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Mechanical Properties and Durability of High Strength Concrete Containing Rice Husk Ash

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Synopsis:

This paper reports an investigation on the mechanical properties and durability of high strength concrete containing rice husk ash (RHA). Mixtures containing 10% RHA by weight of cement and w/cm of 0.27 were cast. RHA was incorporated either as an admixture or as cement replacement material. A superplasticizing admixture was used to provide flowing characteristics. Results on the workability, mechanical properties and initial surface absorption (ISA) test are reported. The specimens were subjected to water and air-drying conditions and tests on the specimens were carried out up to 180 days. By applying a superplasticizer based on polycarboxylic ether, workability of RHA concrete in the range of 200–250 mm slump can be attained. This type of concrete can achieve high strength of 80 N/mm^2 at 28 days, irrespective of method of inclusion of rice husk ash or curing conditions. Compared to condensed silica fume (CSF) concrete at similar w/cm and workability, the strength of RHA concrete is about 6% lower. In general, the mechanical properties of RHA concrete are higher than the control superplasticized concrete but marginally lower than the CSF concrete. Durability of RHA concrete with regards to ISA is similar or better than CSF concrete.

Keywords: durability; flowing concrete; high strength; mechanical properties; rice husk ash

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INTRODUCTION

Rice husk ash (RHA) is now accepted as a highly reactive pozzolanic material with silicon dioxide (SiO_2) more than 85% [1-5]. The incorporation of RHA as an ingredient in blended cement can improve numerous properties of concrete. This effect is due to the reaction of SiO_2 from the RHA and calcium hydroxide to produce calcium silica hydrate that will contribute to improvement in the strength of concrete [1, 5]. Many excellent publications have shown that RHA can be used as a cement replacement material to produce high strength concrete [6-10] and increased durability of concrete such as sorptivity, initial surface absorption (ISA) and chloride resistance [11-14]. Research at the University of Malaya, Malaysia have shown that RHA can be used to produce high strength concrete of 80 N/mm^2 with high workability [15-16]. However compared to CSF, research data on the durability of high strength RHA concrete is rather limited. This paper reports an investigation of using RHA as a supplementary cementitious material to produce high strength and durable concrete.

EXPERIMENTAL PROGRAME

Materials

Locally produced ordinary portland cement (OPC) was used. It has a specific gravity and specific surface of 3.11 and of 3200 m^2/kg respectively. RHA was obtained from burning rice husk in a ferrocement furnace in the laboratory, and later ground using a Los Angeles machine for 5000 cycles. The fineness of RHA retained using a 45 micrometer sieve and its specific gravity were 18% and 2.1 respectively. The surface area and average pore diameter (using nitrogen absorption test method) were 25250 m^2/kg and 4.28 nm respectively. An 'MB-SF' condensed silica fume was used. The chemical composition of OPC, RHA and CSF are presented in Table 1. The new generation of polycarboxylic ether superplasticizer, Glenium 51, having a specific gravity and solid content of 1.09-1.10 and 34%-36% respectively was used. The coarse aggregate was a crushed granite of 20 mm maximum size. Its specific gravity and water absorption were 2.63 and 0.71% respectively. Fine aggregate used was a mining sand conforming to zone 1 of BS 410. Its specific gravity, water absorption and fineness modulus were 2.53, 3.36% and 4.53 respectively.

Mixture Proportions and Tests

Mixture proportioning for all the mixes was based on the Sherbrooke mix design method [17]. Using this method, the control concrete containing superplasticizer (SpOPC) was designed with a water to cementitious (w/cm) ratio of 0.27 and cement content of 537 kg/m^3. The coarse aggregate content for this and subsequent mixes was fixed at 1055 kg/m^3. The investigation was divided into two phases. In phase I, a total of 6 series of "RHA addition" and "RHA replacement" mixtures were cast to evaluate the effects of method of incorporating of RHA on properties of fresh and hardened concrete. RHA was "added" or "replaced" at 5%, 10% and 15% of the cement content. For comparison purposes, CSF mixes containing the same dosage to that of the RHA were also cast. The property of fresh concrete investigated was workability, designed to produce slump in the range of 200-250 mm. The compressive strength of concrete samples was tested at 1, 3, 7 and 28 days of water curing. Based on the results from phase I, the optimum mixes of the RHA "addition" and "replacement" as well as CSF "addition", were selected for further investigations in phase II, together with the SpOPC mix for control purposes. In this phase of the work, the mechanical properties such as compressive strength (100 mm cube), static modulus of elasticity (150 mm dia. x 300 mm cylinder), dynamic modulus of elasticity (150 mm dia. x 300 mm cylinder), splitting tensile strength (150 mm dia. x 300 mm cylinder), modulus of rupture (100 x 100 x 500 mm) and initial surface absorption test (150 mm cube) were examined (ISAT was chosen because it has been recognized as one of method to measure water permeability of concrete [18]. Two non-destructive tests namely ultrasonic pulse velocity (UPV) and rebound hammer were also carried out. The specimens were subjected to water curing and air-drying and tested at the age of 7, 28 and 180 days.

RESULTS AND DISCUSSION

Workability

The measured slump values of all the mixes are given in Table 2. It is apparent that varying amounts of water between 145 l/m^3 and 167 l/m^3 and superplasticizer (Sp) between 0.9-1.0% of cement content was needed to maintain workability of concrete in the range of 200-250 mm. In general, for similar workability, Sp dosage for RHA addition mixes was lower than the replacement series. Compared to the RHA mixes, at the same replacement or addition level, the amount of admixture needed for the CSF mixes were similar or marginally lower. Table 2 also shows that by using the new polymer superplasticizer, high workability mixes can be achieved with lower Sp contents compared to that using sulphonated naphthalene formaldehyde based superplasticizer [15, 16]. This effect is due to the mechanism of the Sp that provides flowable concrete with greatly reduced water demand and improved cement dispersion.

Effect of RHA on Compressive Strength

The compressive strength for various concrete mixes are presented in Table 3. The effects of method of incorporation of RHA, i.e. by "addition" or cement "replacement" on the strength property of HSC are discussed below:

Effect of RHA "Addition" - - From Table 3, it is noted that for the RHA addition series, the optimum strength resulted from 10% addition of RHA, similar to that found previously [16]. Compared to the control SpOPC, except for 15% RHA content, all RHA mixes exhibited superior strength at 28 days. For the CSF "addition" mixes, the compressive strength increased slightly with increasing CSF%. Compared to the CSF "addition" mixes, the RHA "addition" mixes showed lower strength largely due to the greater reactivity of CSF [7, 11]. At 10% addition level, the difference in strength between CSF and RHA concrete is about 3%. All RHA mixes were able to achieve the target strength of 80 N/mm^2 at 28 days.

Effect of RHA "Replacement" of Cement -- For RHA replacement mixes, the highest strength was achieved at 5% cement replacement. At 10% replacement, strength of 80 N/mm^2 was still achievable. Increasing the RHA content further, decreases the strength significantly. Previous research indicated that the optimum replacement of cement by RHA for optimum strength was about 10% to 20% [6,8]. Compared to the CSF mixes, the difference in strength at 5%, 10% and 15% cement replacement was about 1%, 4% and 17% respectively. Except for 15% replacement, RHA can produce HSC of grade 80 at 28 days. This result shows that RHA can be an alternative supplementary cementing material (SCM) to CSF to produce HSC of this magnitude.

Mechanical Properties and Durability of RHA Concrete

Based on the compressive strength results above, the optimum "addition" or "replacement" amount of RHA were taken as 10% and these mixes were selected for all subsequent investigations, results of which are given below.

Effect of Curing on Compressive Strength -- Irrespective of types of curing, data presented in Table 4 show that the use of 10% RHA as "addition" or "replacement" increase the compressive strength of concrete at all ages. For the RHA "addition" mix, higher strength compared to the SpOPC mix was noted. For RHA "replacement" mixes, although marginally lower strengths were observed for water-cured samples, higher strengths were observed under air-drying when compared to the control concrete. This result showed that RHA can contribute to the strength development even when left to dry out. At 28 days, all concrete achieve the target strength of 80 N/mm^2 irrespective of curing type. Under water curing, concrete containing 10% RHA "addition" was able to attain 100 N/mm^2 at 180 days. This result is similar to that found in the CSF concrete.

Strength ratio for the RHA "addition" mix due to the effect of curing is 0.95 and 0.85 at 28 and 180 days respectively. For the "replacement" mix, at both ages, the difference is around 1%. Similar results are observed for CSF addition mixes in which the ratio is 0.96 and 0.87 respectively. Based on these results, it can be concluded that air-drying method do not bring about significant reduction in strength for RHA concrete. This result is similar to that observed previously [16].

The ratio of 7 to 28 days compressive strength of RHA mixes under both curing regimes ranged from 0.84 to 0.89. These results are comparable with the value of 0.8 to 0.9 for HSC under water curing as reported by ACI [19]. For SpOPC, value of 0.91 and 0.85 were obtained for water curing and air-drying respectively, value for CSF "addition" mix ranged from 0.86 to 0.88.

Modulus of Rupture -- The results of the modulus of rupture for various concrete mixes are shown in Table 4. All concrete mixes achieve optimum modulus under water curing, 13% to 22% higher than air-drying. For the RHA concrete mixes, the highest modulus of 9.5 N/mm^2 and 10.2 N/mm^2 at 28 and 180 days respectively were exhibited by the RHA "addition" mix. When compared to the CSF "addition" mix, the modulus of rupture of RHA mixes was marginally lower. The modulus ratio of air-drying to water curing of RHA specimens is in the range of 0.82 to 0.85. This is because concrete of lower w/cm ratio is more sensitive to drying effect [20].

Tensile Splitting Strength -- Table 4 shows that the strength ratio due to curing method for all concrete mixes is 1.03 and 0.97 at 28 and 180 days respectively. The ratio for RHA concrete is 1.01-1.05 and 0.87-1.02 respectively. This indicated that curing method do not substantially affect the splitting tensile strength of RHA concrete at all ages. The results also show that the presence of RHA as a pozzolanic material, either as addition or cement replacement enhanced the splitting tensile strength. Compared to the CSF "addition", the tensile splitting strength of RHA mixes was marginally lower. The ratio of splitting tensile strength to compressive strength of all concrete mixes ranged from 5.6% to 7.4% (Table 5). 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 grade 80 N/mm^2, the ratio of 6.6% and 6.8% were achieved [22].

Static Modulus of Elasticity -- Table 4 shows that at 28 and 180 days, all RHA mixes exhibited higher modulus of elasticity than the control concrete, irrespective of curing regime. Compared to the CSF specimens, at 28 days, the modulus of elasticity of RHA mixes was 2-10% lower. The modulus of elasticity of the RHA concrete is in the range of 35-38 kN/mm^2 and 36-42 kN/mm^2 at 28 and 180 days respectively. This result infers that the modulus of elasticity of RHA concrete is not affected by the method of inclusion of RHA, curing method or age.

Dynamic Modulus of Elasticity -- Two types of specimens i.e. prisms and cylinders were used to evaluate the dynamic modulus of elasticity, as shown in Table 6. All concrete mixes produced higher modulus under water-curing, and prism specimens exhibit the higher value compared to cylinders. The ratio of dynamic modulus of elasticity of cylinder to prism specimens is about 0.88. Compared to the CSF mix, RHA mixes show marginally higher modulus, irrespective of types of curing and testing age. At 28 days, the average static/dynamic modulus ratio for HSC is about 0.8 and 0.84 for prism and cylinder specimens. In the absence of other data, static modulus of elasticity of RHA high strength concrete can be taken as 80% that of the dynamic modulus value.

Ultrasonic Pulse Velocity (UPV) -- The variation of pulse velocity with time for various concrete mixes is shown in Table 7. The results show that the pulse velocity increases with increasing age and water curing produced the higher UPV. In general, all concrete mixes produce pulse velocity above 4.5 km/s at 28 days and beyond, irrespective of curing regime. Concrete with ultrasonic pulse velocity ≥ 4.5 km/s could be classified as excellent concrete [23]. Based on results obtained from the present investigation, RHA concrete can be categorized as excellent concrete.

Rebound Hammer Test -- Table 8 shows for water cured samples, irrespective of the incorporation method, the rebound number (RN) of RHA mixes is higher than the control concrete, but marginally lower than CSF mix at 28 and 180 days. The ratio of the estimated surface strength/actual strength of all the concrete mixes is between 0.38 to 0.4 and 0.3 to 0.37 for water cured and air-dried specimens respectively. This result indicate that the rebound hammer test underestimated the actual strength by about 60%-70%, therefore is not an appropriate tool to appraise the strength of HSC. This is due to the fact that the test is designed to measure the surface zone of concrete i.e. the depth of concrete zone of about 30 mm [23]. A specific calibration chart is required to predict the strength of high strength RHA concrete based on the rebound hammer test.

Water Permeability -- The results of the initial surface absorption test (ISAT) are shown in Table 9. It can be noted that specimens subjected to water curing gave lower ISA value than the air-dried at all ages. For the RHA mixes, the lowest ISA values were exhibited by the RHA "addition" mixes. After 2 hours from start of the test, ISA values of 0.05 and 0.03 ml/m^2/s at 28 and 180 days respectively under water curing were recorded. The results also show that the ISA value decrease with increasing age. For water-cured specimens, ISA values for RHA "addition" specimens were similar to that of CSF, but when compared to the control SpOPC concrete, significant reduction in ISA values were noted. This result implies that incorporation of RHA is beneficial to reduce the permeability of concrete.

CONCLUSIONS

Irrespective of method of inclusion or percentage of RHA, the workability of concrete of 200 to 250 mm slump can be obtained with Sp dosage of less than 1.2% of total cementitious content. The optimum "addition" or "replacement" level of RHA to produce optimum strength is 10% and 5% respectively. Both RHA concrete mixtures when subjected to either water curing or air-drying conditions were able to achieve compressive strength of 80 N/mm^2 at 28 days. Concrete containing 10% RHA "addition" was able to attain 100 N/mm^2 at 180 days. Results also show that air-drying did not significantly affect the strength of RHA concrete mixes, i.e. reduction of less than 5% was noted when compared to water cured samples. The highest strength development resulted from CSF concrete mixes, but at 28 days, difference in strength to that of RHA mixes is no more than 6%. For other mechanical properties, data show that RHA concrete mixes exhibit similar or marginally inferior properties to that of CSF concrete. RHA concrete exhibited similar ISA value to that of CSF indicating the beneficial effect of incorporating RHA to reduce the permeability of concrete.

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301

Table 1. Chemical composition of OPC, RHA and CSF

Materials	Oxide (%)										
	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	P_2O_5	TiO_2	MnO	L.O.I
OPC	20.99	6.19	3.86	65.96	0.20	0.17	0.60	0.05	0.40	0.06	1.53
RHA	88.82	0.46	0.67	0.67	0.44	0.12	2.91	1.00	0.02	0.08	4.81
CSF	92.06	0.48	2.11	0.40	0.63	0.28	1.24	0.02	0.01	0.23	2.54

Table 2. Mixture proportions

Mix No.	Sp	Slump	Water	OPC	RHA or CSF	FA	CA
	(%)	(mm)	(kg)	(kg)	(kg)	(kg)	(kg)
SpOPC	1.0	220	145	537	-	669	1055
RHA5A	1.0	240	152	537	26.9	619	1055
RHA10A	1.0	225	160	537	53.7	657	1055
RHA15A	1.0	200	167	537	80.6	516	1055
RHA5R	1.0	225	145	510	26.9	656	1055
RHA10R	1.1	200	145	483	53.7	645	1055
RHA15R	1.1	220	145	456	80.6	636	1055
CSF5A	0.9	220	152	537	26.9	618	1055
CSF10A	0.9	240	160	537	53.7	567	1055
CSF15A	0.9	200	167	537	80.6	517	1055
CSF5R	1.1	220	145	510	26.9	658	1055
CSF10R	1.1	220	145	483	53.7	647	1055
CSF15R	1.1	200	145	456	80.6	637	1055

Table 3. Compressive strength

Mix No.	Compressive strength (N/mm^2)			
	1 d	3 d	7 d	28 d
SpOPC	44.5	60.6	69.0	83.0
RHA5A	40.0	65.0	72.0	86.3
RHA1A	39.0	61.9	73.3	87.3
RHA1A	29.0	52.0	72.1	83.0
RHA5R	43.9	67.4	77.6	87.8
RHA10R	39.1	58.1	73.6	86.2
RHA15R	25.0	48.0	64.0	77.0
CSF5A	50.0	70.0	78.0	88.4
CSF10A	47.3	64.7	81.7	89.2
CSF15A	53.7	74.0	85.5	91.0
CSF5R	40.0	68.0	82.8	88.[illegible]
CSF10R	43.0	64.0	79.0	89.6
CSF15R	40.0	66.0	83.0	90.1

Table 4. Mechanical properties for various concrete mixtures

Mix No.	Compressive strength (N/mm^2)			7d/28d ratio	Compressive strength (N/mm^2)			7d/28d ratio	Air drying ratio Wet curing	
	Wet curing				Air-drying					
	7d	28d	180d		7d	28d	180d		28d	180d
SpOPC	72.1	85.1	87.4	0.85	73.2	82.0	84.5	0.89	0.96	0.96
RHA 10A	73.3	87.3	101.6	0.84	73.6	83.0	87.1	0.89	0.95	0.85
RHA 10R	71.7	84.4	86.2	0.85	73.9	84.6	86.3	0.87	1.00	1.01
CSF 10A	75.1	88.6	103.7	0.85	74.5	86.4	90.7	0.86	0.96	0.87
Mix No.	Modulus of rupture (N/mm^2)				Modulus of rupture (N/mm^2)			*Av.*	*0.97*	*0.93*
	Wet curing				Air-drying					
	7d	28d	180d		7d	28d	180d			
SpOPC	7.7	8.3	8.5	0.93	6.7	7.0	8.4	0.96	0.84	0.98
RHA 10A	8.0	9.5	10.2	0.84	6.5	7.8	8.6	0.83	0.82	0.84
RHA 10R	7.7	8.4	9.9	0.92	6.0	7.0	8.5	0.86	0.83	0.85
CSF 10A	8.4	9.8	10.5	0.86	6.9	8.1	8.9	0.85	0.83	0.85
								Av.	*0.83*	*0.88*

Table 4. Mechanical properties for various concrete mixtures (continued)

Mix No.	Splitting tensile strength (N/mm^2)			7d/28d ratio	Splitting tensile strength (N/mm^2)			7d/28d ratio	Air drying ratio Wet curing	
	Wet curing				Air-drying					
	7d	28d	180d		7d	28d	180d		28d	180d
SpOPC	4.2	5.0	5.3	0.84	4.9	4.9	5.6	1.00	0.98	1.06
RHA 10A	4.3	5.1	6.7	0.84	4.1	5.2	5.8	0.79	1.01	0.87
RHA 10R	4.6	5.5	6.3	0.84	4.6	5.8	6.4	0.79	1.05	1.02
CSF 10A	5.2	5.7	7.4	0.91	4.4	6.2	6.9	0.71	1.08	0.93
Mix No.	Static modulus of elasticity (kN/mm^2), E_C				Static modulus of elasticity (kN/mm^2), E_C			*Av.*	*1.03*	*0.97*
	Wet curing				Air-drying					
	7d	28d	180d		7d	28d	180d			
SpOPC	28.9	32.4	34.9	0.89	24.9	32.6	32.4	0.76	1.01	0.93
RHA 10A	24.1	35.3	41.1	0.68	27.7	35.1	37.5	0.79	0.99	0.91
RHA 10R	20.9	37.7	42.4	0.55	23.4	33.1	36.4	0.71	0.88	0.86
CSF 10A	30.7	38.1	48.0	0.81	28.9	36.4	38.9	0.79	0.96	0.81
								Av.	*0.96*	*0.88*

Table 5. Tensile splitting/compressive strength ratio

Mix No.	Tensile strength/compressive strength ratio (%)					
	Water curing			Air-drying		
	7 d	28 d	180 d	7 d	28 d	180 d
SpOPC	5.8	5.8	6.1	6.6	6.0	6.6
RHA 10A	5.9	5.8	6.6	5.6	6.3	6.6
RHA 10R	6.4	6.5	7.3	6.2	6.9	7.4
CSF 10A	6.9	6.4	7.1	5.9	7.2	7.6

Table 6. Dynamic modulus of elasticity for various mixtures

Mix No.	Dynamic modulus of elasticity (kN/mm^2), E_D						$\frac{E_C}{E_D}$ ratio, 28 d	
	Water curing			Air-drying			Water curing	Air-drying
	7d	28d	180d	7d	28d	180d		
				Prism				
SpOPC	42.4	45.7	47.8	41.4	40.7	41.9	0.70	0.80
RHA10A	44.6	46.8	47.7	40.9	42.6	45.5	0.75	0.82
RHA10R	44.9	44.6	45.7	39.3	42.4	43.1	0.85	0.78
CSF10A	43.4	44.4	45.6	39.4	40.7	43.5	0.86	0.89
						Av.	*0.79*	*0.82*
				Cylinder				
SpOPC	41.4	44.6	44.7	39.0	41.6	42.6	0.72	0.78
RHA10A	41.0	43.0	44.7	38.9	41.1	42.6	0.82	0.85
RHA10R	39.1	42.1	44.6	38.1	38.5	40.5	0.89	0.85
CSF10A	38.4	41.4	43.5	37.3	39.1	40.7	0.92	0.93
						Av.	*0.84*	*0.85*

Table 7. Ultrasonic pulse velocity (UPV) for various mixtures

Mix No.	UPV (km/s)					
	Water curing			Air-drying		
	7 d	28 d	180 d	7 d	28 d	180 d
SpOPC	4.8	5.0	6.1	4.5	4.9	6.1
RHA 10A	5.1	5.3	6.1	4.7	5.1	6.0
RHA 10R	4.2	4.5	6.0	4.0	4.6	5.7
CSF 10A	5.8	6.2	6.7	5.7	5.9	6.2

Table 8. Rebound hammer test for various mixtures

Mix No.	Rebound Number (RN)			Estimated Surface Strength (N/mm^2)	Actual Strength (N/mm^2)	*Est.*/*Actual* ratio
	7 d	28 d	180 d	28 d	28 d	28 d
			Water curing			
SpOPC	33.7	35.0	33.0	32	85.1	0.38
RHA 10A	38.2	36.7	39.2	35	87.3	0.40
RHA 10R	37.2	36.2	33.5	33	84.4	0.39
CSF 10A	37.0	37.2	41.6	35	88.6	0.40
			Air-drying			
SpOPC	33.0	32.1	37.7	27	82.0	0.33
RHA 10A	35.7	31.9	41.0	27	83.0	0.33
RHA 10R	38.2	35.1	32.2	32	86.2	0.37
CSF 10A	33.0	31.4	41.3	25	86.4	0.30

Table 9. Initial surface absorption test

Mix No.	Flow (ml/m^2/sec.)							
	Water curing				Air-drying			
	10 min.	30 min.	1 hour	2 hours	10 min.	30 min.	1 hour	2 hours
				7 days				
SpOPC	0.30	0.21	0.14	0.10	0.65	0.26	0.22	0.15
RHA10A	0.26	0.14	0.09	0.06	0.28	0.25	0.15	0.10
RHA10R	0.27	0.22	0.14	0.10	0.65	0.24	0.20	0.12
CSF10A	0.21	0.12	0.09	0.06	0.30	0.24	0.10	0.07
				28 days				
SpOPC	0.29	0.21	0.14	0.10	0.55	0.25	0.15	0.14
RHA10A	0.25	0.10	0.07	0.05	0.27	0.23	0.07	0.06
RHA10R	0.25	0.14	0.12	0.09	0.59	0.22	0.14	0.10
CSF10A	0.21	0.12	0.09	0.06	0.22	0.20	0.10	0.06
				180 days				
SpOPC	0.27	0.19	0.13	0.09	0.52	0.22	0.12	0.12
RHA10A	0.25	0.10	0.06	0.03	0.27	0.13	0.07	0.04
RHA10R	0.25	0.14	0.07	0.05	0.29	0.14	0.12	0.09
CSF10A	0.19	0.11	0.07	0.03	0.20	0.12	0.07	0.04