and 10% replacement of RHA generates the highest compressive strengths. Furthermore, the compressive strengths decrease as the amount of RHA replacements increase. Compressive strength results obtained are similar to the results reported by Chopra *et al.* (2015). But maximum strength recorded by Chopra *et al*. (2015) is 15%. This might be due to obtaining RHA directly from the kilns without further grinding in our studies.

When considering the addition of glass powder, 5%, 10%, 15% and 20% replacement of glass powder has shown the best result for compressive strengths. The results aren't tally with the results reported by Vanjare et al. 2012 but are similar to the results recorded by Islam et al.2016. As per the results obtained for the 28-day compressive strengths for ADW-SCC mixes, the maximum compressive strength has recorded for the 15% replacement of ADW. The obtained results are compatible with the results recorded by Ismail *et al*, (2017).

The positive effects of different filler contents in SCC on fresh concrete properties have also shown positive results for hardened concrete properties too. Accordingly, it can be seen that the strength of self compacting concrete with fillers have increased up to a certain percentage of addition of fillers because of the good packing arrangement. So, the strengthening effect of fillers on concrete paste derives from the improvement of the pore structure. According to the 28-day test results, 5% replacement of rice husk ash, 15% replacement of glass powder and 15% replacement of asphalt dust waste has shown good results.

3.4 Cost Analysis

Self-compacting concrete should workable as well as profitable when using industrial waste materials without loss in strength. To decide the profitability of the concrete a cost analysis was carried out as per the market price in July 2018. Only, the cost for 1m^3 of constituent materials for self-compacting concrete was analyzed and cost for transportation was not considered. The mixes selected for calculation and analysis were those which showed optimum results for fresh and hardened state properties. Table 9 shows Cost comparison of controlled self-compacting concrete with RHA-SCC, GP- SCC and ADW-SCC.

Table 8. Cost comparison of controlled self-compacting concrete with M sand only, RHA-SCC, GP- SCC and ADW-SCC

Mixture	The unit price for 1m³		Saving percentage (%)
	LKR	USD	
SCC with M sand only	15568.65	97.50	-
SCC-Rice husk ash	15482.31	96.96	0.55
SCC-Asphalt dust waste	15420.62	96.57	0.95
SCC-Glass powder	15503.12	97.08	0.42

According to table 8, the introduction of industrial waste materials as filler to the self-compacting concrete has resulted in only a marginal profit to the conventional self-compacting concrete. This is due to replacement of fine aggregate contents from fewer amounts of industrial waste materials. The reason for the comparatively lower saving percentage for SCC- glass powder mix is due to additional grinding cost. When comparing the results obtained for fresh and hardened state properties together with the cost analysis, 5% replacement of rice husk ash, 15% replacement of glass powder and 15% replacement of asphalt dust waste has shown optimum results.

4 CONCLUSION

Fresh and hardened state properties of the rice husk ash, glass powder and asphalt dust waste integrated SCC mixes were evaluated and compared with those of the conventional SCC. The results on the properties of fresh self compacting concrete such as slump flow, V funnel time and blocking ratio revealed that rice husk ash, glass powder and asphalt dust waste have a significant effect on the flow, segregation resistance and bleeding resistance. The homogeneity of the pastes containing finest fillers might be a possible cause for obtaining better results for fresh state properties. The increase in rice husk ash, glass powder and asphalt dust waste content from 5% to 15% improved bleeding and segregation resistance of SCC. When compare both results obtained for fresh and hardened properties, 5% replacement of rice husk ash, 15% replacement of glass powder and asphalt dust waste have improved both fresh and hardened state properties of the self compacting concrete. Based on the results, it seems that concrete strength can be increased via improved particle packing. Several of the by products generated from industries widely abundant can therefore be recycled into self-compacting concrete to bring about improvements in strength, durability and rheology while saving material cost upto a certain amount and while preventing environmental pollution caused by open dumpings.

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