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Optimizing Compressive Strength Properties of Binary Blended Cement Rice Husk Concrete for Road Pavement

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Abstract

Different supplementary cementitious materials are often blended with cement to produce sustainable concrete. More often than not, the strength of blended concrete is compromised, if the constituent materials are not carefully selected. In this study, optimization of strength properties of blended cement-rice husk ash (RHA) was carried out to determine the best mix ratio that produced binary blended concrete of high strength. Different mix ratios of cement and RHA were studied at a water cement ratio of 0.4 to produce concrete specimens. RHA was produced by burning 700 °C for an hour and its chemical composition was determined using the X-Ray Fluoresce (XRF) technique. RHA produced was used to replace cement at replacement levels of 2.5, 5, 7.5, and 10 %, and was used as binder. The compressive strength of each concrete mix was determined at 7, 28, and 56 days. Approximately 250 concrete cubes were tested and the results were subjected to statistical analysis. The results showed that compressive strength and internal structure varied with RHA as a replacement for cement. Optimal strength was achieved for a concrete mixture, prepared at a water: cement: aggregate ratio of 1:1.5:3, respectively, and a RHA replacement ratio of 5 %.

Keywords: Pozzolanic reaction, Compressive strength, Microstructure, Strength activity

Introduction

Recently, there has been renewed interest in using bio-materials for construction purposes because they are environmentally friendly and sustainable. Most recent efforts are geared toward limiting the accumulation of greenhouse gases in the atmosphere that cement production significantly contributes to [1]. The production of a tonne of cement releases about 1.2 tonnes of CO_2 [2]. Concrete or cement-based materials on their own have the lower embodied energy and less CO_2 emission compared to other materials such as steel, aluminum, etc. [3], were it not for the huge quantity of concrete consumed. According to [4] global cement consumption in 2015 was 4.6 Gt/a and is expected to reach about 13.5 Gt/a by 2050 [5,6], due to rapid urbanization of many cities in the world, especially in developing countries. This requires provision of adequate infrastructure for their growing populations.

In addition to using concrete in building structures, concrete is now widely used in road pavement construction and maintenance. It is preferred over other paving materials because of its high level of performance, high traffic carrying capacity and longevity as seen in most highways and airports, although initial cost may be higher. For this, significant amounts of concrete will be consumed in order for Africa to pave its remaining 96 % unpaved road network [7]. In Indonesia, concrete would be required to maintain 57 % of its paved road network, which is approximately 516, 239 km, and to pave the remaining unpaved road network. Concrete pavement is the material equally preferred for paving high heavy traffic roads such as the Cipularang toll road that connects Jakarta to Bandung [8]. Consequently, more cement will be needed to provide these infrastructure improvements. Because of the need for reducing CO_2, alternatives to cement (partially or completely) become more of a necessity than a choice. Supplementary cementitious materials (SCMs) are the most promising strategic approach in this regard. It is reported that replacing about 30 % of global cement consumption with SCMs has the potential to reduce CO_2 by an equal amount [9]. The use of fly ash as replacement for cement at different replacement levels with varied water-binder ratios [10]. This paper showed that as the volume of fly ash content went higher above 25 %, strength would be reduced. It was concluded that low strength concrete of fly ash content above 25 % replacement for cement could be used. Similarly, cement waste is also used to produce asphaltic concrete for road pavement having comparable strength with normal asphaltic concrete [11], although the cement waste was used in this study as filler rather than as replacement for cement. In addition to the use of industrial waste as SCMs, ashes of from agricultural by-product are also used as replacement for cement. Different researchers have shown that sawdust ash as stabilizing material may be used in place of cement [3], cassava peel ash may be used as filler in asphaltic concrete [12], while sugarcane straw ash may be used as pozzolan in structural concrete [13]. Rice husk ash (RHA) is another promising SCM that has attracted the attention of many researchers.

Global rice production is put at 748 million metric tonnes (mmt) annually [14], while about 20 % of rice paddy is husk [15], indicating that rice husk is available at commercial levels and that it is sustainable. Presently, most rice milling industries use rice husk as fuel for their boilers, leaving heaps of ash lying fallow. Studies have shown that RHA contains extremely high reactive silica [16], which makes it a very good pozzolanic material and has potential to replace cement by up to 30 % to produce concrete of comparable properties [17]. RHA concrete is similar to fly ash or slag concrete, both of which are well acceptable for high performance. RHA increased early hydration rate of C_3S due to its high specific area [18] and consequently produced denser paste [19]. Similar studies show that presence of RHA in concrete improved later strength [20], enhanced workability, increased durability and provided resistance for alkali silica reaction (ASR) in concrete [21]. In road construction, the use of RHA as stabilizing material for road base construction [22], while used rice husk as aggregate in place of sand for the sub base layer of flexible road pavement [23].

To date, studies utilizing RHA as replacement of cement in concrete have been more of concrete used in building structures with limited reported research work on RHA concrete designed for use in rigid pavement. Nevertheless, there is a recent report, currently in press, on the effect of RHA particle size in mitigating ASR in concrete pavement. This study is limited to a case in Arkansas [24]. In this present study, different concrete mixes containing RHA were optimized with a view to determining the amount of RHA that could be used to replace cement to produce concrete for use in rigid pavement. This study will further create additional value chain for the use of RHA.

Materials and methods

Materials

Materials used are Portland Composite Cement (PCC) produced by PT Semen Baturaja was used as binder and was obtained from a retail market. Rice husks were obtained from a rice mill at Gasing, South Sumatra and were burnt up to a temperature of 700 °C for an hour to obtain ash. **Figure 1** shows the sample of the RHA used produced.

Figure 1 Sample of the RHA.

Aggregates

Local granite of maximum nominal size of 12 mm was used as coarse aggregate, while river sand of maximum nominal size of 3.18 mm was used as fine aggregate. Sand was obtained from River Tanjung Raja, South Sumatra. The physical properties of the aggregates are presented in **Table 1**, while their particle size distribution curves are shown in **Figure 2**.

Table 1 Physical Properties and Grading Coefficients of Aggregates (ASTM 136).

Parameters	Granite	Sand
Specific Gravity	2.68	2.57
Water Absorption (%)	14.20	22.5
Bulk Density (kg/m^3)	1690	1520
Fineness Modulus	5.45	4.81

Water and admixture

Potable water was used for mixing the concrete and a Sulphonated Naphthalene polymers-based superplasticizer with the brand name Sika ViscoCrete -5930 [25] was used as water reducing agent to facilitate flow of the concrete mix (Dosage of 150 mL per cubic m (m^3) of the concrete sample was used based on the recommendation of the producer.

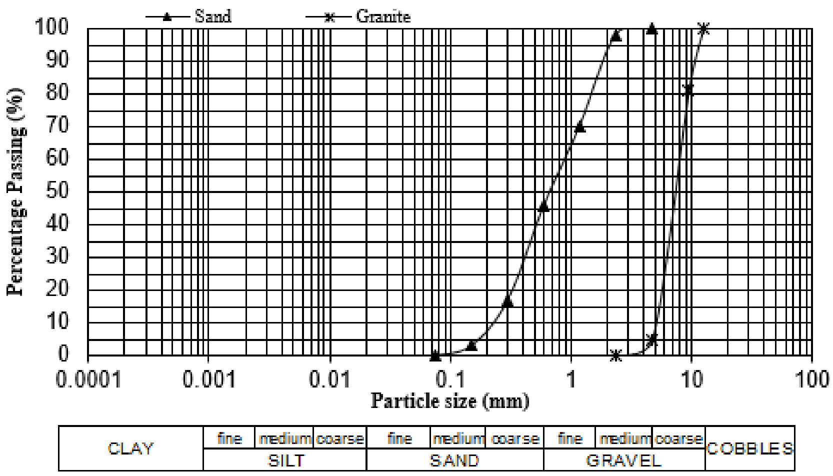


Figure 2 Particle-size distribution of the aggregates (sand and granites).

Table 2 Particle sizes of sand and granite.

Mesh size (mm)	Percentage passing (%)	
	Sand	Granite
0.15	3	0
0.3	17	0
0.6	46	0
1.18	90	0
2.36	98	0
4.75	99	10
9.5	100	81
12.5	100	100
19	100	100

Mixing and casting of concrete samples

The mixes that were used in this study were based on the highways standards which specifies the mix ratios for highways concrete [26]. The concrete mix was batched by weight. Three different mix ratios of concrete specimens were prepared. Normal concrete (0 % RHA) was used as reference, while other concrete samples contained RHA, replacing cement (by weight) at 2.5, 5, 7.5, and 10 % replacement levels. After mixing each concrete specimen, it was poured in a cube mould of size 150 mm in 2 layers with each layer compacted for 10 min on a vibration table. The moulds and their content were covered with polythene for 24 h. Then the concrete cubes were removed from the moulds and cured in water for 7, 28 and 56 (**Figure 3**).

Thirty concrete cubes were produced from each of the 3 concrete mixes. The choice of concrete mix used was based on the common standard mix ratio for concrete pavement in the UK (BS EN 12390). The mix ratio varied with decreasing content of cement. A water binder ratio of 0.4 was used throughout, while SP was applied based on the specification of the manufacturer. The detail of quantities of materials used for each concrete mix per m^3 are presented in **Table 3**.

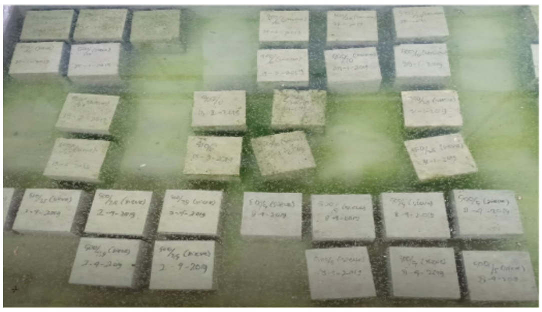


Figure 3 Sample of concrete cubes under curing.

For ease of reference, each concrete sample is coded. For instance, the first mix ratio that contained 0 and 2.5 % RHA is represented by M1-0 and M1-2.5, respectively, where "M1" indicates concrete mix 1 of mix ratio 1:1.56:1.64 (Binder: Sand: Granite) and "2.5" represents a proportion of RHA in the concrete mix of 2.5 %. The same nomenclature is used for the remaining mix ratios. The mix design adopted was based on what was currently being used in UK for rigid pavement (BS EN 12390).

Table 3 Mix proportion of the blended Cement-RHA binder per m^3 of the mix ratio.

Mix Ratio	Mix Notation	Proportion of RHA	Cement (kg)	RHA (kg)	Sand (kg)	Granite (kg)	Water (kg)
1:1.56:1.64	M1-0	0	500.00	0	780	820	200
	M1-2.5	2.5	487.55	12.50	780	820	200
	M1-5	5.0	475.0	25.00	780	820	200
	M1-7.5	7.5	462.5	37.5	780	820	200
	M1-10	10	450	50	780	820	200
1:1.77:1.88	M2-0	0	450	0	796.5	846	180
	M2-2.5	2.5	438.75	11.25	796.5	846	180
	M2-5	5.0	427.5	22.5	796.5	846	180
	M2-7.5	7.5	416.25	33.75	796.5	846	180
	M2-10	10.0	405	45	796.5	846	180
1:2.07:2.17	M3-0	0	400	0	828	868	160
	M3-2.5	2.5	390	10	828	868	160
	M3-5	5.0	380	20	828	868	160
	M3-7.5	7.5	370	30	828	868	160
	M3-10	10.0	360	40	828	868	160

Methods

Material characterization

The chemical composition as well as physical properties of the cement and that of RHA used were determined. The XRF technique was used to determine oxide composition, while provision provided in British Standard [27] was followed for the determination of specific gravities of cement, RHA and the aggregates. The tests were conducted at the Geology Laboratories, Bandung, Indonesia. Densities of the aggregates were equally determined.

Strength determination

At the expiration of each curing age, concrete cubes were removed from the curing tank and were allowed to stay at room temperature for 30 min before they were taken to the crushing machine to determine their crushing force. Compressive strength was then determined using Eq. (1). The average of 3 readings was noted as the strength of the concrete sample;

$$S = \frac{F}{b^2} \tag{1}$$

where: S = Compressive strength (N/mm^2), F = crushing force (N), b = size of the cube (mm).

XRD and SEM investigation of concrete samples

After determining the strength of the concrete samples as described in the previous section, RHA concrete samples that gave the highest strength along with normal concrete were used as samples for XRD and SEM analysis. This is with a view to determining possible phases that were formed which are responsible for strength development. The procedure described by [28] was followed in preparing the samples and taking SEM images, while the description reported by [29] was adopted for the XRD analysis.

Results and discussion

Material properties

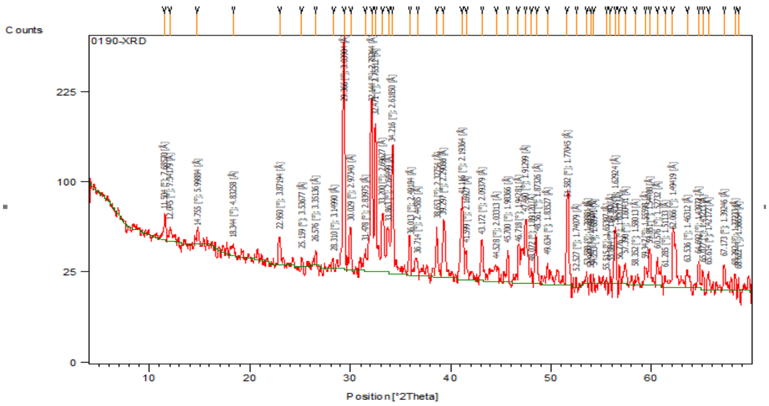
Table 4 summarizes the oxide composition of RHA and cement used in this study as determined from XRF. CaO and SiO_2 are major oxides of the cement, representing about 74 %, while Al_2O_3 and Fe_2O_3 were other oxides present at relatively low quantity and making up the remaining composition. It is not surprising that the cement had a high value of loss on ignition (LOI) because it is a composite cement. The higher value of LOI suggested that the additives added to the clinker to make the composite are susceptible to heat on burning and so experienced loss, making the LOI higher. For a normal CEM I cement, the limit of 4.18 is recommended by British Standard EN 196 [30]. The mineral composition of the clinker (% mass) as estimated from Bogue's equation are 75.99 % (C_3S), −12.27 (C_2S), 8.48 (C_3A) and 7.91 (C_4AF) [41].

The C_3S (Alite) seemed to dominate the composition and would influence the performance of the cement, while the negative value of C2S (Belite) showed that the cement contained low silica relative to CaO. XRD pattern of the cement (**Figure 3**) also supported this composition. Hydration of C_3S in the clinker is known to be responsible for early strength development [31].

Table 4 Chemical composition of the cement and RHA.

Material	Oxides Composition (%)								LOI
	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	SO_3	
Cement	15.71	4.86	2.60	57.98	0.88	0.34	0.62	1.47	14.88
RHA	94.24	0.23	0.83	0.61	0.84	0.28	1.62	-	0.78

On the other hand, RHA had substantial silica content (94.24 %), while the combined silica, alumina and ferric was 95.3 % with traces of other oxides. It is interesting to note that RHA seems very stable under heat as shown by its LOI value, indicating that the RHA does not contain organic constituents that are susceptible to heat. The RHA contains silica in quantity adequate for accepting it as a good pozzolanic material ASTM C618-19. Similarly, the silica content found in our RHA is similar to what [32] obtained and about 15 % higher than what [33] reported. To buttress suitability of the RHA as pozzolanic material further, the XRD pattern of the RHA suggested the RHA is amorphous with high broad peaks at 22.2 θ (2Theta angle) and contained some crystalline phases, which are suspected to be quartz (christoablite), having peaks at 2 Theta angle of 22 (**Figure 4(a)**). But in the case of cement, alite and belite were major compound found with traces of portlandite (**Figure 4(a)**) the scanning electron microscopic (SEM) pictures of the cement and RHA are presented in **Figure 5**. It is shown that the cement contained particles that are agglomerated with octahedral shaped particles (**Figure 5(a)**), while RHA had multilayered particles with some forms of honeycomb structure (**Figure 5(b)**).



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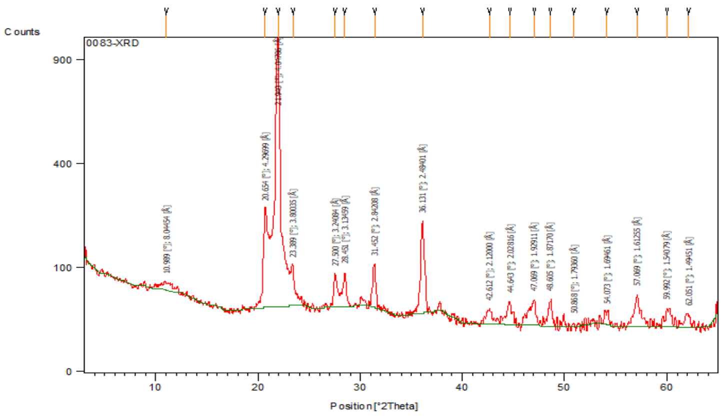
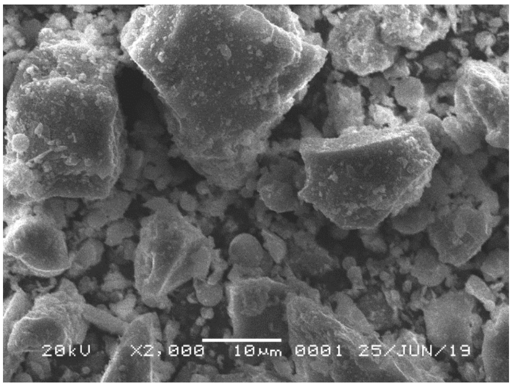


(b)

Figure 4 XRD patterns of (a) cement (b) RHA.



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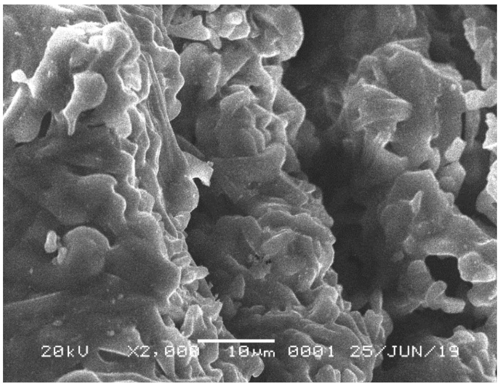


(b)

Figure 5 SEM Picture of (a) Cement and (b) RHA.

The RHA particles are less porous as indicated by SEM image and the low value of LOI. This result is in contrary to what [34] reported on the RHA used in their study, which contained high LOI. Several authors have attributed porosity of RHA structure to high value of LOI [35,36].

Effect of RHA on the compressive strength

The compressive strength of each of the mixes M1, M2 and 3 at ages 7, 28 and 56 days are presented in **Figures 5 - 7**, respectively. There seems to be a common trend in strength pattern for all the mixes as the proportion of RHA increased, with the exception of strength at 56 days. At 7 days, for instance, the strength of concrete specimen M2-0 (Mix 2 without RHA) had the highest strength, which was about 114 and 131 % of the strength of M1-0 and M3-0, respectively (**Figure 6**). As the RHA was added to the mix, the strength sharply reduced at 2.5 % content of RHA and then rose to the peak at 7.5 % content of RHA for both concrete M2-0 and M3-0. The trend was entirely different for concrete M1 that had gradually increased in strength with an increase in RHA content until it started descending at 7.5 % RHA. As the age of concrete reached 28 days, all the mixes without RHA (M1-0, M2-0 and M3-0) had the same strength pattern with their respective strength at age 7 days, with marginal increase in strength. Compressive strength of M1 - 0 increased from 26.6 to 31.1 N/mm^2, representing about a 17 % increase, while strength of M2-0 and M3-0 increased by about 19 and 25 %, respectively (**Figure 7**). These results showed that the concrete had substantial strength, where their 7-day strength is more 75 % of the 28-day strength. The probable reason for this performance could be attributed to the higher content of C3S of the cement, as discussed in the previous section. Similar trends were observed with the increase in RHA content in the concrete mixes. In this case, the highest strength was recorded for concrete specimen M1 and M3 at 5 % RHA content, where the mix M2 had its lowest strength. A further observation of the strength development above 28 days (at 56 days), showed the strength pattern similar to 28-day strength, except for concrete containing lower quantity of RHA of 2.5 % excluding mix M3 (**Figure 8**). Summarily, the presence of RHA is found to influence the strength of all the concrete mixes. Concretes M1 and M3 seem to have strength comparable to normal concrete strength at all ages when the RHA content was not more than 5 %, while concrete M2 had comparable strength with up to 7.5 % RHA for all the ages. Further increase in RHA content above these values (5 and 7.5 % as the case may be) would lead to decrease in strength. This is because RHA content would have been in excess of what is required to combine with the available lime to form additional cementitious product. Once lime is able to take up the required RHA, the remaining quantity of RHA will be dormant within the concrete matrix and would likely cause reduction in strength [37].

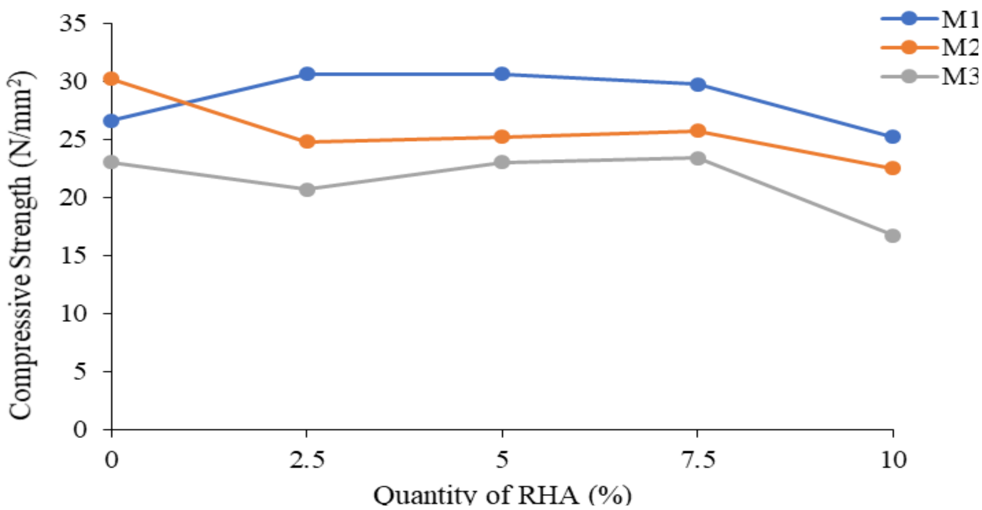


Figure 6 Effect of RHA on strength for each mix ratio at age 7 days.

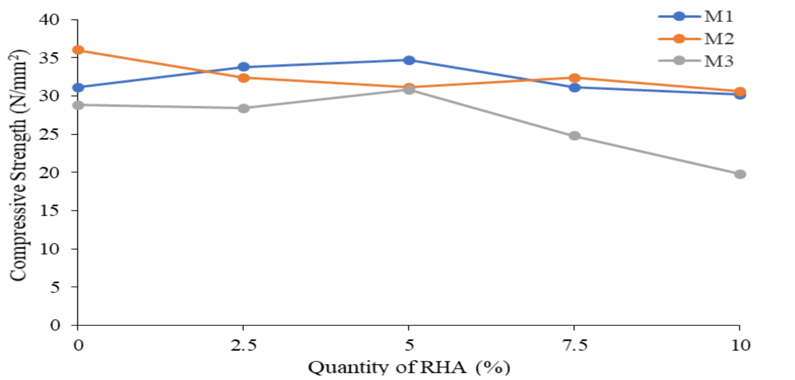


Figure 7 Effect of RHA on strength for each mix ratio at 28 days.

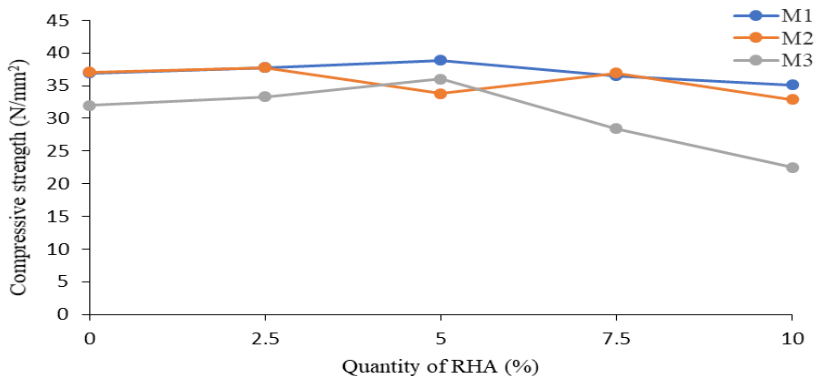


Figure 8 Effect of RHA on strength for each mix ratio at 56 days.

Interestingly, the strength of concrete M2-7.5 was at par with M1-7.5 at ages 28 and 56 days, despite the fact that concrete M1 had higher strength far above M2 at age 7. What could be deduced from this is that there is more complete pozzolanic reaction in M2-7.5 than in M1-7.5. For practical implication, concrete specimens M1-7.5, M2-7.5 and M3-5 are acceptable for use as concrete road pavement having 28 -day strength higher than 27.5 N/mm^2 [38].

Strength activity index of the RHA concrete

From the data presented in **Table 5**, it is apparent that the presence of RHA affects the Strength Activity Indices of the blended concrete. According to ASTM C618 [39], SAI is a measure of the pozzolanicity of supplementary cementitious material (SCM) and it is a ratio of strength of blended concrete to the strength of normal cement at the same curing age. It is expressed as a percentage. It is seen that except concrete M3-10, all other concrete specimens had SAI higher than the minimum of 75 % specified by ASTM C618-19.

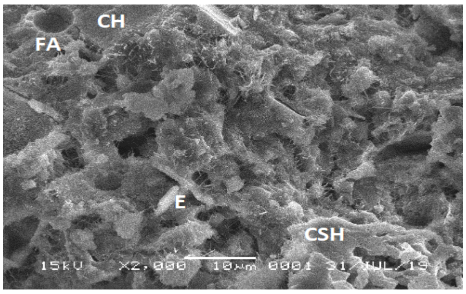
Table 5 Strength Activity Index of the Concrete specimens.

Mix Ratio	%RHA Content	Strength Activity index (%)		
		Curing Periods (Days)		
		7	28	56
1:1.56:1.64	0	100.00	100.00	100.00
	2.5	115.04	108.68	102.44
	5	115.04	111.58	105.42
	7.5	111.65	100.00	98.92
	10	94.74	97.11	95.12
1:1.77:1.88	0	100.00	100.00	100.00
	2.5	82.12	90.00	101.89
	5	83.44	86.39	91.11
	7.5	85.10	90.00	99.46
	10	74.50	85.00	88.68
1:2.07:2.17	0	100.00	100.00	100.00
	2.5	90.00	98.61	104.06
	5	100.00	106.94	112.50
	7.5	101.74	86.11	88.75
	10	72.61	68.75	70.31

SEM and XRD analysis

Figure 8 shows the microstructure images of concrete samples with 5 % RHA and without RHA (0 %) cured in water for 7 days. The choice of these samples was based on the results obtained from the strength, where presence of 5 % RHA seems to produce concrete with higher strength. In the figure, it is shown that the presence of RHA had influence on the formation of hydration products. In the normal concrete (**Figures 9(a), 9(c)** and **9(d)**), round shaped particles were observed, which is an indication of fly ash that was used as constituent of the composite cement. Some fly ash grains seem also to appear hollow. Meanwhile, the FA grains are not prominent in the image of concrete mix M3-0. This was probably due to the relative low content of cement.

Similar observations were reported in a cement that includes 30 % fly ash [37], however as RHA ash was added to the cement mixture, the effect on the microstructure seems to be significant as the hollow shape of the fly ash is being filled up with RHA making the concrete appeared denser than normal concrete. It is also observed that fly ash grains were less conspicuous in the RHA concrete when compared to normal concrete. This is evidence in of the compressive strength (**Figure 6**). Other major products formed are calcium hydrate (CSH), portlandite (CH) as well as some traces of ettringite (E).



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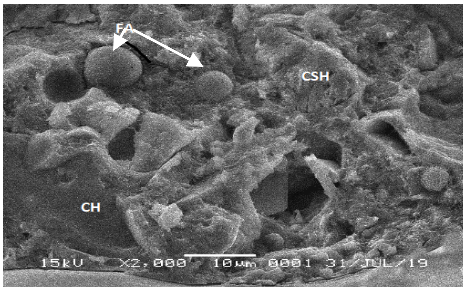

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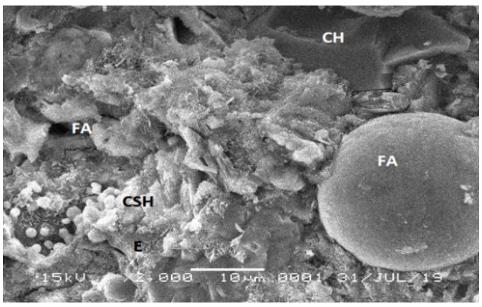

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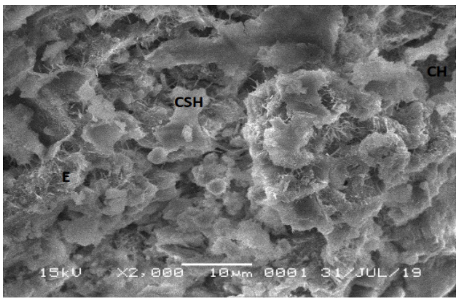

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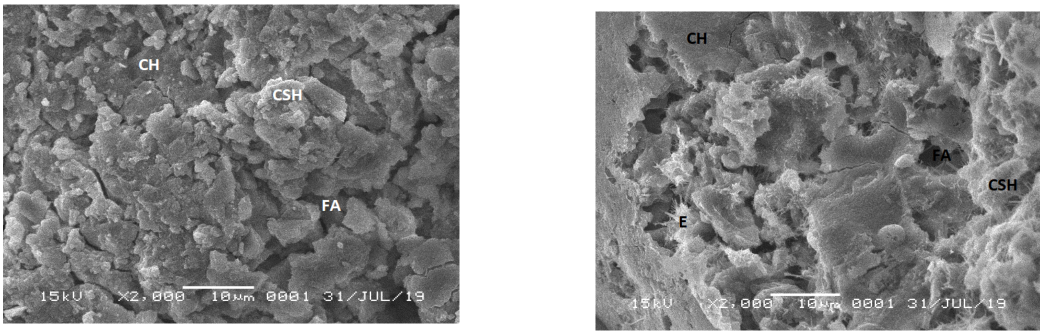

(e) (f)

Figure 9 Scanning electron microstructure images of 7-day old concrete of mix: (a) M1-0, (b) M1-5, (c) M2-0, (d) M2-5, (e) M3-0 and (f) M3-5.

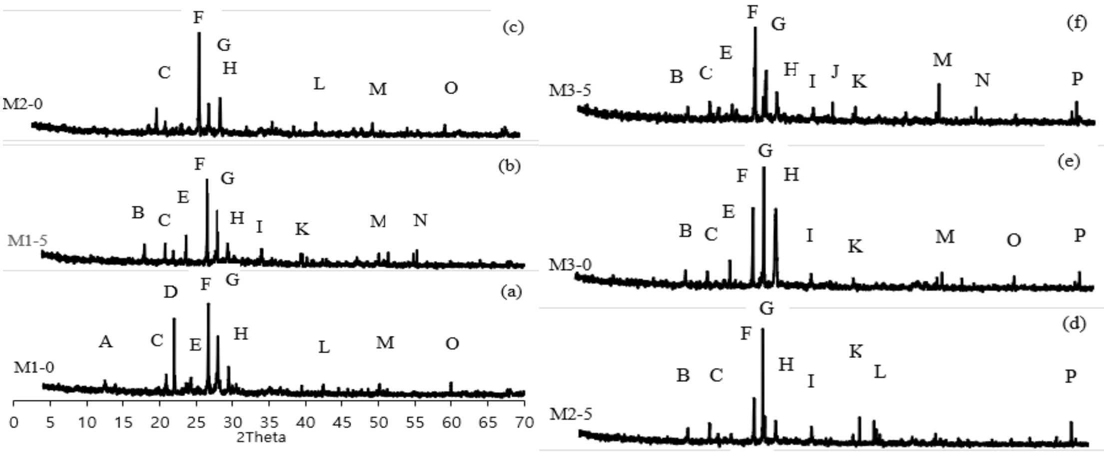

Figure 10 XRD patterns 7 - day old concrete of mix: (a) M1-0, b) M1-5, (c) M2-0, (d) M2-5, (e) M3-0 and (f) M3 - 5.

Different phases were identified in the selected hydrated concrete samples containing different amounts of cement and 5 % RHA as shown in the XRD patterns in **Figure 10**. The normal concrete (M1-0, M2-0 and M3-0) tends to have increased peak intensities compared to the corresponding concrete that contained 5 % RHA. This effect suggested that RHA had influence on the peak intensities of the phases, perhaps due to pozzolanic reactions that occurred or the amorphous nature of RHA. Generally, the same phases are identified in all the samples but at different peaks. At about 13 ° (2Theta), mineral albite was identified in only concrete sample M1-0 (the concrete sample that contained the highest quantity of cement 500 kg/m^3 without RHA). Albite is known to be a sodium rich mineral, which was in the form of silicate of sodium, calcium and aluminum. It is a strength building mineral. So, it was suspected to be responsible for the early strength of concrete sample M1-0 (**Figure 6**) compared to other samples. Several other phases were identified that are common to all the samples considered in the study. Nevertheless, RHA concrete samples predominantly contained silicate of sodium, aluminum and calcium.

In this study, RHA was used to replace cement in 3 different mixes for producing blended concrete for road pavement, which is applicable in UK and other regions. Strength properties were studied, and XRD and SEM analyses of the concrete samples were performed. The following could be concluded from the study:

1) The strength activity indices of the cement-RHA blended concrete were not less than 80 % in all the mixes, except for M3 - 10 concrete mix.

2) Presence of RHA in the mixture contribute to strength development through pozzolanic reaction.

3) Concrete that contained RHA appeared more dense than normal concrete; hence an optimum of 5 % of cement could be replaced with cement to produce concrete of adequate strength for use as rigid pavement.

4) Future study would need to consider performing durability assessment on the adopted mix proportion to be able to generalize the use of the concrete in road pavement.

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