INTERNATIONAL JOURNAL OF INTEGRATED ENGINEERING VOL. 11 NO. 9 (2019) 285–294

IJIE

Journal homepage: http://penerbit.uthm.edu.my/ojs/index.php/ijie
ISSN : 2229-838X e-ISSN : 2600-7916

The International Journal of Integrated Engineering

Performance of Acid Leached Rice Husk Ash (ARHA) in Mortar

Yong Seng Wong[1], Wai Hoe Kwan[1,*], Foo Kwan Lee[1], Jin Chung Sin[1], Soon Han Wai[1]

[1]Faculty of Engineering and Green Technology,
Universiti Tunku Abdul Rahman, 31900 Kampar, Perak, MALAYSIA

*Corresponding Author

DOI: https://doi.org/10.30880/ijie.2019.11.09.030
Received 21 February 2019; Accepted 16 October 2019; Available online 31 December 2019

Abstract: RHA is one the most available agricultural wastes in rice producing countries. Roughly of 20% of the total amount of paddy is husk which giving an annual total production of 120 Mtons which causes disposal problem due to low commercial interest and uses. The presence of metal impurities (Na_2O and K_2O) in non-treated RHA that incorporating in concrete can trigger alkali reaction in harden concrete. In order to overcome the issue, hydrochloric acid as the leaching agent for acid leaching treatment on RHA effectively removed metallic impurities from the RHA. In this study, ARHA was prepared by acid leaching treatment in order that the end product conformed to the engineering standards in terms of chemical and morphological properties. There are total of 3 proposed acid leaching parameters on RHA (1 M, 0.1 M and 0.01 M HCl leaching treatment with the duration of 2 days) prior to combustion at 800°C for 2 hours. The chemical properties and morphology study of the ARHA would be firstly characterized base on the x-ray fluorescent (XRF), x-ray diffraction (XRD), particle size analyzer, loss on ignition (LOI) and BET analyzer. 0.1 M of HCl leaching treatment RHA (ARHA2) prior to combustion at 800°C for 2 hours effectively removed impurities and produced > 90 % of pure amorphous silica with high surface area and pore volume. Hence, the effects of incorporating ARHA2 as partial replacement (2.5 %, 5 %, 7.5 %, and 10 %) of cement were investigated. The compressive strength, ultrasonic pulse velocity (UPV), porosity, gas permeability and the water absorption of ARHA mortar were determined to identify the characteristics of AHRA mortar. The results show that the replacement 10 % of ARHA into the mortar gave a positive result, it improved 29% of compressive strength compared to the control mix. In term of durability properties, there was approximate 2.2 % reduction in the total porosity as the replacement level of ARHA2 increased from 0 % to 10 % of total binder in the mortar.

Keywords: Acid leached, rice husk ash, hydrochloric acid, amorphous silica

1. Introduction

Here Approximately 600 Mtons (million tons) of paddy is produced every year worldwide. 20 % of the total amount of paddy is husk that yields an annual total production of 120 Mtons (million tons) [1]. Rice husk (RH) is the shell that protects rice during the growing season. It is an agricultural waste product that contains a high amount of silica. In general, RH contains 75 % to 90 % of organic matters, for example, 40 % of cellulose, 30 % of lignin and mineral parts [2], it also contains metallic impurities such as aluminum oxide (Al_2O_3), iron (III) oxide (Fe_2O_3), calcium oxide (CaO), magnesium oxide (MgO) and, more importantly, deleterious alkalis like potassium oxide (K_2O) fraction within the RH [3]. The presence of K_2O content that remains in RH can cause melting on the surface of RH and acts as

*Corresponding author: kwanwh@utar.edu.my

a crystallization catalyst for silica during combustion [4]. Besides that, some researchers claim that Na_2O has the same behavior as K_2O that can act as the catalyst for silica crystallization. Preliminary acid leaching treatment on the RH helps to obtain relatively pure silica content with a high specific surface area from the RH after the burning process [5].

Many researchers have found that different treatment conditions such as the different concentration of acid, different types of acid used and different durations of leaching process in RH produces rice husk ash (RHA) with very high purity of silica content (SiO_2) [6, 7, 8]. Acid leaching treatment on RH can enhance the pozzolanic properties and reduce the sensitivity of burning conditions of RH. The preliminary hydrochloric acid (HCl) leaching treatment on the RH effectively removes impurities from the RH [2, 3]. Many researchers had been done on the incorporation of rice husk ash (RHA) in the concrete. Ferraro et al. [9] had observed that RHA with the presence of high amorphous silica in a large specific surface area which can be considered as an efficient pozzolanic material and can be used as a supplementary cementing material (SCM). Most of the studies were performed to determine the effectiveness of partial replacement of RHA as pozzolan in the concrete mix and the enhanced performance of RHA concrete. Ganesan et.al [10], Abalaka and Ahmadu [11], Chao-Lung, Anh-Tuan and Chun-Tsun [12] had made the same agreement that 20 % of RHA replacement of cement by mass resulted in enhancing the early-age compressive strength. Khan et.al [13] concluded that concrete incorporating with 25 % RHA as the replacement of cement had the same compressive strength as ordinary concrete. In terms of durability properties, addition of RHA into cement reduces the formation of $Ca(OH)_2$ which can protect the concrete in an aggressive environment [14]. This paper presents discussions on the acid leached rice husk ash (ARHA) and the comparison of ARHA mortar with different replacement ratio from 2.5 %, 5 %, 7.5 %, and 10 % in terms of fresh mortar state, compressive strength, porosity and the gas permeability.

2. Experimental Programme

The laboratory investigations cover the characterization of the acid leached RHA, testing of fresh and hardened mortar containing various percentage of acid leached RHA.

2.1 Preparation of ARHA

RH samples were collected from Langkap, located in the district of Hilir, Perak Malaysia. The RH samples went through a preliminary washing process to eliminate dust and unwanted materials that were mixed in the RH samples from the rice mill. After the preliminary washing process, the RH samples were dried in the oven for 24 hours. Every 1 kg of RH was leached in 4 liter of diluted HCl acid solution at different molarity for 2 days. The molarities for the acid solution to produce ARHA1, ARHA2 and ARHA3 were 1.0M, 0.1M and 0.01M respectively. Subsequently, RH was washed with tap water until it achieved a neutral pH value [2].

2.2 Characterization of ARHA

The chemical compositions of ARHA and RHA samples were monitored by X-ray fluorescence (XRF).X-ray diffractometry (XRD), using Siemens D500, CuKα radiation at 40kV/20mA with a scanning angle of 2θ within the range of 3˚ to 70˚ to analyze the mineralogical phase of the ARHA and RHA samples. The result of the XRF test is illustrated in Table 1. The un-burnt carbon content of ARHA and RHA samples was determined by Loss on Ignition (LOI). Particle sizes of ARHA and RHA samples were monitored by a Malvern Mastersizer 2000. Specific gravities of ARHA and RHA samples were measured by BET analyzer. From the investigations, ARHA2 was found to have the highest silica content and hence it was selected as the SCM as the accordance of ASTM C618-08a to partially replace the cement content of a mortar for the subsequent testing on fresh and hardened properties.

Table 2 - Mix proportions of mortar containing different percentage of ARHA2

Replacement Ratio (%)	Binder (kg/m^3)		Sand (kg/m^3)	w/b Ratio	Superplasticizer (%)
	OPC	ARHA2			
0.0	557.	0.0	1391.0	0	1.0 – 2.5
2.5	543.	13.9			
5.0	529.	27.9			
7.5	515.	41.8			
10.0	501.	55.7			

2.3 Mortar Mixture Design

In this research, several replacement ratios of ARHA2 mix designs were developed for the ARHA mortar. The replacement ratio of ARHA2 in ARHA mortar is 2.5 %, 5 %, 7.5 % and 10 % by weight of cement. The ratio of binder to fine aggregate is 1:2.5 while the water to binder (w/b) ratio is 0.5. The dosage of polycarboxylate ether based water reducing agent was varied in order to obtain a workable mix. Table 2 presents the mix proportions of mortar at various cement replacement level using ARHA2. ARHA2 mortar mix design and replacement ratio is measured based on the weight of cement.

2.4 Testing of Hardened ARHA Mortar

The rheological behavior of the ARHA2 mortar mixtures was determined by carrying out flow table test in the accordance with BS EN 12350-5 [15]. Engineering and durability properties of ARHA2 mortar were determined from compressive strength, ultrasonic pulse velocity, porosity and permeability. The compressive strength test and ultrasonic pulse velocity test were conducted using 50mm cube and Universal Testing machine in accordance with BS EN 12390-3 [16] and BS EN 12504-4 [17]. The test was performed on the ARHA2 and control mortar cubes at curing age of 3, 7, 14, 28, 56, 90 and 180 days respectively. Meanwhile, the permeability and porosity test were performed using cylindrical specimen with 45 mm diameter and 40 mm height. The age of testing is the same as the aforementioned. Porosity test and the permeability test were carried out in the accordance with RILEM [18] and BS 1902-3.9 [19]. The results were determined based on average of 5 samples. Water permeability of a mortar can be measured by the value of water absorption. The lower the water absorption value, the greater the deterioration resistance would be. Replacing the cement content by ARHA2 could reduce the cavities or void in the microstructure of the mortar. The water absorption percentage is shown by weighing method with reference to Eq. (1).

$$\text{Water absorption} = [(M_w - M_d)/M_d] \times 100\ \% \qquad (1)$$

where: M_w = Mass of wet specimen, g, M_d = Mass of oven dried specimen, g.

3. Results and Discussion

3.1 Mineralogical of ARHA

The XRF test detects the major chemical compositions of the ARHA and RHA, include SiO_2, TiO_2, CaO, Fe_2O_3 and Al_2O_3. Meanwhile, other minor compositions include Na_2O, K_2O, MgO, MnO and P_2O_5 are also detected. The variations in chemical compositions with other reported studies could be due to the sources of RH which vary based on different geographical factors, climate factors, year of harvesting, sample preparation and equipment used [20].

Table 1 - Chemical compositions of ARHA and RHA samples

Chemical Composition	RHA	ARHA1	ARHA2	ARHA3
Si	94.55	99.30	99.49	98.84
Ti	0.05	0.	0.	0.
Al_2	0.26	0.	0.	0.
Fe_2	0.18	0.	0.	0.
Mn	0.08	b	0.	0.
Mg	0.36	0.	0.	0.
Ca	0.72	0.	0.	0.
Na_2	0.07	0.	b	0.
K_2	2.39	0.	0.	0.
P_2	0.85	0.	0.	0.
LOI	0.570	0.344	0.377	0.256
Particle Size, µm	24.97	24.19	25.82	25.06
Specific Gravity	2.39	2.	2.	2.

*ARHA1 – 1M Leached Treatment, ARHA2 – 0.1M Leached Treatment, ARHA3 – 0.01M Leached Treatment, bdl – Below Detection Limit

Referring to the Table 1, RHA samples regardless of being treated or untreated with acid, contained exceptional high percentage of silicon dioxide (SiO_2), ranging from 94.55 % to 99.49 %. However, metallic impurities contents such as aluminum oxide (Al_2O_3), Iron (III) oxide (Fe_2O_3), calcium oxide (CaO), magnesium oxide (MgO) and, most importantly deleterious alkalis like potassium oxide (K_2O) in the ARHA samples showed a significant drop in percentage compared to the non-treated RHA. P_2O_5 and Fe_2O_3 content in ARHA samples showed a decreasing trend when concentration of HCl was increased. K_2O in ARHA2 was successfully removed by more than half compared to the untreated RHA. It was observed that 0.1 Mol of HCl leaching for 2 days (ARHA2) is effective in producing RHA with the highest SiO_2 content (99.49 %).

XRD analysis was performed on ARHA and RHA samples to identify the mineral phase of silica oxide. Amorphous silica can be confirmed when there were no sharp peaks exist in the X-Ray diffractogram [21]. In amorphous materials, atoms are randomly arranged. Hence, no crystal diffraction signal is yielded and captured during the scanning sequence of the X-ray diffractometry. The X-Ray light incident in a crystal plane of atoms is scattered in random directions due to the random orientation of atoms and given a broad peak or background hump. Therefore, the homogeneity of composite is not seen as it will give a high-intensity narrow peak. Therefore, the SiO_2 in the ARHA was in amorphous phase as the broad peak of the graph located on the 2θ angle of 22^o to 25^o. The temperature was fixed at 800^{o}C during the incineration process of RH. No crystalized form of silica was observed in the ARHA samples (Fig. 1). It might be due to the function of acid leaching treatment that had removed the potassium oxide (K_2O) from the RH. The K_2O in the RH caused the surface to melt and act as a crystallization agent for silica [22].However, in the RHA sample, it was observed that two peaks occurred at the XRD spectrum between 10^o to 14^o which indicated the crystallization transformation of silica in the RHA.

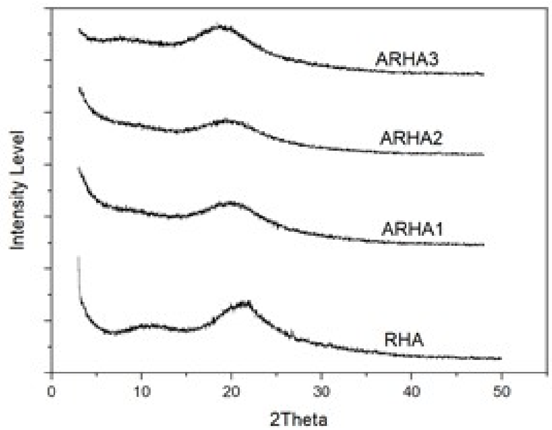

Fig. 1 - X-ray diffractometry patterns for RHA, ARHA1, ARHA2 and ARHA3

Loss on Ignition (LOI) is used to determine the unburnt carbon content in the ARHA and RHA during the combustion process. When ARHA and RHA samples were incinerated, decomposition of organic matters and carbon would occur. The carbon content transformed into carbon dioxide (CO_2) when the temperature was continuously increased and sufficient oxygen (O_2) was supplied during the combustion process. During heating whereby RH were slowly heated up to ideal temperature (600^{o}C - 700^{o}C) from ambient temperature, the carbon content from the rice husk could be oxidized before it reached the dissociation of K_2O that blocked ARHA and RHA samples' surface contact with O_2 [23]. ARHA samples contained 0.256 % to 0.377 % loss of ignition which indicated that ARHA had very low content of carbon content compared to normal RHA (0.57 %). In particular, ARHA samples were pure white in color as an indication of the absence of unburnt carbon as a result of removal of K_2O from the ARHA samples. Hence, acid leaching treatment on ARHA reduced crystallinity tendency during combustion [3].

BET measurements of ARHA2 and RHA samples (Table 3). The BET analysis on the specific surface area and the total pore volume of ARHA2 sample were found to be 128.886m^2/g and 0.258m^2/g, respectively.

Table 3 - Comparison of BET Surface Area Analysis on Optimum Result of ARHA2 and RHA

Sampl	BET Surface Area,	Specific Gravity,	Pore Volume,
RHA	9.3	2.	0.2
ARHA	128.8	2.	0.0

The surface area and pore volume for RHA sample were 9.3916m^2/g and 0.049m^2/g respectively. With the acid leaching treatment, the surface area of the ARHA2 was significantly increased by 1372% to 128.886 m^2/g while the pore volume was drastically reduced by 81% to 0.049 m^2/g. This indicates that the acid leaching treatment refined the pore structure of the RHA. This also further supports the statement that removal of K_2O by hydrochloric acid leaching reduces surface melting and preserves the pore structure of the RHA. However, acid leaching treatment on RH with acid concentration did not show any significant changes in the specific gravity between ARHA and RHA samples (Table 3). The specific gravity was ranged from 2.19 to 2.39.

3.2 Fresh ARHA Mortar Properties

Workability for concrete is a broad and subjective term describing how easily freshly mixed concrete can be mixed, transported, placed, consolidated and finished with minimal loss of homogeneity [19]. The workability values in terms of flow table results for varying ARHA2 percentage of mortars mix at ambient temperature are presented in Table 4.

Table 4 - Flow table results of all specimens

Replacement Ratio	Flow Diameter
0	20
2	19
5	18
7	18
10	17

The results of flow table test determine the workability of fresh mortar. It shows that incorporation of ARHA2 in mortars lead to a decrease in flow diameter although the dosage of the high range water reducing agent has been increased from 1.0% to 2.5%. The reduction in workability was due to the absorption of mixing water by the ARHA2 particles as their surface area was increased. As a result, the water demand for the mortar was increased by the increasing cement replacement ratio. Kamau et al. [29] reported that the coarseness and high specific surface area of the RHA could increase the water demand for mortar mixing.

3.3 Compressive Strength

The compressive strength result illustrates in Fig. 2 and Table 5 shows the percentage different of 28 days strength with respect to the control specimen. With 10% of cement replacement level using ARHA2, the 28 days strength increases from 32.92 N/mm^2 to 42.38 N/mm^2, approximate 29%. There is a total of 28.73% of incensement in 10% ARHA2 replacement mortar's compressive strength compared to the control set during the 28 days of curing age.

Table 5 - Compressive strength of all specimens

Replacement Ratio (%)	Compressive Strength at 28 Days (N/mm^2)	Percentage Difference against Control (%)
0	32.92	-
2.5	38.47	16.86
5.0	39.43	19.78
7.5	39.91	21.23
10.0	42.38	28.73

The enhancement of compressive strength due to the pozzolanic reaction which was initiated by the ARHA2 to produce additional secondary calcium silicate hydrate (C-S-H) gel [20]. ARHA2 also served as inner fillers and refined the micro pores of the mortar matrix [21]. This is in good agreement with Chopra et al. who reported that incorporating of RHA into concrete could reduce porosity and increase the contact surface between RHA and cement which ultimately contributed to the increase in compressive strength [25]. Inclusion of RHA in the concrete could enhance the early strength of concrete during the setting of cement which leads to a denser density and less porous structure of the concrete morphology structure [26]. The highly reactive siliceous properties of ARHA2 particles are the major contributing factors to this phenomenon. Huang and Ye reported that RHA could enhance the compressive strength of the cement paste due to the high pore volume of RHA which can act as the water reservoir to absorb water during the mixing of ARHA2 mortar. The absorbed water then was released in the cement paste that delays the internal desiccation of ARHA2 mortar and ARHA2 which could act as the internal curing agent [28]. The absorbed water by the RHA, as discussed above, will release back to the cement matrix and promote the hydration of cement at later ages. Hence, this effect will reduce the potential of cement paste cracking and increase the compressive strength of cement paste.

3.4 Ultrasonic Pulse Velocity (UPV)

Fig. 3 illustrates the UPV of all specimens and the percentage difference in 28 days result with respect to the control mix presented in Table 6. The 28 days UPV results increase from 3.95 km/s to 4.03 km/s when the ARHA replacement ratio increased from 0 - 10%. Nonetheless, the total enhancement is only 2.03% which is not significant.

The enhancement could be due to the filling effect of the ARHA2 particles. According to the rating in standard, all specimens could be classified as "good" quality concrete [17]. The 10% replacement of ARHA2 into mortar showed higher UPV value may be due to the higher rate of hydration that occurred in the mortar compared to control. The properties of lower porosity in ARHA2 mortar also could affect the UPV value [29].

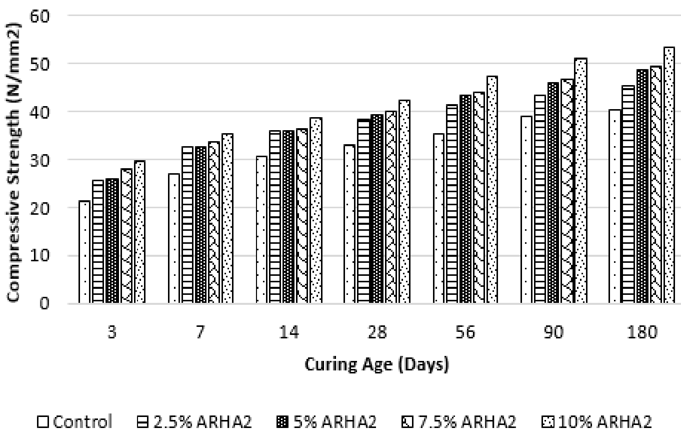

Fig. 2. Compressive strength of mortar for varying percentage of AHRA2 and control mix

Table 6 - UPV results of all specimens

Replacement Ratio (%)	UPV in 28 Days of Curing (km/s)	Percentage Difference against Control (%)
0	3.95	-
2.5	4.00	1.27
5.0	4.02	1.77
7.5	4.02	1.77
10.0	4.03	2.03

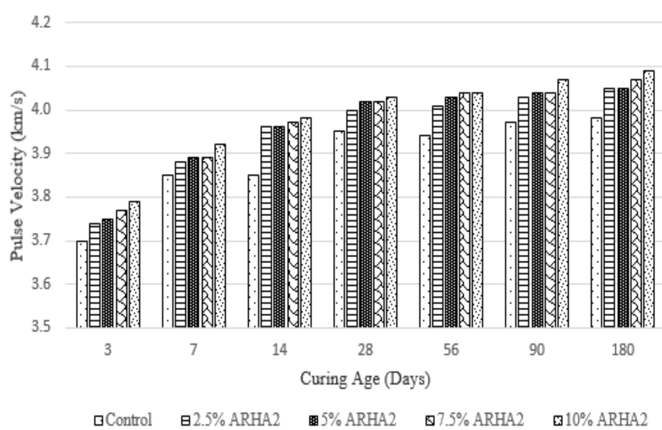

Fig. 3 - UPV result of mortar for varying percentage of AHRA2 and control mix

3.5 Porosity Test

Table 7 presents the porosity data of all specimens. The mixes that incorporated with ARHA2 shows less porous compared to the control specimen. The trend of the ARHA2 mortar porosity results showed decline along the curing age as expected. This due to the ARHA2 as SCM had increased the hydration process of the ARHA2 mortar [31]. The porosity of the mixes at 180 days has reduced from 18.1 % to 15.9 %. There is a total of 2.2 % reduction of porosity as the replacement of ARHA2 content increased from 0 % to 10 %. An increase of ARHA2 contents in mortar showed a decrease in the porosities result of ARHA mortar. This can be explained that the addition ARHA2 acts as the inner fillers due ARHA2 having smaller pore volume (0.049m^2/g) and also promotes formation of additional C-S-H gel which eventually filed up the pores [17].

Table 7 - Porosity results of all specimens

Replacement Ratio (%)	Curing Age (Days)						
	3	7	14	28	56	90	180
0	20.7	20.3	20.0	19.3	18.9	18.4	18.1
2.5	19.6	19.4	19.1	18.7	18.5	18.2	17.8
5.0	18.9	18.7	18.4	18.1	17.8	17.5	17.1
7.5	18.1	17.9	17.5	17.2	16.8	16.4	16.1
10.0	17.9	17.5	17.1	16.8	16.6	16.2	15.9

3.6 Gas Permeability Test

The gas permeability result is presented in Table 8. The result shows that replacing 10% of the total binder using ARHA2 has obtained the lowest intrinsic permeability, especially in the long term age of 180 days. The intrinsic permeability value that was recorded by the mortar containing 10% ARHA2 at 180 days was 2.87 x 10^{-17} m^2, approximate 10.6% lower than the control specimen. The highly reactive amorphous silica in the ARHA2 reacted with the portlandite to form extra C-S-H gel and hence it increased the tortuosity of the capillary paths in the microstructure.

Table 8 - Gas permeability result of all specimens

Replacement Ratio (%)	Curing Age (Days)						
	3	7	14	28	56	90	180
0	7.61	4.13	3.76	3.69	3.54	3.42	3.21
2.5	7.15	6.78	6.54	6.37	6.21	6.04	5.93
5.0	6.37	5.25	5.15	4.32	4.27	4.24	4.18
7.5	5.57	5.16	4.89	4.68	4.38	4.15	4.03
10.0	4.67	3.89	3.45	3.18	3.03	2.98	2.87

**Gas permeability, K (x 10^{-17} m^2)*

The additional of ARHA2 in mortar had increased the hydration process of the mortar and lead to a reduction of calcium hydroxide in the paste. With the presence of ARHA2 in the mortar could reduce the pore size and result less permeable mortar [31]. This would enhance durability of the mortar and make it suitable for applications in the aggressive environments.

3.7 Water Absorption Test

The result for water absorption test is shown in Fig. 4. The percentage of water absorption in 28 days reduces from 6.14 % to 5.15 % when the replacement level of ARHA2 increased to 10%. The water absorption result decreases as the replacement ratio of ARHA2 increases. Apparently, mortar with 10% replacement of ARHA2 showed the least water absorption value along the curing age.

Although the percentage of reduction is relatively small compared to the gas permeability and porosity results, a reduction trend was observed as the ARHA replacement level increased. This further strengthens the statement that the highly reactive ARHA particles contribute to the refinement of microstructure of the mortar matrix. Especially in the early ages, i.e. 3 days, the reduction in fluid transport properties is very significant, up to approximate 28.5%. The fine ARHA2 particles possibly serve as nucleation sites for the growing of C-S-H which enhance the cement hydration process at the early age. Thus, a relatively denser microstructure would form.

3.8 Correlation between UPV vs. Compressive Strength

Using 65 data points for ARHA2 mortar with varying replacement ratio and 5 data for control mix were plotted to explore the relationship between UPV and compressive strength. The linear regression was applied as in Fig. 5 to establish the UPV vs. compressive strength relationship. From the data, the pulse velocity was ranged from 3.70 to 4.03 km/s for which compressive strength ranges from 21.41 to 53.48 N/mm^2. The correlation between UPV and compressive strength the coefficients of determination, R^2 is 0.8931 which indicated strong relationship between UPV value and compressive strength. The correlation equation is shown in the following:

$$PV = 0.0126CS + 3.4723 \tag{2}$$

where: PV = Pulse Velocity, km/s, CS = Compressive strength, N/mm^2.

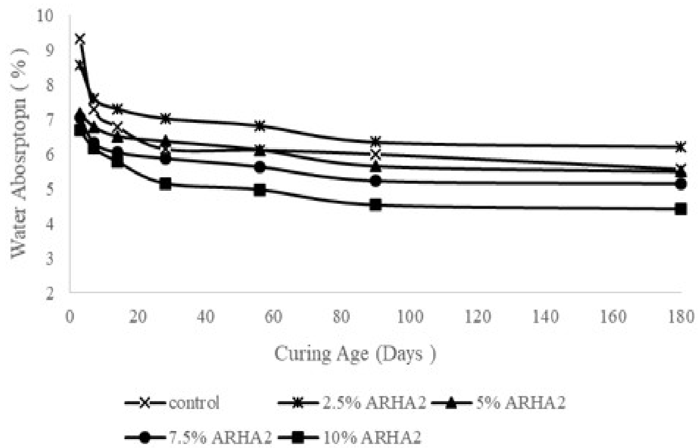

Fig. 4 - Water absorption result of mortar for varying percentage of AHRA2 and control mix

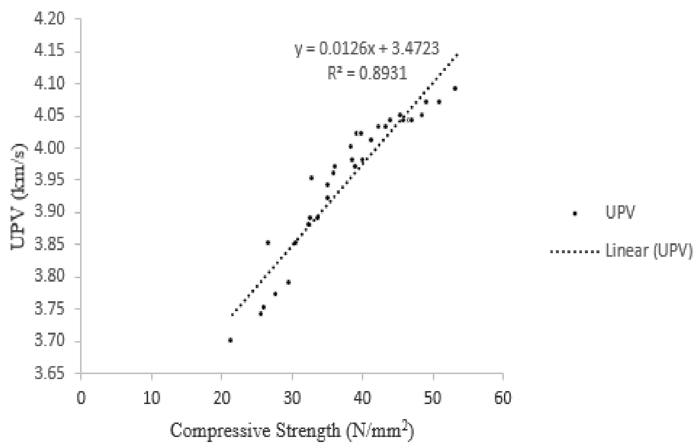

Fig. 5 - Correlation of UPV (km/s) versus compressive strength (N/mm^2)

4. Conclusion

The following conclusions can be drawn from the extensive laboratory investigations of this study:

- Acid leaching can effectively remove the presence of metal impurities (Na_2O and K_2O) from the RHA. Hence the lower content of Na_2O and K_2O can lower the alkali reaction in the hardened concrete.
- RHA with high SiO_2 content could be obtained by acid leaching treatment on rice husk using hydrochloric acid (0.01 M - 1.0 M) for 2 days and then incinerate in a controlled temperature, 800^{o}C for 2 hours in the O_2 atmosphere. The variation on the concentration of HCl is not sensitive in the yield of SiO_2 content in RHA. Using 0.1 M HCl and 2 days leaching duration can achieve the highest amount of SiO_2 content (99.49 %) in the RHA.
- The BET surface area of RHA treated with 0.1M HCl solution for 2 days has been increased by 13.7 times to 128.886 m^2/g compared to the untreated RHA and the pore volume has been reduced by 81% to 0.049 m^2/g.
- Acid leaching treatment with various acid concentrations would not significantly alter the specific gravity of the RHA, and generally keeping in the range of 2.19 - 2.39.
- Mortar containing ARHA2 in the binder is less workable due to the large surface area properties of ARHA2 which increased the water demand of the fresh mortar.
- RHA could affect both the strength and permeability by strengthening the aggregate-cement paste interface and by blocking the large voids in the hydrated cement paste through pozzolanic reaction. The incorporation of ARHA2 as the SCM in mortar can improve the compressive strength of the mortar. 10 % of ARHA2 replacement ratio in the total binder content shows the optimal result which can improve the compressive strength by 29% compared to the control mix. The compressive strength of the mortar containing ARHA is steadily increased beyond 28 days.

- Inclusion of RHA in the concrete can enhance the early strength of the mortar which leads to a denser and less porous microstructure. This is due the fine ARHA2 particles may increase the reactivity index during the early age of cement hydration.
- Inclusion of RHA in cement paste could enhance the compressive strength of the cement paste due to the high pore volume of RHA which can act as the water reservoir to absorb water during the mixing. The absorbed water then is released in the cement paste which can act as the internal curing effect. The absorbed water by the RHA, as discussed above, will release back to the cement matrix and promote the hydration of cement at later ages. Hence, this effect will reduce the potential of cement paste cracking and increase the compressive strength of the cement paste.
- Mortar that incorporate with 10 % of ARHA2 as SCM shows a positive result in reducing the cavities or void in the mortar morphology structure itself. This is because of the ARHA2 has the finer particle size that can act as the inner filler and also the highly reactive silica which promote pozzolanic reaction.
- For the durability properties of ARHA2 mortar, positive results were showed in terms of the porosity, intrinsic gas permeability and water absorption properties. There was approximate 2.2 % reduction in the total porosity as the replacement level of ARHA2 increased from 0 % to 10 % of total binder in the mortar. The lowest gas permeability and water absorption properties were achieved by 10 % of replacement ARHA2. As the curing age was prolonged, a reduction trend was observed in the porosity, intrinsic gas permeability and water absorption.

Acknowledgement

This research was supported/partially supported by the UTAR Research Fund (IPSR/RMC/UTARRF/2016-C2/K02). We thank our colleagues from the University of Tunku Abdul Rahman who have provided insight and expertise that have greatly assisted the research, although they may not agree with all the interpretations/conclusions of this paper.

References

[1] Mahmud, H. and Habeeb, G. Study on properties of rice husk ash and its use as cement replacement material. Material Research, Volume 13, (2010), pp. 1-2.
[2] Gholizadeh Vayghan, A., Khaloo, A. and Rajabipour, F. The effects of a hydrochloric acid pre-treatment on the physicochemical properties and pozzolanic performance of rice husk ash. Cement and Concrete Composites, Volume 39, (2013), pp. 131-140.
[3] Feng, Q., Yamamichi, H., Shoya, M. and Sugita, S. Study on the pozzolanic properties of rice husk ash by hydrochloric acid pretreatment. Cement and Concrete Research, Volume 34, (2004), pp. 521-526.
[4] An, D., Guo, Y., Zhu, Y., & Wang, Z. A green route to preparation of silica powders with rice husk ash and waste gas. Chemical Engineering Journal, Volume 162, (2010), pp. 509-514.
[5] Saad, S., Nuruddin, M., Shafiq, N. and Ali, M. The Effect of Incineration Temperature to the Chemical and Physical Properties of Ultrafine Treated Rice Husk Ash (UFTRHA) as Supplementary Cementing Material (SCM). Procedia Engineering, Volume 148, (2016), pp. 163-167.
[6] Le, H. and Ludwig, H. (2016). Effect of rice husk ash and other mineral admixtures on properties of self-compacting high performance concrete. Materials & Design, Volume 89, (2016), pp. 156-166.
[7] Le, H., Siewert, K. and Ludwig, H. Alkali silica reaction in mortar formulated from self-compacting high performance concrete containing rice husk ash. Construction and Building Materials, Volume 88, (2015), pp. 10-19.
[8] Safiuddin, M., West, J. and Soudki, K. Hardened properties of self-consolidating high performance concrete including rice husk ash. Cement and Concrete Composites, Volume 21, (2010), pp. 708-717.
[9] Ferraro, R., Nanni, A., Vempati, R. and Matta, F. Carbon Neutral Off-White Rice Husk Ash as a Partial White Cement Replacement. Journal of Materials in Civil Engineering, Volume 20, (2010), pp. 1078-1083.
[10] Ganesan, K., Rajagopal, K. and Thangavel, K. Rice husk ash blended cement: Assessment of optimal level of replacement for strength and permeability properties of concrete. Construction and Building Materials, Volume 22, (2008), pp. 1675-1683.
[11] Abalaka, A. and Ahmadu Bello University, O. Strength Development and Durability Properties of Concrete Containing Pre-Soaked Rice Husk Ash. Construction Science, Volume 14, (2013).
[12] Chao-Lung, H., Anh-Tuan, B. and Chun-Tsun, C. Effect of rice husk ash on the strength and durability characteristics of concrete. Construction and Building Materials, Volume 25, (2011) pp. 3768-3772.
[13] Khan, R., Jabbar, A., Ahmad, I., Khan, W., Khan, A. and Mirza, J. Reduction in environmental problems using rice-husk ash in concrete. Construction and Building Materials, Volume 30, (2012), pp. 360-365.
[14] James, J. and Subba Rao, M. Reactivity of rice husk ash. Cement and Concrete Research, Volume 16, (1986), pp. 296-302.
[15] British Standard 12350 (2009) Testing fresh concrete Part 5: Flow table test.

[16] British Standard 12390 (2009) Testing hardened concrete Part 3: Compressive strength of test specimens.
[17] British Standard 12504 (2004) Testing concrete Part 4: Determination of ultrasonic pulse velocity.
[18] Rilem, T. CPC 11.3 Absorption of water by concrete by immersion under vacuum. E & FN Spon, (1994), pp. 36-37.
[19] British Standard 1902 (1981) Methods of testing refractory materials Part 3: General and textural properties. Sub 3.1: Determination of permeability to gases.
[20] Johar, N., Ahmad, I. and Dufresne, A, Extraction, preparation and characterization of cellulose fibres and nanocrystals from rice husk. Industrial Crops and Products, Volume 37, (2012), pp. 93-99
[21] Lee, S. Dictionary of composite materials technology. 1st Edition. New York, (2001) pp. 9-10.
[22] Bakar, R., Yahya, R. and Gan, S. Production of High Purity Amorphous Silica from Rice Husk. Procedia Chemistry, Volume 19, (2016), pp. 189-195.
[23] Krishnarao, R., Subrahmanyam, J. and Jagadish Kumar, T. (2001). Studies on the formation of black particles in rice husk silica ash. Journal of the European Ceramic Society, Volume 21, (2001), pp. 99-104.
[24] Tattersall, G. Workability and Quality Control of Concrete. 1st Edition. Oxford: Taylor & Francis, (1991), pp. 1-7.
[25] D. Chopra, R. Siddique and Kunal, "Strength, permeability and microstructure of self-compacting concrete containing rice husk ash", Biosystems Engineering, Volume 130, (2015), pp. 72-80.
[26] Bayuaji, R. The influence of microwave incinerated rice husk ash on foamed concrete workability and compressive strength using taguchi method. Jurnal Teknologi, Volume 75, (2015), pp. 265-274.
[27] Antiohos, S., Papadakis, V. and Tsimas, S. Rice husk ash (RHA) effectiveness in cement and concrete as a function of reactive silica and fineness. Cement and Concrete Research, (2014), pp.20-27.
[28] Huang, H. and Ye, G. Use of rice husk ash for mitigating the autogenous shrinkage of cement pastes at low water cement ratio. Ultra-high performance concrete and high performance construction materials, Volume 27, (2016), pp.1-8.
[29] Kamau, J., Ahmed, A., Hyndman, F., Hirst, P. and Kangwa, J. (2017). Influence of Rice Husk Ash Density on the Workability and Strength of Structural Concrete. European Journal of Engineering Research and Science, 2(3), p.36.
[30] Kannan, V. (2018). Strength and durability performance of self compacting concrete containing self-combusted rice husk ash and metakaolin. Construction and Building Materials, 160, pp.169-179.
[31] Janbuala, S. and Wasanapiarnpong, T. (2015). Effect of Rice Husk and Rice Husk Ash on Properties of Lightweight Clay Bricks. Key Engineering Materials, 659, pp.74-79.