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Effects of Silica in Rice Husk Ash (RHA) in producing High Strength Concrete

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ABSTRACT

High strength concrete (HSC) are known to have a higher amount of cement binder in the mix design properties with low w/b ratio. The high mass of cement content produced substantial heat liberation in the concrete due to the reaction between cement and water, which can lead to cracking. Additive likes silica fume is too expensive to use in the HSC in order to overcome the problems, however, the initiative of utilizing the rice husk ash (RHA) which have high silica content are apply for the design of HSC. The RHA is obtained by burning the rice husk which is an agro-waste material, and was found to have good pozzolanic material properties. This paper highlighted the study conducted in determining the effect of silica content in RHA in HSC production. The strength performance considered in this study is 60 N/mm^2 and 70 N/mm^2. The percentages used as cement replacement varies, *i.e*. 10%, 20%, 30%, 40% and 50% of RHA by cement weight, and with addition of superplasticizer. Compressive strength test was conducted at age of 28, 60 and 90 days to see the development of strength, while for the durability index performance, the Rapid Chloride Penetration Test (RCPT) tested at age 28, 60 and 90 days and water absorption test tested at age 28 and 90 days of water curing were performed. This research paper reported that 10% replacement of cement with RHA was found to be the optimum replacement in achieving the targeted strength, however, for durability index performance, higher replacement level (up to 50%) can be achieved, resulted in decreased in charge passed and decreased in water absorption, therefore, improved the durability performance of the concrete. These shows that high amount of silica in RHA gave some effects on the strength and durability of the HSC.

Keywords: *Rice Husk Ash (RHA), High Strength Concrete, Compressive Strength, Durability Performance*

1. INTRODUCTION

High strength concrete (HSC) was considered when specified concrete able to resist higher loading compare to the normal strength concrete range. The HSC was important in construction of high rise building to reduce column sizes in order to increase available space, long bridge constructions, marine foundations and heavy duty industrial floors as reducing cross section of structural elements is required [1]. The HSC can be achieved by addition of two materials which are superplasticisers and microsilica (or silica fume). Combination of the two admixtures tend to increase the required strength whereby the superplasticers able to reduce the water/cement ratio [2], thus reduced permeability and less space for silica gel to fill up the interface zone between the aggregate surface and cement paste, resulting more dense concrete to be achieved.

Problem regarding limited supply of silica fume [3] and variation from half to twice the cost per bag of Portland cement encourage the use of rice husk ash (RHA) as an alternative material to replace the silica fume function. Besides, the production of cement gave harm to environment, *i.e*. for every ton of cement manufactured for use in concrete emits a ton of the greenhouse gas carbon dioxides (CO_2) into the atmosphere. It is also reported by Michael [4] that cement production accounts for about 5% of all CO_2 emission related to human activity. The function of RHA can be good as silica fume replacement due to the essential asset of RHA containing approximately 85% to 95% by weight of amorphous silica [5, 6]. The present of amorphous silica was beneficial as filler to improve the interface transition zone and to produce more dense concrete. This was successful for the normal concrete where better strength of concrete were reported [7, 8, 9, 10, 11, 12]. According to Kartini [12], besides improved the compressive strength, the replacement of OPC with RHA helps to improve the durability index of normal grade concrete (*i.e*. 30, 40 and 50), in which this properties are difficult to achieve by using pure Portland cement alone. This research paper highlighted the work carried out on the replacement of OPC with RHA in higher strength, *i.e*. grade 60 and 70.

2. EXPERIMENTAL PROGRAMME

2.1 Material Preparation

The rice husk was taken from rice mill located at Kuala Selangor, Malaysia and brought to burn in a ferrocement furnace at the Faculty of Civil Engineering, Universiti Teknologi MARA (UiTM). The production of ash begins by placing about 20 bags of rice husk in the wire mesh caging inside the furnace and continuously, start and maintain the fire for about 1 hour at the bottom of the furnace. Then, the rice husk was left to burn further for 24 hours. The next 24 hours are required to cool down the ash inside the furnace. Normally the ash that lies within the middle third of the furnace was taken for grinding using Los Angeles (L.A) machine, as it was found to be amorphous [6]. The drum of L.A machine was set to rotate for 5000 revolutions using electric motor at speed of 33.3 revolutions per minute (rpm). Table 1 shows the chemical composition of RHA and OPC [12]. The specific gravity of RHA is 2.1 and the median particle diameter is 25.83 µm.

Table 1: Chemical composition of RHA and OPC [12]

Chemical Composition	OPC	RHA
SiO_2	15.1	96.7
Al_2O_3	2.56	1.01
Fe_2O_3	4.00	0.05
TiO_2	0.12	0.16
MgO	1.27	0.19
CaO	72.2	0.49
Na_2O	0.08	0.26
K_2O	0.41	0.91
P_2O_5	0.06	-
MnO	0.06	-
SO_3	2.9	-
LOI	1.33	4.81

The cement used in this research work was Ordinary Portland Cement (OPC) Type I, having a specific gravity of 3.11 and median particle diameter of 21.2 µm. The gravel and mining sand were used as coarse and fine aggregates respectively. The maximum size for coarse aggregate is 20 mm and for the fine aggregate is 5mm. Coarse and fine aggregate were tested for its particle size distribution by sieve analysis as according to BS EN 812-103.1 [13]. The superplasticizer (Sp) used was RHEOBUILD 1000, which is water soluble and sulfonated naphthalene formaldehyde condensed base satisfying Type A and Type F requirements of the BS 5075-3 [14]. The purpose of Sp was to increase the workability of the concrete as the amount of RHA replacement resulted in dried mixture of the fresh concrete. Study conducted by Shafiq *et al.* [15], Hwang and Wu [16] and Mehta [17] had concluded that concrete with RHA required more water for a given consistency due to its absorptive character of the cellular RHA particles. Thus, in maintaining constant amount of water in the mix in achieving the required slump (workability), the needs to add Sp is definite.

2.2 Mixture Proportion

The control OPC concrete was designed to achieve the target strength of 60 N/mm^2 and 70 N/mm^2. The mixture proportion obtained for both strength were as shown in Table 2, in which for the strength of 60 N/mm^2 and 70 N/mm^2, the amount of cement used were 605 kgm^{-3} and 680 kgm^{-3} with 0.34 and 0.30 water/cement ratio (w/c) respectively.

Table 2: Mix Proportion of concrete grade

Concrete Grade	Cement (kg/m^3)	Water (kg/m^3)	Aggregate (kg/m^3)	
			Fine	Coarse
60	605	205	690	915
70	680	205	655	865

2.3 Laboratory Test Conducted

2.3.1 Compressive Strength Test

The compressive strength of concrete cube was conducted in accordance to the BS EN 12390-3 [18]. This test was conducted in order to gauge the strength properties of hardened concrete. The specimen used was sized 100 mm cube and tested at ages of 28, 60 and 90 days.

2.3.2 Rapid Chloride Penetration Test (RCPT)

For RCPT test, the concrete cylinder specimen of 200 mm long (height) was cut into three slices with 50 mm thickness each, and 25 mm height at top and bottom of the cylinder were discarded. The sliced specimens were undergone 1 hour air drying, 3 hours vacuum, 1 hour additional vacuum under de-aerated water and followed by 18 hours immersed in water based on ASTM C 1202 [19] procedures. Prior to the test, the slices were mounted to the halves cell and clamped together. One side of the cell was filled with 3.0% sodium chloride (NaCl) and the other side was filled with 0.3 N sodium hydroxide (NaOH). Power supply was connected to both side of the slices, the negative terminal was connected to NaCl solution, whilst, the positive terminal was connected to NaOH solution. Direct current (DC) power supply was maintained at 60 volts throughout the experiment. The total charge passed through the slices were monitored to avoid damage to the cell and eventually interrupt the process of chloride ions penetration.

2.3.3 Water Absorption Test

For water absorption test, the 100 mm cubes specimen were taken out from the curing tank after undergoing water curing for 28 and 90 days. These specimens before subjected to the test were oven dried to achieve constant mass at 105 ± 5 ^{o}C for 72 ± 2 hours, and then stored in air-tight containers until testing period. The test conducted was based on BS 1881-122 [20]. The percentage of water absorption was calculated respectively at 28 days and 90 days of water curing. The test was conducted for 4 hours with 30 minutes interval and the percentages of increase in weight were calculated based on the initial weight of concrete specimens before immerse (W_0) and the weight after immerse (W_1) in water.

3. RESULTS AND DISCUSSIONS

3.1 Compressive Strength Test

The results of compressive strength for concrete Grade 60 for different mixes and ages were illustrated as shown in Figure 1.

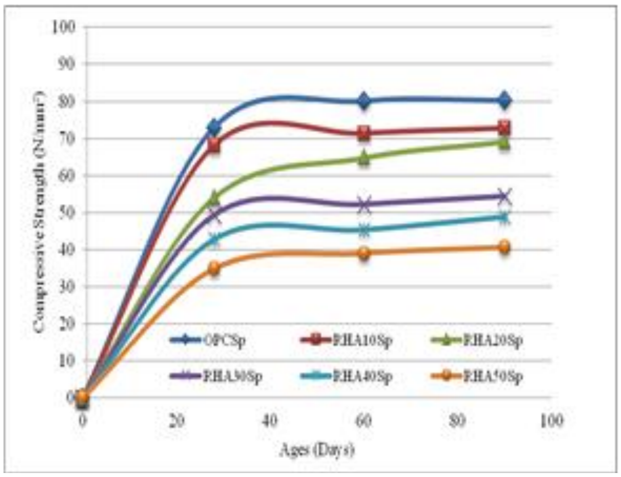

Figure 1: Compressive strength of Grade 60 concrete

At 28 days, most of RHA concrete attained lower value of compressive strength as compared to the OPC control concrete. OPC control concrete attained the highest value of compressive strength at 28 days, which is 73 N/mm^2. While, RHA concrete at 10% replacement achieved the second highest value, which is 68 N/mm^2, however prolong the period of curing (*i.e.* up to 90 days) resulted in further development of strength. The RHA concrete with 20%, 30%, 40% and 50% replacement taken at 28 days showed lower strength of below 60 N/mm^2 (targeted strength). Therefore, it can be concluded that higher percentages of RHA replacement resulted in reduction of the concrete strength. Study conducted by Shukla, *et al*. [21] also reported that their concrete of Grade 60 at replacement more than 10% gave a reduction in the compressive strength.

Figure 2 illustrated the compressive strength results of Grade 70 concrete with various replacement of OPC with RHA with respect to ages. From the observation made, the 28, 60 and 90 days strength of OPC were 74.4 N/mm^2, 77.9 N/mm^2 and 82.9 N/mm^2 respectively. At 10% replacement, the result shows reductions of strength about 3%, 5% and 8% for 28 days, 60 days and 90 days respectively compared to OPC concrete. Then, followed by RHA20Sp *i.e.* 19%, 21%, and 25% reductions of strength. As the percentage of replacement increases, *i.e.* 30%, the reduction of strength raised to 30%, 33%, and 36% for 28, 60 and 90 days respectively. For RHA40Sp, the strength declined further to 43%, 45% and 47% compared to OPC. Further increased the percentage of replacement to 50%, the reduction of strength was about half the strength of the pure OPC concrete, in which the results were 51%, 53%, and 56% for 28 days, 60 days and 90 days respectively. So, it can be clearly seen that as the percentages of replacement increased, it results in reduction of strength. The lower reduction was from RHA10Sp, while the higher reductions come from RHA50Sp.

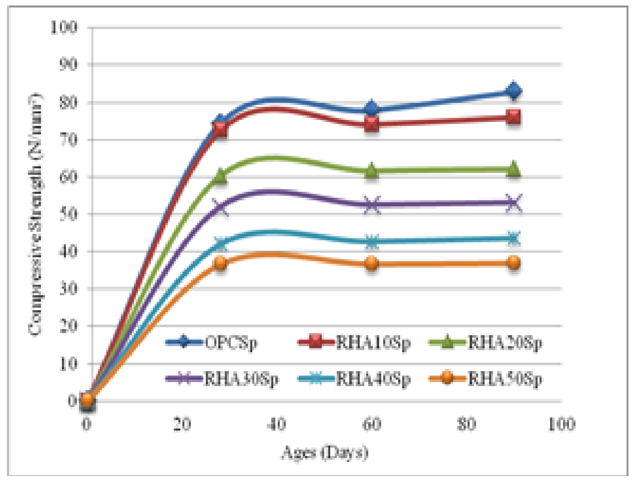

Figure 2: Compressive strength of Grade 70 concrete

The reduction of strength using RHA in the concrete was also experienced by Dong *et al*. [1]. This might be because the increase of replacement with RHA affect the primary product of hydration formed between cement and water. Even though RHA enhances concrete in the secondary products as a results of the pozzolanic reaction between $Ca(OH)_2$, silica and alumina, but it occurs in a very slow rate compared to the primary reaction. That might be the reason why the reduction of strength was significant.

3.2 Rapid Chloride Penetration Test (RCPT)

RCPT was conducted for 6 hours as according to ASTM C1202 [19] for 28 days, 60 days and 90 days. The values of charge passed (in Coulomb unit) onto the RHA concrete were tabulated in Table 3.

From Table 3, it is convinced that increased the percentage replacement of RHA resulted in less charge passed values, and the values reduced as the period of curing increased. With reference to the ASTM C1202 [19], the concrete with RHA replacement can be considered as having low to very low chloride ion penetrability for both concrete grade (*i.e*. Grade 60 and

Grade 70), in fact as the percentage of replacement increased, the chloride ion penetration reduced.

Table 3: Charge Passed after 6 hours period

Mixture Designation	Concrete Grade	Charge Passed (Coulombs)		
		28 days	60 days	90 days
OPCSp	60	2807	1857	1781
RHA10Sp		1052	557	550
RHA20Sp		555	360	357
RHA30Sp		525	327	271
RHA40Sp		354	182	136
RHA50Sp		139	80	73
OPCSp	70	2824	1646	1247
RHA10Sp		961	632	558
RHA20Sp		613	447	350
RHA30Sp		547	352	172
RHA40Sp		334	220	145
RHA50Sp		202	141	60

While with OPC concrete, the value of chloride ion penetrability falls in the moderate range. This showed that with RHA in the concrete, it makes the concrete less porous, thus significantly improved the resistance of concrete to chloride penetration. Study conducted by Givi *et al.* [11] stated that the high content of SiO_2 in RHA produces very reactive pozzolanic material to form extra calcium silicate hydrate (C-S-H) gel that will improved the development of concrete at later age and resulted in more dense and impermeable concrete by time. Rukzon and Chindaprasirt [22] also stated that the secondary process refine the average pore size and improved the interfacial zone. Therefore, lower coulomb charged was resulted as the percentage of RHA increased.

The rate of improvement in terms of chloride ion penetration of the concrete was shown in Table 4. Based from Table 4, it shows that the higher the percentage of RHA replacement, the higher the percentage of chloride ion penetration in relative to the control OPC concrete, thus, more impermeable the concrete which resulted in better durability index performance.

Table 4: Rate of improvement of RHA concrete with respect to OPC concrete

Mixture Designation	Concrete Grade	Improvement Chloride Ion Penetrability (%)		
		28 days	60 days	90 days
OPCSp	60	-	-	-
RHA10Sp		63	70	69
RHA20Sp		80	81	80
RHA30Sp		81	82	85
RHA40Sp		87	90	92
RHA50Sp		95	96	96
OPCSp	70	-	-	-
RHA10Sp		66	62	55
RHA20Sp		78	73	72
RHA30Sp		81	79	86
RHA40Sp		88	87	88
RHA50Sp		92	91	95

3.3 Water Absorption Test

The results of water absorption test conducted for four (4) hours with an intervals of 30 minutes were tabulated in Table 5. From the table, it can be seen that as percentage of replacement of RHA increases, the water absorption value for the RHA concrete consequently reduces. RHA replacement level of 50% gave the lowest water absorption value at 28 days and 90 days, for both concrete grade (*i.e.* Grade 60 and Grade 70). This might be due to more C-S-H gel formed to fill the spaces created between cement particles with presence of moisture. Therefore, the replacement of OPC with RHA in the concrete contributes to improvement in rate of water absorption of the concrete.

When subjected to prolong curing, RHA concrete gave better performance with respect to water absorption as compared to OPC concrete. The extra C-S-H gel created from the pozzolanic reaction will filled the spaces between cement particles therefore reducing the degree of voids in the concrete, hence, resulting to more impermeable and dense concrete. Neville [23] revealed that if water absorption rate is below than 10% by mass of the concrete, it can be considered as good concrete. So, all types of mixture designation in the present research can be considered as good concrete since the percentage absorption rate only lies between 2.5% to 3.5%.

Table 5: Water absorption of OPC and RHA concretes

Mixture Designation	Concrete Grade	Water Absorption (%)	
		28 days	90 days
OPCSp	60	3.41	2.45
RHA10Sp		3.28	2.05
RHA20Sp		3.25	1.98
RHA30Sp		3.15	1.96
RHA40Sp		3.03	1.52

RHA50Sp		3.00	1.46
OPCSp		3.19	2.55
RHA10Sp		3.05	2.32
RHA20Sp		2.89	2.20
RHA30Sp	70	2.78	2.10
RHA40Sp		2.69	1.96
RHA50Sp		2.53	1.83

4. CONCLUSION

From the study conducted, the following conclusions were made:

a. The compressive strength of RHA concrete was below the compressive strength of OPC concrete, and with increase in the percentage of RHA replacement in the mix, it resulted in decrease in the compressive strength. However, 10% replacement of cement with RHA attained the targeted compressive strength.

b. Increasing in the percentage of RHA replacement level up to 50% resulted in less charge passed values (Coulomb), thus shows that RHA concrete is more impermeable and better resistance to chloride ion. This might be due to high content of SiO_2 in RHA.

c. Incorporating of RHA as replacement to cement contributes to low percentage of water absorption, hence improved the durability index of the concrete. The percentage of water absorption obtained for all mixtures designation lies in between 2.5% to 3.5% which can be considered as good concrete.

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