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Mechanical Properties of Rice Husk Ash as a Mineral Addition in Concrete

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ABSTRACT

It is shown that some of the wastes have properties that would improve the quality of concrete produced. One such waste is agricultural waste rice husk, which constitutes about one-fifth of 600 million tones of rice produced annually in the world. The performance of RHA concrete was found to be varied among those of researchers and most of the studies encompassed for the utilisation of high grade concrete. This paper reported the investigation carried out on the mechanical properties of normal strength concrete of grade 30 N/mm^2 with various partial replacement level of ordinary Portland cement (OPC) with Rice Husk Ash (RHA). Two(2) batches of same grade of concrete with and without use of superplasticiser (Sp) were adopted. The mechanical properties evaluated are in terms of compressive strength, flexural strength and tensile splitting strength of RHA concrete with and without superplasticiser (Sp). The results show that the optimum replacement level of RHA was 20 % and with the addition of Sp the replacement of RHA was taken as 40 %. However, the results of the study show that the performance in term of flexural strength and tensile splitting strength does not significantly improved with the replacement of cement with RHA.

***Keywords**: Rice Husk Ash (RHA), Ordinary Portland Cement (OPC), compressive strength, flexural strength, tensile splitting strength*

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Introduction

Substituting basic materials in construction are well known for conservation of dwindling resources and preventing environmental and ecologist damages caused by quarrying and depletion of raw materials. Many researchers had shown that some of the wastes have properties that would improve the quality of concrete produced.

One such waste material is agricultural waste rice husk, which constitutes about one-fifth of 609 million tonnes of rice produced annually in the world [1]. Assuming ash to rice husk ratio of 22 % [2], therefore the total ash production could be as high as 27 million tones per year. One of the constituent materials in making concrete is cement. Knowing that the raw material from earth sources will be scarce and the demand for cement is increasing because of economic and population growth, the effort to find alternative materials that must be of both inexpensive and require very little energy to produce has to be undertaken. According to the analysis reported in Pelabur Magazine [3], the demand for cement in Malaysia increased from 13 % (11.4 million tones) to 21 % (14.0 million tones) for year 2000 and will be increasing for the next decade. Thus, the use of this rice husk ash as supplementary cementing material (SCM) is expected to meet the increase in demand of cement, as approximately 1.2 million tonnes of the current world cement production is expected to grow exponentially to about 3.5 billion tonnes per year by 2015 [3]. Consequently, replacing RHA with OPC will tremendously save cost.

RHA has a potential as a cheap cementing material since rice husks are essentially waste material having about 92 % to 95 % silica (SiO_2), highly porous morphology, light-weight, angular and have a very high external surface area. Its absorbent and insulating properties are useful to many industrial applications, and the ash has been the subject of many research studies [4].

With that in mind, study on the performance which was assessed in term of compressive, flexural and tensile strengths with respect to different percentages namely 5 %, 10 %, 20 %, 30 %, 40 % and 50 % RHA by weight of cement and with or without Sp were carried out. On top of that, the physical and chemical properties of the rice husk ash were also conducted.

Experimental Work

Material Preparation

The rice husk was obtained from a rice mill in Kuala Selangor, Malaysia and was burnt in a ferrocement furnace to produce rice husk ash (RHA). For each incineration, the furnace can accommodate rice husk of about 50 to 60 kg. After maintaining the flame underneath the furnace for about one hour, the husk started to burn slowly on its own for about 24 hours. The ashes were allowed to cool inside the furnace for another 24 hours before taken out for grinding using a Los Angeles (LA) machine. The physical properties and chemical composition of the resulting RHA were performed and the results will be discussed in the subsequent section.

Other materials used in the concrete mixture were Portland cement-Type II, granite coarse aggregate of 20 mm maximum size and mining sand of 5 mm maximum size as fine aggregate. The fineness modulus for the coarse aggregate and fine aggregate were 2.43 and 4.61 respectively. The superplasticizer (Sp) used is sulphonated naphthalene formaldehyde condensed polymer based admixture.

Mix Proportion and Specimen Preparation

The control OPC concrete was designed to achieve 30 N/mm^2 using the DOE method [5]. Based on this, the cement content of 325 kgm^{-3} was adopted for all mixes. The water to cementitious material ratio (w/b) of the control mix is 0.63. In ensuring that the designed concrete mixes were able to achieve the targeted slump in a range between 40 mm to 50 mm, the slump test was conducted. RHA being pozzolanic and having adsorptive character, concrete mix with large addition of RHA requires more water to maintain the same workability. This problem was overcome by adding Sp in maintaining the slump of 100-150 mm.

For determination of optimum level of RHA replacement to cement, fourteen (14) series of concrete specimens were cast, and it comprises of four (4) batches of which the 1st batch and 3rd batch are a control series and consisted of 100 % OPC and 100 % OPC plus Sp respectively. The second series and the fourth series were OPC with different percentages of RHA replacement with and without Sp respectively. The optimum replacement level of RHA was determined from the results of the compressive strength, and then the selected optimum mixes were recast and tested for its flexural and tensile strengths. Table 1 summarises the mix proportions for control and various RHA concrete.

Two hundred eighty (280) cube specimens of 100 mm × 100 mm × 100 mm were prepared and to be subjected to compressive strength test. For flexural strength and tensile strength tests, twenty four (24) prism and cylinder specimens each were prepared respectively. All specimens were demoulded after 24 hours and water cured until tested at age of 1, 3, 7 and 28 days.

Table 1: Mix Proportions and Workability for Control and Various RHA Concrete Mixes

Batch	Mix No.	Quantities of Materials (kg)					Sp (%)	w/b	Slump (mm)
		Cement	RHA	Water	Aggregate				
					Fine	Coarse			
1st batch	OPC	325	-	205	900	940		0.63	52
2nd batch	OPCRHA5	309	16	210	899	936		0.64	53
	OPCRHA10	293	32	212	898	934		0.65	48
	OPCRHA20	260	65	221	894	930		0.68	41
	OPCRHA30	228	97	228	890	927		0.70	40
	OPCRHA40	195	130	234	887	924		0.72	41
	OPCRHA50	163	162	248	881	916		0.76	40
3rd batch	OPC Sp	325	-	205	900	940	0.40	0.63	138
4th batch	OPCRHA5Sp	309	16	205	900	940	0.54	0.63	148
	OPCRHA10Sp	293	32	205	900	940	0.60	0.63	141
	OPCRHA20Sp	260	65	205	900	940	1.00	0.63	105
	OPCRHA30Sp	228	97	205	900	940	1.61	0.63	116
	OPCRHA40Sp	195	130	205	900	940	2.27	0.63	149
	OPCRHA50Sp	163	162	205	900	940	3.08	0.63	150

Results and Discussion

Physical and Chemical Properties of Rice Husk Ash

From the fineness test conducted, it was found that the fineness of RHA as that retained on 45 µm sieve was about 21.87 %, which conformed to grade A of dry pulverized–fuel ash (pfa) based on ASTM C430. The specific surface area of RHA determined using nitrogen absorption method ranged between 10.857 m^2/g to 17.463 m^2/g and the specific gravity of 2.1. The average particle size of RHA is 25.83 µm.

A typical chemical composition of the ash obtained after burning and grinding is shown in Table 2. From Table 2, it can be seen that 96.7 % is of SiO_2 and this satisfies the ASTM C618-2003 requirement that minimum SiO_2 which should be 70 %. The $SiO_2 + Al_2O_3 + Fe_2O_3$ were 97.8 %. The RHA used in the present work can be classified as Class N pozzolanic.

Table 2: Chemical Composition of RHA

Chemical Composition	Content in %
Silicon dioxide (SiO_2)	96.70
Aluminium oxide (Al_2O_3)	1.01
Ferric oxide (Fe_2O_3)	0.05
Calcium oxide (CaO)	0.49
Magnesium oxide (MgO)	0.19
Sodium oxide (Na_2O)	0.26
Potassium oxide (K_2O)	0.91
Phosphorous oxide (P_2O_5)	0.01
Titanium oxide (TiO_2)	0.16
Sulphur trioxide (SO_3)	-
Loss on ignition	-

Figure 1 shows the X-ray diffraction (XRD) of RHA particles; indicating that the structure of silica present in RHA used is of amorphous material with a diffused peak of 140 counts at about $\theta = 22^{o}$ while, Figure 2 shows the elementary diffraction X-ray (EDAX).

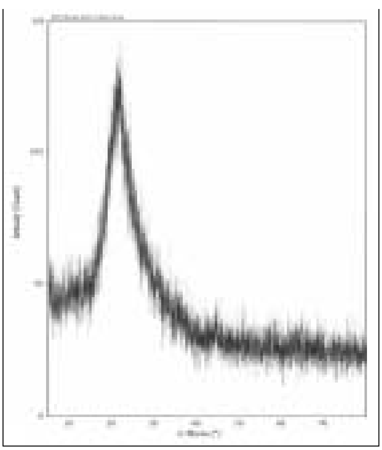

Figure 1: XRD of RHA Particles

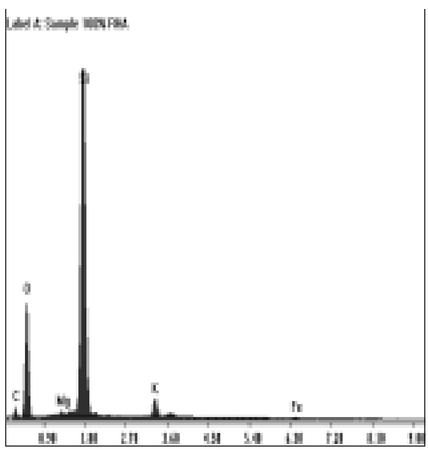

Figure 2: EDAX of RHA Particles

Workability Test

The results of the measured slump of all the series of mixes are tabulated in Table 3. It is clearly seen that with the increased of percentage of RHA incorporated in the mix, it resulted in the increased amount of water and Sp required to obtain the targeted workability of the concrete. For the first and second batch of mixes, the amount of water was modified to obtain a constant consistency in term of slump which ranged from 40 and 50 mm and as a result the water/binder (w/b) varies from 0.63 to 0.76. This might be attributed to the fact that concrete mixes with large addition of RHA requires more water due to the adsorptive character of cellular RHA particles. This statement is in an agreement with those of Hwang and Wu [6], Shimizu and Jorillo [7] and Zhang and Malhotra [8].

For the third and fourth batch of the mixes, dosage of Sp was modified to obtain a constant consistency (workability) in term of slump ranging from 100 to 150 mm and as a result the dosage of Sp varied from 0.4 % to 3.08 % with RHA replacement increasing from 5 % to 50 %. It is obvious from Table 3 that concrete containing RHA requires more Sp, while maintaining the same amount of water. Study conducted by Nehdi [9], Singh *et al*. [10] and Shafiq *et al*. [11] revealed that the Sp content of the concrete mixtures increased with increasing RHA content to achieve a given workability. It is obvious that concrete containing RHA requires more water or Sp for a given consistency due to its absorptive character of cellular RHA particles.

Compressive Strength

The development of compressive strength of the concrete specimens tested at the age of 1, 3, 7 and 28 days are presented in Table 3.

As tabulated in Table 3 and illustrated in Figures 3 and 4, the compressive strength for concrete specimens with 5 % of RHA for those without Sp addition shows improvement than that of the control mixes at any age. The concrete specimens with higher replacement level of RHA namely 10 % and 20 % attained lower compressive strength corresponding to the same age of control but achieved higher strength than that of OPC (control) at reaching 28 days of age. The concrete specimens with 30 % of RHA replacement and above attained strength lower than that of control throughout the duration. This might be due to higher amount of water content required for RHA concrete as a result of cellular structure of RHA which absorb water and hence resulted in lower strength. The

Table 3: Compressive Strength of RHA Concrete of Various Mixes With and Without Sp

Designation	W/B	Sp (%)	Slump (mm)	Compressive strength (N/mm^2)			
				1 day	3 days	7 days	28 days
OPC	0.63	-	52	11.6	17.65	24.83	30.68
OPCRHA5	0.64	-	53	12.2	18.91	26.13	34.31
OPCRHA10	0.65	-	48	12.9	17.77	23.26	34.80
OPCRHA20	0.68	-	41	12.2	15.98	22.90	34.71
OPCRHA30	0.70	-	40	9.2	12.15	21.04	30.33
OPCRHA40	0.72	-	41	7.6	10.39	18.71	28.77
OPCRHA50	0.76	-	40	3.5	7.33	12.99	20.83
OPC Sp	0.63	0.40	138	10.8	19.10	24.37	30.88
OPCRHA5Sp	0.63	0.54	148	11.0	17.66	22.26	30.23
OPCRHA10Sp	0.63	0.60	141	13.8	17.94	22.65	31.48
OPCRHA20Sp	0.63	1.00	105	12.8	18.59	30.02	39.05
OPCRHA30Sp	0.63	1.61	116	11.4	15.67	25.41	35.21
OPCRHA40Sp	0.63	2.27	149	7.4	12.19	22.28	34.04
OPCRHA50Sp	0.63	3.08	150	4.33	9.30	17.96	30.57

result of this study is in line with the finding of Sugita *et al*. [12] who reported that the addition of RHA could attains maximum increment in compressive strength at blending ratio of 20 %.

Up to 20 % replacement and without Sp, the compressive strength attained at age of 28 days was higher than that of OPC (control). The optimum utilisation of RHA for cement replacement is considered at 20 % replacement if without Sp addition. Overall, the results show that RHA can be used as an alternative binder to OPC.

From Figure 4, it shows that with addition of Sp, the replacement level of up to 40 % could improve the compressive strength compared to that of OPCSp (control). As the water content is maintained, the Sp addition allows RHA concrete to be more cohesive and achieve full compaction and hence enhance the compressive strength. It is essential to incorporate Sp for higher replacement level of RHA without sacrificing the desired compressive strength due to absorptive cellular structure of RHA. For example, RHA concrete with Sp, the desired strength which is 30 $/mm^2$ at age of 28 days are still achievable even up to 50 % replacement.

It is appeared that water/binder (w/b) ratio of up to 0.68, the compressive strength attained is higher than those of w/b of 0.63 (concrete

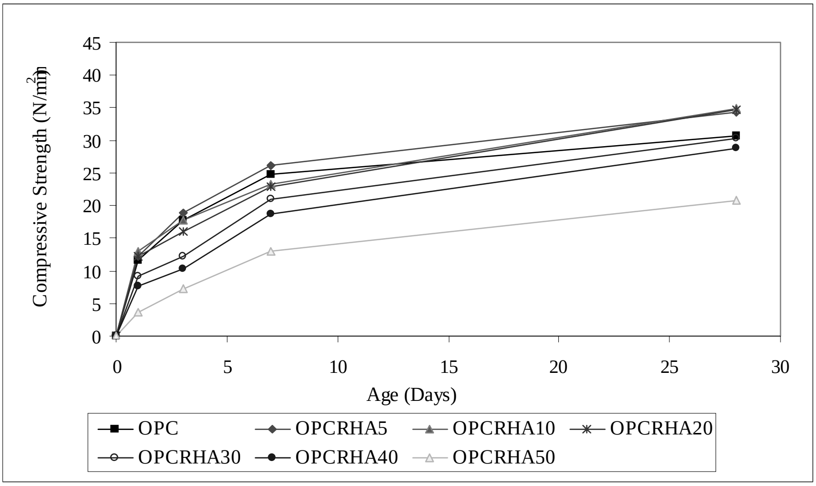

Figure 3: The Development of Compressive Strength of RHA Concrete with Various Level of RHA Replacement (without Sp)

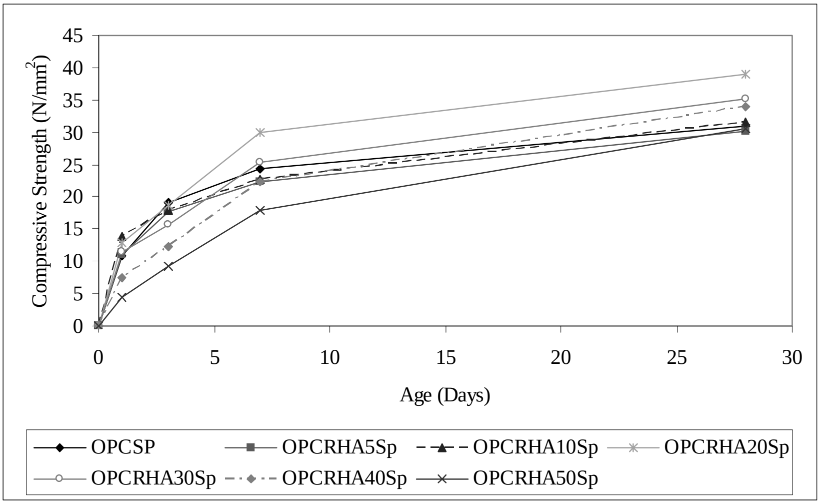

Figure 4: The Development of Compressive Strength of RHA Concrete with Various Level of RHA Replacement (with Sp)

without RHA). The pozzolanic effect of RHA is still dominant even though the amount of water added is higher. However, as the water content increases (to maintain a constant slump) above than 0.68, the effect of using higher amount of water become more dominant and supersede the pozzolanic effect contributed by RHA particles. Consequently, the compressive strength attained is lower than that of OPC (control) with w/b of 0.63. Conversely, this also could well explain the effect of using different dosage of Sp, where up to 1 % of Sp, the compressive strength attained is either equal or higher than that of 0.4 % of Sp. It is RHA20Sp with 1 % dosage of Sp gives highest compressive strength to RHA with easiness of compaction and also due to the RHA pozzolanic effect. Further replacement with RHA would not provide additional pozzolanic effect regardless of dosage level of Sp. The pozzolanic reactivity would be in halt as there is not enough C-S-H gel from the primary hydration of OPC with water for pozzolanic reaction to be taken place.

The compressive strength for RHA concrete specimens with respect to 1 day of age increases as the RHA replacement level increases from 5 % to 50 %. It is appeared that the concrete specimens composed of 50 % RHA (with and without Sp) recorded highest increment in compressive strength at age of 28 days when compared to early age (1 day) as shown in Table 4. However, the increases in compressive strength

Table 4: The Percentage Increase in Compressive Strength of Various Mixes of Concrete with Respect to 1 Day Strength

Series	Designation	Water/ Binder (W/B)	Sp (%)	Increase in compressive strength with respect to 1 day age (%)			
				1 day	3 days	7 days	28 days
OPC	OPC (Control)	0.63	-	-	51.8	113.5	163.8
OPCRHA5	RHA5	0.64	-	-	54.5	113.5	180.3
OPCRHA10	RHA10	0.65	-	-	37.7	80.2	169.6
OPCRHA20	RHA20	0.68	-	-	31.0	87.7	184.5
OPCRHA30	RHA30	0.70	-	-	32.1	128.7	229.7
OPCRHA40	RHA40	0.72	-	-	37.4	147.5	280.6
OPCRHA50	RHA50	0.76	-	-	107.7	268.0	490.1
OPC Sp	OPCSp (Control)	0.63	0.40	-	76.7	125.4	185.7
OPCRHA5Sp	RHA5Sp	0.63	0.54	-	61.0	102.9	175.6
OPCRHA10Sp	RHA10Sp	0.63	0.60	-	29.6	63.7	127.5
OPCRHA20Sp	RHA20Sp	0.63	1.00	-	45.4	134.7	205.3
OPCRHA30Sp	RHA30Sp	0.63	1.61	-	37.9	123.7	210.0
OPCRHA40Sp	RHA40Sp	0.63	2.27	-	65.9	203.1	363.1
OPCRHA50Sp	RHA50Sp	0.76	3.08	-	114.8	314.8	606.0

with Sp were generally higher than that recorded for those without Sp. The addition of Sp at same water binder ratio does enhance the compressive strength development.

Flexural Strength

The flexural strength of the concrete specimens is shown in Table 5 and Figure 5. It shows that the flexural strength of concrete specimens incorporated with 20 % RHA decreases as compared to OPC (control). This is attributed to higher w/b incorporated into concrete containing 20 % RHA. The additional water content contributes dominant factor to the flexural strength of concrete with RHA replacement.

Table 5: Flexural Strength and Tensile Splitting Strength for Various RHA Concrete Mixes

Designation	Sp (%)	Water/ Binder (W/B)	Flexural Strength (N/mm^2)		Diff. w/r to control at 28 days (%)	Tensile splitting strength (N/mm^2)		Diff. w/r to control at 28 days (%)
			7 days	28 days		7 days	28 days	
OPC (control)	0.63	-	3.51	4.13	-	1.69	2.37	-
RHA20	0.68	-	2.43	3.84	-7.02	1.41	2.08	-12.24
OPCSp (control)	0.63	0.40	3.23	4.22	2.18	1.84	2.20	-7.17
RHA30Sp	0.63	1.61	2.81	4.16	0.73	1.23	1.69	-28.69

The addition of Sp did not enhance significantly the flexural strength of RHA30Sp concrete specimens compared to OPC (control) and also compared to that of OPCSp (control). Nevertheless, the addition of Sp would help in maintaining the workability without adding water content and do not compromise the flexural strength. As a result, the flexural strength of RHA concrete up to 30 % replacement level would be maintained. The flexural strength of concrete specimens with Sp attains almost similar value with OPC (control) at age of 28 days. It is expected that the flexural strength of 20 % RHA would increase with the addition of Sp. Therefore, it is appeared that the inclusion of RHA and with the assistance of Sp influence the compressive strength but not much on flexural strength.

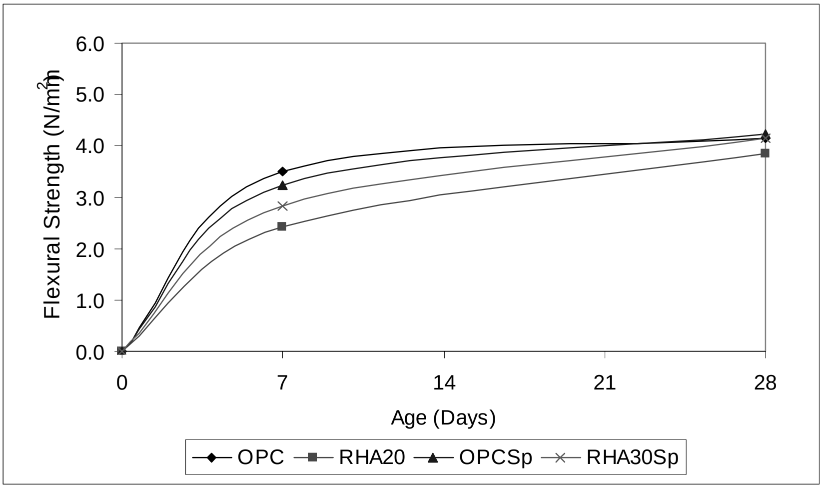

Figure 5: Flexural Strength of RHA Concrete Specimens and OPC (control)

Tensile Splitting Strength

The tensile strength of the concrete specimens is as shown in Table 5 and Figure 6. It shows that the tensile strength of concrete specimens incorporated with RHA decreases as compared to OPC (control). The addition of Sp did not be able to assist the concrete with RHA to achieve

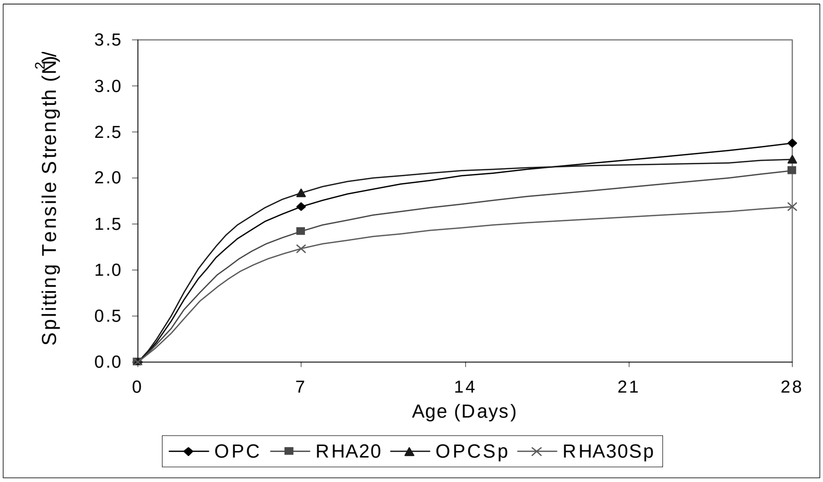

Figure 6: Tensile Splitting Strength of RHA Concrete

higher tensile strength. Addition of Sp in concrete containing RHA is essential in order to maintain the workability due to the absorptive characteristic of RHA. However, due to more water (liquid from Sp) introduced, it causes a decrease in tensile strength. If the amount of water content added is reduced accordingly due to the addition of Sp, the tensile strength achieved would be expected to be higher.

Conclusions

From the result of the research work obtained, the following conclusions can be drawn:

1. It is appeared that up to 20 % replacement of RHA to cement, the compressive strength is enhanced compared to that of control concrete without RHA replacement.
2. With the aid of Sp, the replacement level up to 40 % of RHA could be employed.
3. Without the addition of Sp, the replacement level of RHA above 20 % would decrease the compressive strength of concrete as the water requirement to maintain the slump increases.
4. Replacement of RHA does not significantly improve the flexural and tensile splitting strength of concrete.
5. The maximum dosage of Sp is found to be 1 % (by total weight) which gave highest compressive strength of RHA concrete. As the dosage of Sp increases, the compressive strength of RHA concrete decreases.

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