Production of high strength high performance 100 MPa rice husk ash concrete

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Abstract— **The high demand of high strength high performance concrete (HSHPC) in concrete industries attracts researchers to be more focused on improving the performance characteristics of HSHPC: workability, mechanical properties and durability. Applying high strength concrete, one of the performance characteristics, is beneficial for high rise buildings to increase the space of occupation and save the cost of maintenance in the long term. There is a need to study on HSHPC incorporating rice husk ash (RHA) due to limited information on utilizing RHA in HSHPC with low w/b. The binder and w/b adopted in this study were 550 kg/m^3 and 0.25, respectively. The results reported included fresh, hardened and durability properties of high performance 100 MPa concrete incorporating 0%, 10%, 15% and 20% RHA as well as 10% condensed silica fume (CSF). The results revealed that the compressive, flexure and tensile strengths, and modulus of elasticity of concrete incorporating 10 % RHA are better than that of 10% CSF and plain concrete. The initial surface absorption (ISA) value of RHA is also better than that of OPC and CSF concrete at 28 days. RHA is proven as the alternative to silica fume in producing high performance concrete through achievable workability, strength, durability and strength efficiency of cement. The outcomes show the potential of using RHA to produce HPC. RHA has the prospective for contributing to the sustainable development and economic prosperity of the construction and agricultural industries especially to the rice growing nation worldwide.**

Keywords-component: high performance concrete; rice husk ash; workability; mechanical properties

I. INTRODUCTION

High strength high performance concrete (HSHPC) is known as superior concrete, which meets special performance and uniformity, and those requirements cannot always be achieved by using conventional material and normal mixing, placing and curing practice [1]. In recent years, researchers focused on the performance characteristics of concrete such are workability, mechanical properties and durability [2, 3] to improve those properties. Applying high strength concrete, one of the performance characteristics, is beneficial for high rise buildings by increasing the space of occupation and save the cost of maintenance in the long term [4]. Concrete strength of up to 80 MPa, e.g. Petronas Towers, has been used in the lower columns of high rise building. To produce such concrete a low water binder and condensed silica fume (CSF), a supplementary cementious material (SCM), were used.

It is known that silica fume is suitable for concrete to produce high compressive strength at early age [5] due to high content of reactive SiO_2 and tiny spherical shape of the particle. SiO_2 of SCM and $Ca(OH)_2$ of cement hydration product with available moisture react to form additional CSH [6], which improved mechanical properties and durability of concrete due to lower porosity and denser concrete [7, 8]. Even though silica fume is important to improve mechanical properties of concrete; the price is very high compared to cement. As an alternative, rice husk ash (RHA) can be used as SCM due to its chemical composition being similar to CSF. RHA is a residue from burning rice husk, which is a waste of rice mill. Malaysia is one of the rice producers in Southeast region and produce rice annually of about 2.6 million tons/year [9] and 20% of paddy will produce rice husk as waste. Some of them are used as parboiling paddy and generate electricity and the rest is dumped in the landfill area. If rice husk is burned in open area, it creates environment problem due to air pollution. However, burning rice husk with controlled combustion at 500-700 ^{o}C produces RHA with rich amorphous silica and high content of SiO_2, which is very reactive [10]. RHA can be produced from 20 % of rice husk weight. Furthermore, chemical composition of RHA should comply with ASTM C618 for being used as pozzolan in cement and concrete. The combined proportion of silicon dioxide (SiO_2), aluminum oxide ($A1_2O_3$) and iron oxide (Fe_2O_3) in the ash should be not be less than 70%, and LOI should not exceed 12% [11].

The optimum replacement of cement with RHA in concrete depends on its particle size and w/b of concrete. Hwang et al. [12] reported 30% replacement of cement with RHA in concrete with water to binder ratio (w/b) 0.35 can be used without impairing concrete strength. Bakar [13] reported that if the particle size of RHA is less than particle size of cement in concrete of w/b 30, it can be used up to 15% percent to replace cement. Bui et al. [14] replaced cement with 20% of amorphous RHA and the concrete showed excellent characteristics in its mechanical and durability properties. Furthermore, they mentioned that the crystalline form of RHA due to over combustion can still be used to reduce chloride penetration even though the compressive strength is lower than that of plain concrete [14]. Habeeb [15] mentioned that the finer particle size of RHA improves the mechanical properties and drying shrinkage of concrete. Mahmud et al. [16] reported that the mechanical properties of RHA concrete of 60-80 MPa could be achieved by utilizing w/b ratio equal to 0.27 and Sp. However, there is limited information on the optimum replacement of RHA and on the effect on performance characteristic of concrete at low w/b ratios. It is known that the surface area of RHA is higher than CSF even the particle size of CSF is less than RHA and this affects the workability of fresh concrete, so that more dosage of superplasticizer (Sp) is needed for similar workability.

This paper explores the feasibility of using RHA to produce 100 MPa concrete. Effects of various percentages of RHA on fresh, hardened and durability properties of concrete are reported. The replacements of cement with RHA adopted in this study were 0, 10, 15 and 20 % at w/b equal to 0.25. The fresh and hardened property measured were slump and mechanical properties such as compressive strength, tensile strength, flexural strength and modulus of elasticity up to the age of 180 days. For durability, initial surface absorption test (ISAT) was conducted at 7, 28 and 90 days.

II. MATERIAL AND METHODOLOGY

A. *Material*

The ingredient materials used in this study were cement, rice husk ash (RHA), condensed silica fume (CSF), aggregates, water and superplasticizer (Sp). Ordinary Portland cement (OPC) Type I class 42.5 from local manufacturer was used and its specific gravity and specific surface area are 3.15 and 3280 m^2/kg, respectively. RHA was produced by uncontrolled burning in ferrocement furnace, but the temperature of burning did not exceed 700 ^{0}C so that RHA is in amorphous form. RHA was ground in LA machine for 16000 cycles to get average particle size of 13.50 µm. Its specific gravity and surface area was 2.06 and 23455 m^2/kg. Major chemical composition of RHA and CSF consist of SiO_2, of above 90 %. The particle size of cement is greater than that of RHA and CSF, 1.5 and 40 times respectively. However, the surface area of RHA and CSF is much greater than that of cement, almost 100 times. It is related to the nature of the porosity of the RHA particles and the tiny spherical shape of CSF particles. The specific gravities of mining sand and crushed granite aggregate used were 2.36 and 2.67, respectively. The nominal maximum size of coarse aggregate was 19 mm. Aggregates were washed to minimize the clay in mining sand and dust in crushed granite aggregate. The mixtures were mixed using tap water. Figure 1 shows the particle size distributions of all mixture constituents. The average particle size of RHA is less than that of OPC.

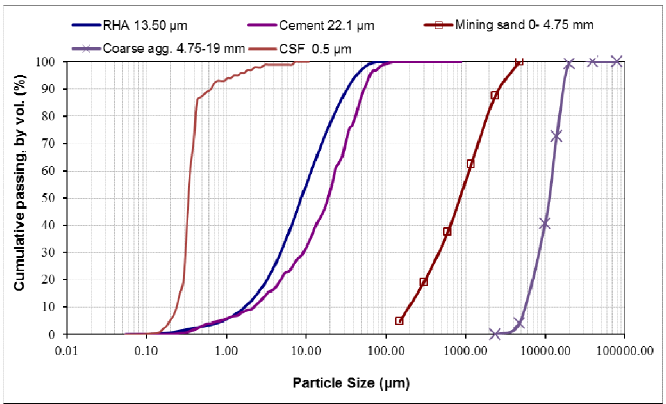

Figure 1. Particle distributions of constituent materials in HSHPC

B. *Mixture proportioning and test*

Five concrete mixes having the same w/b of 0.25; of which one control and three mixtures with different proportions of RHA and one mixture containing CSF were investigated in this study. The high performance concrete of the mixes was maintained by adjusting the superplasticizer dosage. The mix proportions of the produced mixtures (for 1 m^3 by weight) are presented in Table 1.

TABLE 1. MIX PROPORTION AND WORKABILITY FOR OPC, RHA AND CSF CONCRETE

Mix ID	W/b	Ingredient (kg/m^3)						
		Sp (l/m^3)	Water	Cement	RHA	CSF	Aggregate	
							Fine	Coarse
OPC-25	0.25	2.38	137.5	550	0	0	702	1050
RHA10-25	0.25	3.49	137.5	495	55	0	690	1050
RHA15-25	0.25	3.93	137.5	468	82.5	0	685	1050
RHA20-25	0.25	4.15	137.5	440	110	0	681	1050
CSF10-25	0.25	3.13	137.5	495	0	55	692	1050

C. *Test of samples*

For all samples, fresh concrete was placed in two layers except three layers for cylinder of 150 mm diameter x300 mm and then all samples were vibrated. The samples were covered with plastic sheet and demolded after 24 hours. All samples were cured in water tank and taken out before test on specific days. The mechanical properties of concrete included in this study are compressive strength, tensile strength, flexural strength and modulus of elasticity. For compressive strength, cubes of 100x100x100 mm were used and the test follows BS EN 12390-3:2009. The specimens for the tensile strength were cylinders of 100 mm diameter x 200 mm and the test follows BS EN 12390-6:2009. The specimens for the flexural strength were prisms of 100x100x500 mm and the test follows BS EN 12390-5:2009. The specimens for modulus of elasticity were cylinders of 150 mm diameter x 300 mm and the test follows BS EN 13412:2006. The specimens were tested at 1, 3, 7, 28, 56, 91 and 180 days after water curing. The numbers of specimens for each testing were three specimens for compressive strength and two for tensile strength, flexural strength and modulus of elasticity. The specimens for initial surface absorption test (ISAT) were cubes of 100x100x100 mm and the test follows ASTM C 1202 – 05. The ISAT was tested after 7, 28 and 90 days of water curing.

III. RESULTS AND DISCUSSIONS

A. *Effect of RHA on fresh concrete*

All mixtures were kept at similar workability by maintaining the slump in the range of 200-220 mm. Table 2 reveals that fresh properties of concrete are influenced by inclusion of RHA and CSF. As can be seen, the Sp dosage increases almost 50% compared to plain concrete. The increased dosage of Sp in RHA and CSF mixture could be related to the increase in specific surface area of the fine particles and also on absorption of Sp, which reduce the actual dosage of Sp available. Similar observation had been reported by Zhang et al. [17]. The fresh density of concrete decreased when incorporating RHA and CSF due to replacement of cement with SCM was based on weight basis. Thus this increases the volume of the binder as their specific gravity is lower than that of cement [18].

TABLE 2. THE PROPERTIES OF FRESH CONCRETE

Mix ID	W/b	RHA or CSF (% of binder)	Sp content (% of binder)	Slump (mm)	Fresh Density (Kg/m^3)	Air content (%)
OPC-25	0.25	0	0.43	210	2478	1.8
RHA10-25	0.25	10	0.71	210	2458	1.7
RHA15-25	0.25	15	0.84	213	2448	1.7
RHA20-25	0.25	20	0.94	212	2441	1.6
CSF10-25	0.25	10	0.63	211	2452	1.7

B. *Effect of RHA on compressive strength*

Figure 2 shows the compressive strength of all mixes up to 180 days. At early age of 1 day, the RHA and CSF have lower strength than plain concrete and it is due to lower hydration process in those concrete which have less cement content compared to plain concrete. Concrete incorporating 10 % RHA and 10% CSF both have almost similar compressive strength, about 70 % of that of plain concrete. For 15% and 20 % RHA, the compressive strength is 66 % and 49 % of plain concrete. It is clear that higher percentage replacement of RHA really affect the early strength of RHA concrete. Langan et al. [19] in their study on silica fume concrete at low w/b ratios mentioned that the reactivity of the silica fume is hampered so that the hydration of the cementious system is significantly retarded. At 7 days, the compressive strength of 10% RHA and 10% CSF concrete are 1 % higher than that of plain concrete even when they have less cement content. The 15% and 20% RHA concrete show improvement in compressive strength as their difference from plain concrete are almost 93 % and 82 %, respectively. At 28 days, the compressive strength of concrete incorporating 10% RHA is 9 % higher than that of plain concrete. However, compressive strength of concrete incorporating 15% and 10% CSF are almost similar to that of plain concrete. The compressive strength of concrete incorporating 20% RHA only achieved 83 % of that plain concrete. It also shows that the RHA and CSF can act as micro filler and contribute also to pozzolanic activity [20]. It is important to note that all mixes achieve higher than 100 MPa at 180 days. It shows that the compressive strength of RHA concrete can achieve the target strength with various replacements with different ages of concrete. In this study only water curing was considered. Mahmud [16] mentioned that at low w/b, there was insignificant difference between water curing or drying curing on concrete strength. Based on these facts, it is possible to substitute CSF with RHA in similar replacement amount and achieve the target strength.

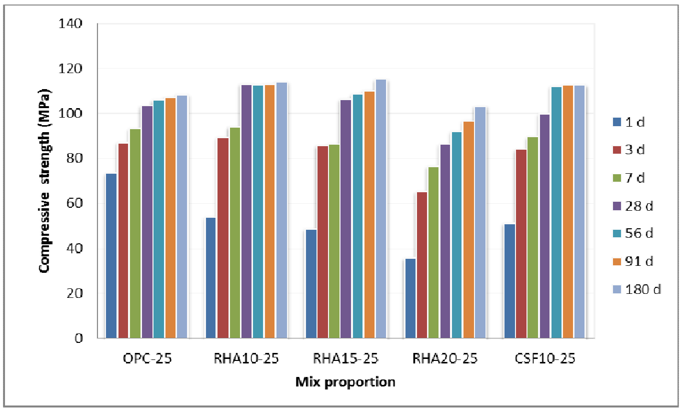

Figure 2. Compressive strength of HSHPC

C. *Effect of RHA on splitting tensile strength*

The splitting tensile strength of all the mixes is shown in Figure 3. The mix containing 10% RHA and 10% CSF showed similar tensile strength at 7 days compared to that of plain concrete. Tensile strength of concrete incorporating 15% RHA and 20% RHA are 95 and 93 % of that of plain concrete. It could be that the CSH formed from hydration of $Ca(OH)_2$ and SiO_2 at higher percentage of RHA is not of same quality and quantity of CSH from hydration of concrete incorporating 10% RHA. The splitting tensile of 10% RHA and 10% CSF concrete is higher than that of plain concrete at 28 days and beyond by about 4%. However, the difference in the splitting tensile strength of 10% RHA and 10% CSF concrete is negligible, only about 1-2%. As known, the RHA and CSF mixture have lower cement content compared to plain concrete. However, those mixtures can still achieve similar tensile strength of plain concrete due to the pozzolan reaction of RHA or CSF. The tensile strength development at 90 days is not much different for all mixes, only up to 4% increase compared to that at 28 days. Only concrete incorporating 20% RHA cannot achieve similar tensile strength of plain concrete at 90 days. The ratio of splitting tensile strength to compressive strength of 10% RHA and 10% CSF concrete ranged between 6% to 7% at 28 days. Previous research showed that this value is in the range of 9% to 10% at 28 days for medium strength concrete [21]. For high strength concrete containing natural pozzolan and silica fume and of compressive strength of 80 MPa, the ratio of 6.6% and 6.8% were achieved [22].

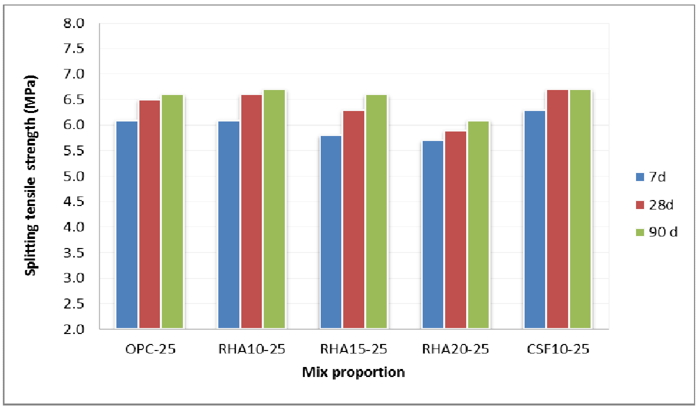

Figure 3. Splitting tensile strength of HSHPC

D. *Effect of RHA on flexural strength*

Figure 4 shows that at 7 days, the flexural strength of concrete incorporating 10%, 15%, 20% RHA and 10% CSF mixes were lower than plain concrete. But at 28 days the flexural strength of concrete incorporating 10% RHA and 10% CSF mixes was 5% higher than that of plain concrete, which is insignificant. The flexural strengths of all concrete mixes at 28 and 90 days are in the range of 8.0 to 10.3 MPa. The flexural strength of 10% RHA and 10% CSF concrete achieve higher than that of plain concrete at 90 days. The ratio of flexural strength and compressive strength is between 9 - to 10%, which is a little bit higher than that of tensile strength to compressive strength ratio.

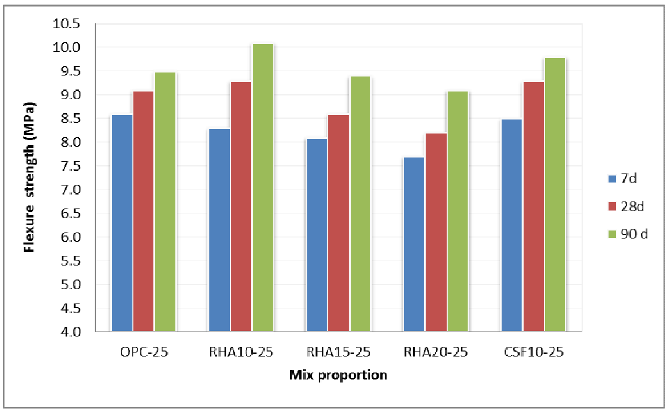

Figure 4. Flexural strength of HSHPC

E. *Effect of RHA on modulus of elasticity*

Figure 5 shows the modulus of elasticity of 0%, 10%, 15% and 20% RHA and 10% CSF concrete at 7, 28 and 90 days. At 7 days and later, the modulus of elasticity of 10%, 15 % RHA and 10% CSF concrete was higher than that of plain concrete. Only concrete incorporating 20% RHA showed modulus of elasticity of 90 % of that of plain concrete. Similar results were found by Yin et al. [23] in concrete containing fly ash when they produced C-100 high performance concrete. In high performance concrete, the packing density is of more concern than in normal concrete. This result shows that the modulus of elasticity of 10% RHA and 10% CSF concrete increased slightly by about 10% compared to that of plain concrete, which indicates RHA and CSF improves the stiffness and volume stability of concrete. At 90 days, concrete incorporating 10% RHA and 10% CSF are 5% higher than that of plain concrete. However, value of modulus of elasticity of concrete incorporating 15% RHA and 20% is similar and 5% lower than that of plain concrete, respectively.

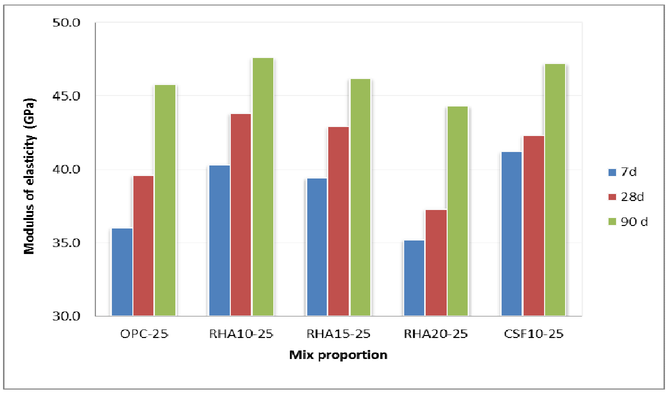

Figure 5. Modulus of elasticity of HSHPC

F. *Effect of RHA on durability of concrete*

The ISAT was conducted to find the rate of flow of water into concrete per unit area at a stated interval from the start of the test at a constant applied head and temperature. Results are expressed as ml/ml^2/s at a stated time from the start of test. The results of ISAT of measurement at 10 minutes are shown in Fig. 6. The ISA values of concrete incorporating 10% RHA exhibited lower ISA value than that of concrete incorporating 15% RHA but higher than that of concrete incorporating 10% CSF. However, the ISA values are higher for plain concrete. The concrete incorporating RHA and CSF exhibited significant reduction in ISA value. This is expected since the RHA and CSF act as micro filler and its extreme fineness allows it to fill the microscopic voids between cement particles, which greatly reduce the permeability. After 90 days, the rate of ISA value is decreased lower than that of ISA value at 28 days. It means the process of pozzolanic reaction still continue as reaction of cement is almost reaching the peak at 28 days. The incorporation of RHA in concrete is beneficial to reduce the permeability of concrete.

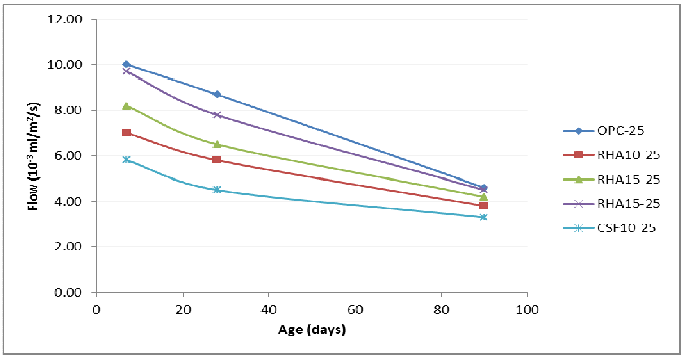

Figure 6. ISA value of HSHPC measured at 10 minute

G. *Effect of RHA on strength efficiency of cement*

Figure 7 shows the strength efficiency of concrete containing of 0%, 10%, 15%, 20% RHA and 10% CSF. The strength efficiency of cement is denoted as MPa/kg cement. It shows that the strength efficiency value of RHA and CSF concrete is higher than that of OPC concrete after 3 days. At 180 days, all mixes regardless of percentage of cement replacement achieved above 0.2 except for OPC mixes, which only achieved 0.2. The compressive strength efficiency of cement rises up to 0.25 for 10% replacement of cement with RHA. The values of 0.20 and 0.25 of efficiency coefficients are similar with 5 and 4 kg of cement/m^3 to produce 1 MPa of concrete strength. It is clear that using RHA and CSF in high performance concrete will reduce 20% of cement consumption to get similar compressive strength of concrete without RHA or CSF. Similar results are also reported by Hwang [12], who concluded that inclusion of RHA in concrete mixture increase the strength efficiency of cement. The energy consumption and the detrimental CO_2 emission to the environment during the production of cement can significantly be reduced by the incorporation of RHA or CSF in concrete.

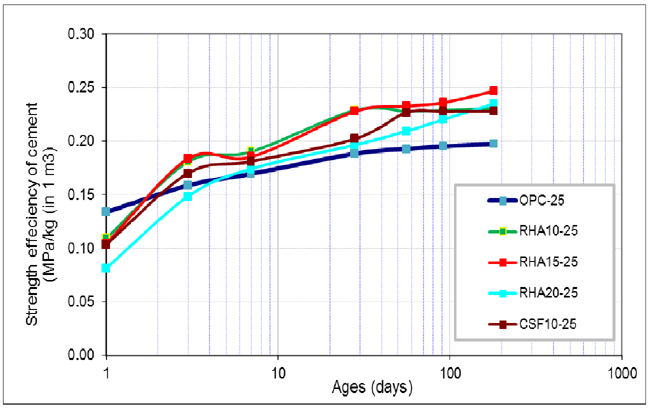

Figure 7. Strength efficiency of cement in HSHPC

IV. CONCLUSION

1. The compressive strength of concrete incorporating 10% and 15% RHA can achieve 100 MPa at 28 days and it could be related to the optimum packing density of the mixture, the filler effect and the pozzolanic activity of RHA. However, the compressive strength of concrete incorporating 20% RHA can only achieve 100 MPa at 180 days.

2. The mechanical properties of RHA and CSF concrete improved compared to that of plain concrete from 7 days onward.

3. Durability test through ISAT show that RHA and CSF concrete is better than plain concrete. Lower ISA values were recorded for RHA and CSF concrete compared to the plain concrete.

4. The strength efficiency of cement for concrete incorporating RHA and CSF is higher than that of plain concrete, which means that the usage of SCM does not reduce the strength but increase strength in term of strength per 1 kg cement.

5. It is feasible to produce 100 MPa concrete containing RHA. Performance of this type of concrete is better than plain concrete. Since CSF is much more expensive than RHA in production HSHPC of 100 MPa, RHA is the alternative supplementary cementious material to CSF.

V. ACKNOWLEDGMENT

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