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Assessing the suitability of fly ash and rice husk ash from Misamis Oriental, Philippines in producing bricks for pedestrian and light traffic applications

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Abstract

Fly ash (FA) and rice husk ash (RHA) are agro-industrial wastes generated continually thereby requiring sustainable and environment-friendly ways in the treatment process. This study aimed at assessing the suitability of FA and RHA from Misamis Oriental, Philippines in producing bricks that can possibly be used for pedestrian and light traffic purposes. Quantitative experimental method was used in the study. Bricks were manufactured utilizing 40 to 95% Class F-type FA, 0 to 55% Class F-type RHA, 5% bentonite as the binder, 800^0C-firing temperature and 4-8 hours-firing time. Scanning electron microscopy (SEM) was used for morphological characterization of the bricks. % FA utilization was directly proportional to compressive strength of the bricks but inversely with water absorption, abrasion resistance and saturation coefficient. % RHA utilization was inversely proportional to compressive strength but directly proportional to the other mechanical properties. Firing time had no effect at all. SEM revealed that internally, bricks were combination of spherically and irregularly-shaped particles. Parameters used produced bricks but not suitable for pedestrian and light traffic purposes. It is recommended to increase the firing temperature and vary other parameters in the production such as %water added, number of days of air drying, molding pressure among others.

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Introduction

Coal power plants produce coal ashes when coal is being combusted for electricity generation (Mehta, 1983). The generation of these coal ashes would increase day by day because coal power plant operation is usually continuous. There are two known types of coal ashes, namely, the fly ash and bottom ash (Mehta, 1989). However, between these two, the problem lies heavier with fly ash than bottom ash because its generation would go up to 85% from the total coal ash produced in the plant (Jafri and Kumar, 2013). There should be sustainable and effective solution for this problem.

The best way is to utilize fly ash for construction purposes. The potential for fly ash in construction is evident in many studies. And its application usually is into replacements to cement, lime, clay etc. in the production of construction materials (Abbas *et al.*, 2017; Leiva *et al.*, 2016; Bansal *et al.*, 2015; Sil and Roy, 2015; Pawar and Garud, 2014; Richard *et al.*, 2013). Herein, the process would be sustainable, economic- and environment-friendly since it basically reduces the time and costs of production especially for cement and lime and prevents harmful gases that are to be emitted from the process of manufacturing them. It also saves natural land resources (Xue *et al.*, 2009) which are to be used in manufacturing them prior to their use for construction.

To take an example, in bricks production, fly ash was studied to replace clay. Recent studies revealed fly ash was amenable to replace clay at about 15-25% and at firing temperatures, 800-1000°C (Abbas *et al.*, 2017; Pawar and Garud, 2014; More *et al.*, 2014) yielding good compressive strengths and% water absorption. Leiva *et al.* (2016) even utilized fly ash up to 80% and still obtained bricks with good mechanical properties and with no environmental problems after leaching process.

There should be no environmental problems for any fly ash-based products so that they can thoroughly be used as construction and building materials. This is because fly ash contains heavy metals (Xu *et al.*, 2004; Levandowski and Kalkreuth, 2009) which make it hazardous. Thus, leaching process usually the US EPA 1311 method, is to be applied for construction materials with fly ash to assess if they are environmentally safe to use or not.

In order to solve problems in heavy metals in fly ash utilization, incorporation of other locally available raw materials could be best option to immobilize them in the mixture. The idea of adding rice husk ash (RHA) in the utilization is due to the fact that majority of its component is pozzolanic that it contains 90-95% silica (Mehta, 1992) and it is just readily available in rice mills (Mehta and Monteiro, 1993; Malhotra, 1993). This study involved utilization of both fly ash and rice husk ash in the production of bricks specifically. The combination between fly ash and rice husk ash in the production of bricks is feasible and was already studied by More *et al.* (2014). The potential of rice husk ash for brick production is evident also in many studies. According to recent studies, RHA was utilized from 2-50% to replace clay. From this range of utilization, bricks produced were of good mechanical properties (Eliche-Quesada *et al.*, 2017; Kazmi *et al.*, 2016; Sutas *et al.*, 2012; Hegazy *et al.*, 2012).

This study involved production of bricks with the aim of utilizing them for pedestrian and light traffic purposes. There has been no studies that involved production of said bricks with the utilization of both fly ash and rice husk ash which were obtained in Misamis Oriental, Philippines. Specifically, the effects of the production parameters such as composition and firing time to the compressive strength, water absorption, saturation coefficient and abrasion resistance of the bricks were obtained. These mechanical properties have to meet the standard specifications stipulated in ASTM C 902. Further, the morphological characteristics of these bricks were also obtained to validate the utilization of both raw materials.

Materials and methods

Characterization of Fly Ash and Rice Husk Ash Samples

The surface morphologies of the fly ash (FA) and rice husk ash (RHA) samples (100-mesh sized) were characterized by Scanning Electron Microscopy (SEM) in 1000 X, 3000 X, 8000 X and 10,000 X magnifications at the Chemistry Analytical and Research Laboratory, Ateneo de Davao University, Davao City, Philippines. The specific gravities and moisture contents of the samples were obtained using the ASTM C 128 and AASHTO T 255 procedures, respectively, at the Chemistry Laboratory, USTP-Cagayan de Oro Campus, Cagayan de Oro City, Misamis Oriental, Philippines.

The fly ash and rice husk ash samples were characterized by their elemental and oxide compositions by Energy Dispersive X-ray Spectroscopy (EDX) and X-ray Fluorescence Spectroscopy (XRF) techniques. The EDX analyses were conducted along with SEM whereas the XRF spectroscopy was done at HOLCIM (Phils.), Lugait, Misamis Oriental, Philippines.

Production of Fly Ash/Rice Husk Ash Bricks

The materials used in this study were FA, RHA, bentonite and water. The FA, RHA and the bentonite as the binder were all obtained in Misamis Oriental, Philippines. The FA-RHA-bentonite mixtures were prepared according to the compositions stipulated in the table below (Table 1) with 17-20% of water being added. According to Leiva *et al.* (2016), about 17-20% of water addition was enough to produce bricks with% fly ash utilization up to 80%. The samples were shaped in a 2” x 2” x 2” metallic mold material and underwent manual pressing at 10 MPa. After pressing, they underwent air-drying for one day and oven-drying for 4 hours at 100°C. After oven-drying, the samples were fired at 800°C in 4 hours, 6 hours and 8 hours, respectively, in an electrical muffle furnace to test the effects of firing time to the resulting mechanical properties such as the compressive strength, water absorption, saturation coefficient and abrasion resistance.

Cultrone and Sebastián (2009) and Leiva *et al.* (2016) have performed brick production with fly ash at 800-1000°C firing temperatures. On the other hand, firing time for 4-8 hours in brick production is also feasible. Eliche-Quesada *et al.* (2017) performed firing time of 4 hours for clay brick production with rice husk ash. Lingling *et al.* (2005) conducted firing time of 8 hours for production of clay brick with fly ash. The experimental set-up was done in three trials so as to study the effects of the factors to the resulting mechanical properties of the bricks as shown in Table 2 below.

Table 1. Composition percentages of raw materials.

Raw Materials	Composition (% weight)			
Fly Ash	95%	80%	60%	40%
Rice Husk Ash	0%	15%	35%	55%
Bentonite (Binder)	5%	5%	5%	5%

Table 2. Design for bricks production

Sample	Production Parameters			Mechanical Properties			
	% Fly Ash Utilization	Firing Temperature (°C)	Firing Time (Hours)	Compressive Strengths (psi)	Water Absorption (%)	Saturation Coefficient	Abrasion Resistance
1	80	800	6				
2	60	800	8				
3	60	800	4				
4	40	800	6				
5	95	800	4				

Mechanical Properties Tests for the Produced Fly Ash/Rice Husk Ash Bricks

The resulting mechanical properties of the bricks should suit to the standard specifications provided by ASTM C 902 which stipulates the standard mechanical properties of bricks that can be used for pedestrian and light traffic applications. These mechanical properties are the compressive strength, water absorption, saturation coefficient and the abrasion resistance.

Compressive Strength

The compressive strength tests of the FA/RHA bricks were performed following the ASTM C 109 procedure (using 2-inch cube) at the Department of Public Works and Highways (DPWH) Bulua, Cagayan de Oro City, Misamis Oriental. Each sample was placed carefully in the testing machine below the center of the loading block and loads were applied on faces that were in contact with the true plane surfaces of the mold. From the recorded maximum load, the compressive strength in Megapascal (MPa) was calculated as the ratio of the maximum load (N) to the area of loaded surface (mm^2).

Water Absorption

Water absorption test was done using IS 3495. The samples were dried in a ventilated oven at 105 °C to have constant masses. The samples were then cooled at room temperature and be weighed as w_1. Completely dried samples were immersed in clean water at temperature 27 ± 2 °C for 24 hours. The samples were then removed and traces of water will be wiped out with a damped cloth and weighed as w_2. Water absorption was calculated as the percentage in (w_2-w_1) over w_1.

Saturation Coefficient

Saturation coefficient is the ratio of absorption by 24-hour submersion in cold water to that after 5-hour submersion in boiling water. The bricks were submerged but this time in boiling water at 5 hours. Then, the water absorptions for these samples were calculated. After that, saturation coefficients were computed (ASTM C 902).

Abrasion Resistance

Pavement bricks are exposed to the continual abrasive effect of pedestrian and vehicular traffic. Abrasion resistance is a measure of the resistance of paving brick to the wearing action due to traffic. The abrasion index was calculated by dividing the 24-hour cold water absorption by the compressive strength (units of psi) and then multiplying by 100 (ASTM C 902).

Surface Morphological Characterizations of the Produced Fly Ash/Rice Husk Ash Composite Materials

Surface morphological characteristics for the produced bricks were obtained using Scanning Electron Microscopy (SEM) at 500 X, 2,000 X, 5,000 X and 15,000 X magnifications, respectively at the Chemistry Analytical and Research Laboratory, Ateneo de Davao University, Davao City, Philippines to view the structures and orientations of the combined fly ash and rice husk ash particles. This was conducted along with Energy Dispersive Spectroscopy (EDX) to obtain elemental analyses of one point in the micrograph.

Results and discussion

Table 3 below shows the physical characteristics of samples of fly ash and rice husk ash. As shown in the table, fly ash sample has lesser% moisture having 0.09% compared to that of rice husk ash. Rice husk ash is denser than the fly ash with a specific gravity of 5.34 compared to 3.53 of fly ash. Rice husk ash has 25.65% absorption compared to 2.47% only for fly ash. Further, colors of fly ash and rice husk ash were determined as brownish black and gray, respectively.

Table 3. Physical characteristics of fly ash and rice husk ash.

Physical Characteristics	Sample	
	Fly Ash (FA)	Rice Husk Ash (RHA)
Moisture Content (%)	0.09340	3.66832
Specific gravity	3.53569	5.34921
Absorption (%)	2.47902	25.65808
Color	Brownish black	Gray

Table 4 below shows the oxide analyses of both fly ash and rice husk ash samples conducted thru X-ray

Fluorescence (XRF) technique. As shown in the table, the fly ash sample is rich with SiO_2 (48.42%), Al_2O_3 (15.07%), Fe_2O_3 (12.93%) and CaO (10.31%). On the other hand, the rice husk ash is rich mainly of SiO_2 which amounts to 90.77%. Based on what is implied at the ASTM C 618, the fly ash is a Class F type since the total amount of SiO_2, Al_2O_3 and Fe_2O_3 is 68.94%, which is greater than 70%. This implies that said fly ash is pozzolanic. In the same way, the rice husk ash sample is also a Class F type because the total amount of SiO_2, Fe_2O_3 and CaO is 91.34% and thus, pozzolanic.

Table 4. X-ray Fluorescence (XRF) analyses of fly ash and rice husk ash

Raw Material	Chemical Composition (%)										
	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	P_2O_5	TiO_2	Na_2O	K_2O	MnO
Fly Ash	48.42	15.07	12.93	10.31	6.95	0.78	1.07	0.658	1.50	0.713	0.137
Rice Husk Ash	90.77	0.33	0.24	0.90	1.03	0.40	1.45	-	0.50	1.52	-

Fig. 1.1 below shows the SEM morphologies of the fly ash sample at 1,000X, 3,000X, 8,000X and 10,000X magnifications. It is clearly shown in these morphologies that fly ash is made up predominantly of spherically-shaped particles (Khairul Nizar *et al.*, 2014; Davidovits, 2011; Bada and Potgieter -Vermaak, 2008). On the other hand, Fig. 1.2 below shows the SEM morphologies of the rice husk ash sample. Based on the morphologies, it can be observed that rice husk ash particles are irregularly-shaped particles. Same findings were obtained also by Kazmi *et al.* (2016) and Eliche-Quesada *et al.* (2017).

(a) (b)

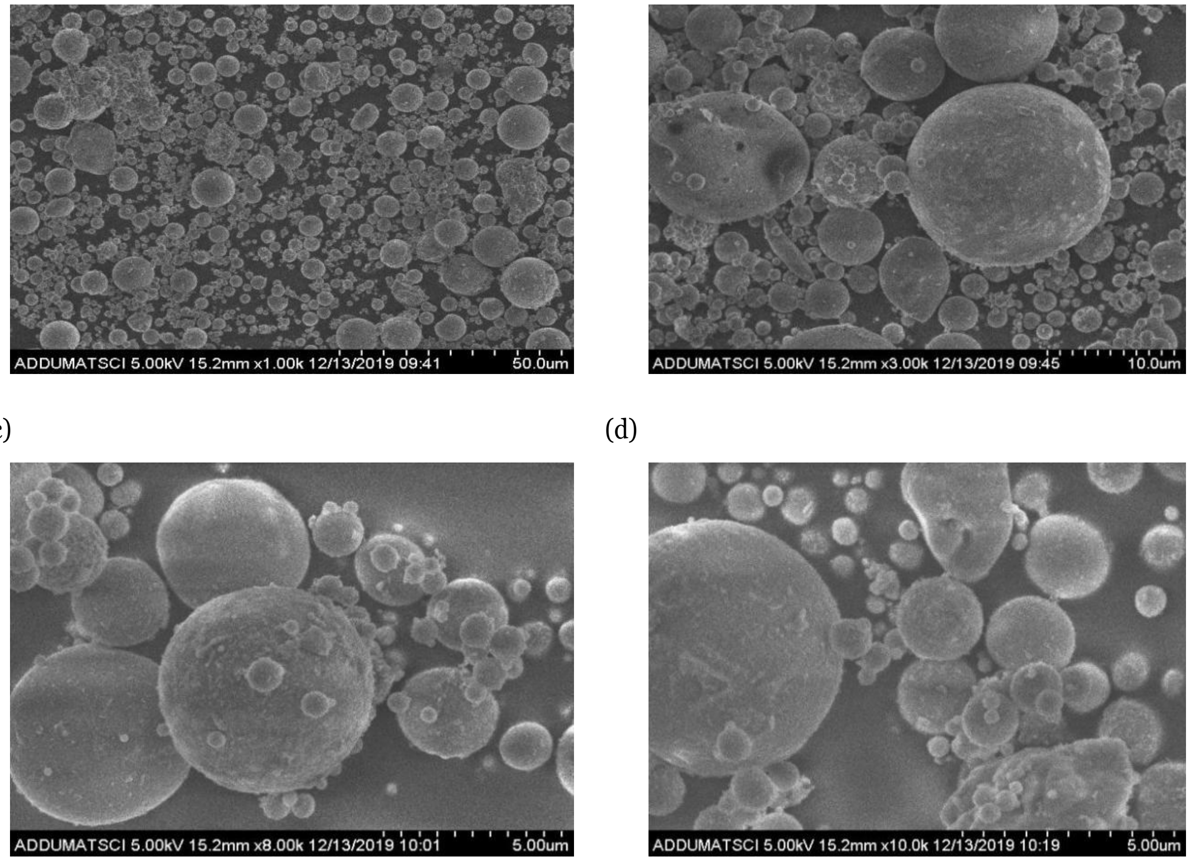


Fig. 1.1. (a) SEM Morphology of the Fly Ash Sample at 1000 X magnification, (b) SEM Morphology of the Fly Ash Sample at 3000 X magnification, (c) SEM Morphology of the Fly Ash Sample at 8000 X magnification and (d) SEM Morphology of the Fly Ash Sample at 10, 000 X magnification.

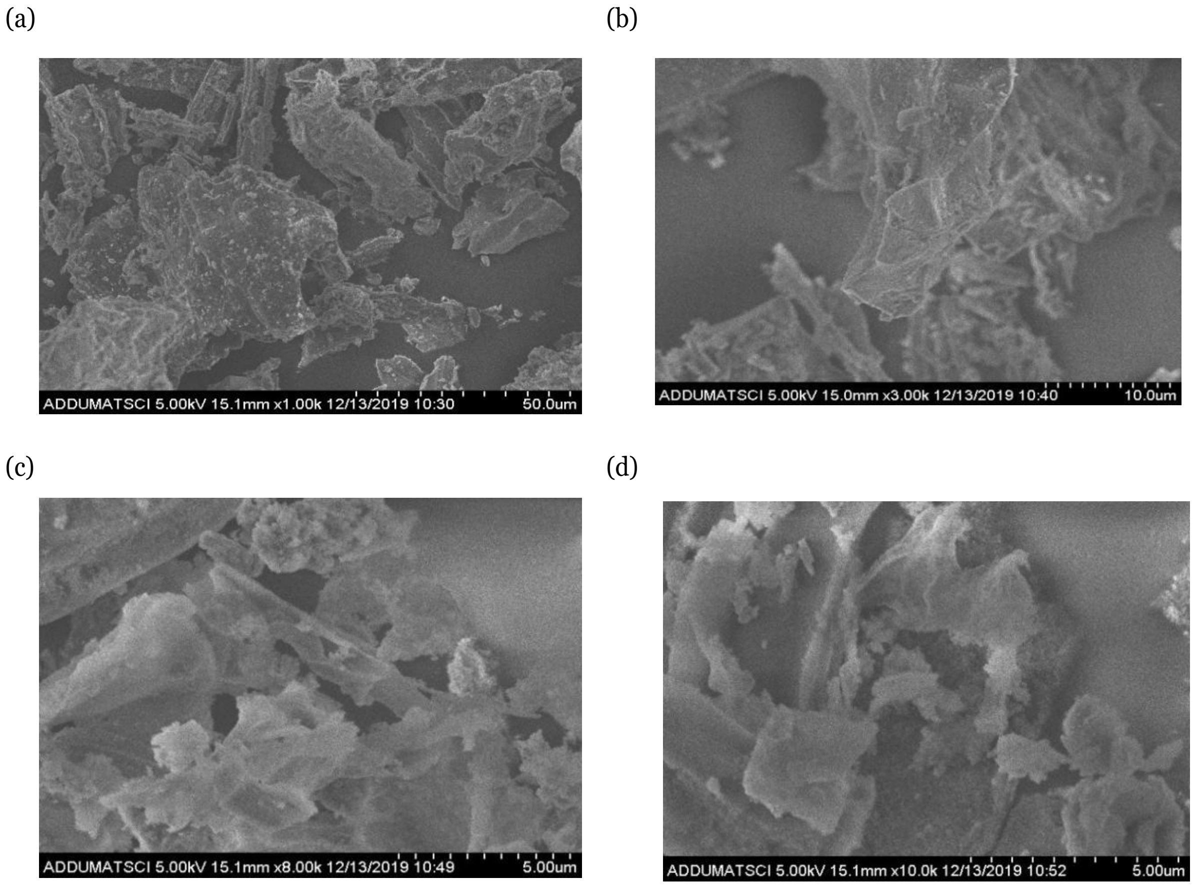


Fig. 1.2. (a) SEM Morphology of the Rice Husk Ash Sample at 1000 X magnification, (b) SEM Morphology of the Rice Husk Ash Sample at 3000 X magnification, (c) SEM Morphology of the Rice Husk Ash Sample at 8000 X magnification and (d) SEM Morphology of the Rice Husk Ash Sample at 10, 000 X magnification.

The Energy Dispersive X-ray Spectroscopic (EDS) analyses of both fly ash and rice husk ash samples are shown in Fig.s 2.1 and 2.2 below. It can be observed that the EDS analysis of fly ash revealed it is mainly rich with silicon (Si) and calcium (Ca). This is in consonance with its oxide analysis in Table 4 that it mainly contains oxides of silicon (Si) and calcium (Ca) also which are SiO_2 and CaO, respectively. On the other hand, the EDS analysis of rice husk ash sample revealed presence of silicon (Si) alone. This is also in consonance with its oxide analysis in Table 3.2 which shows that it is mainly rich with silica (SiO_2).

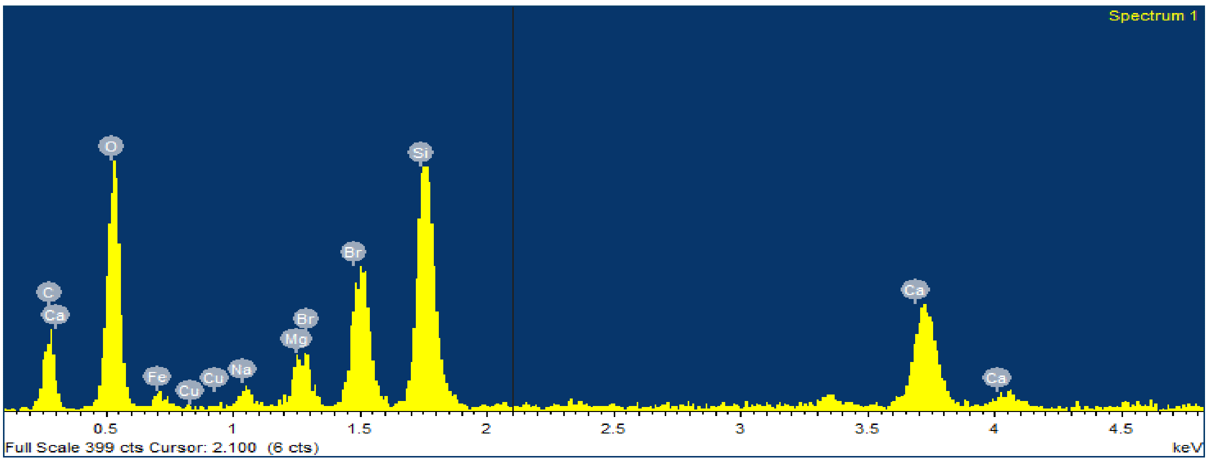


Fig. 2.1. Energy Dispersive X-ray Spectroscopic (EDS) Analysis of the Fly Ash Sample.

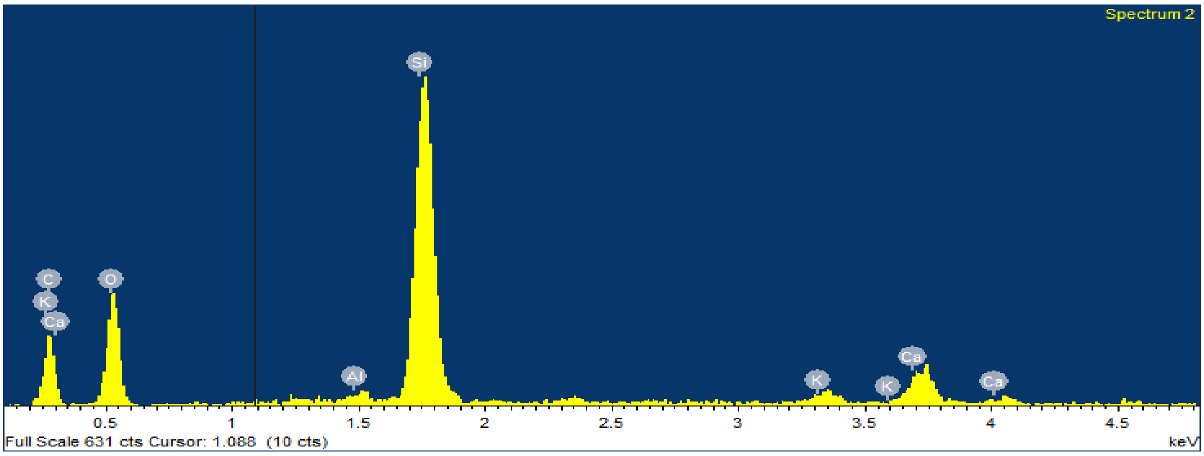


Fig. 2.2. Energy Dispersive X-ray Spectroscopic (EDS) Analysis of the Rice Husk Ash Sample.

Mechanical Properties of Fly Ash-Rice Husk Ash Paving Bricks

The compressive strengths of produced fly ash-rice husk ash paving bricks are shown in Table 5 below. These bricks were being produced with fly ash utilization up to 95%, firing temperature consistently equal to 800ºC and 4-8 hours firing time. As shown in the table, the compressive strengths range from 0.11 MPa to 1.57 MPa. The sample with the highest compressive strength was produced with 95% fly ash utilization, 800 ºC-firing temperature and 4 hours-firing time. It can be observed that compressive strengths of the bricks increase with increasing fly ash percentages. On the other hand, increasing the rice husk ash percentages decreases the compressive strengths. Further, increase of firing time resulted to no effect in the compressive strengths. The compressive strengths of the bricks are much lower compared to compressive strength standard values stipulated in ASTM C 902.

Table 5. Compressive strengths of fly ash-rice husk ash bricks

Sample	Production Parameters			Compressive Strengths (psi)	Average Compressive Strength (psi)
	% Fly Ash Utilization	Firing Temperature (ºC)	Firing Time (Hours)		
1	80	800	6	320.3521 101.1638 129.2649	183.5936
2	60	800	8	39.3415 28.1011 39.3415	35.5947
3	60	800	4	28.1011 39.3415 28.1011	31.8479
4	40	800	6	28.1011 16.8606 5.6202	16.8606
5	95	800	4	252.9096 252.9096 179.8468	228.5553

The data for water absorption of the fly ash-rice husk ash bricks are shown in Table 6 below. Specifically, it can be shown that increasing the fly ash percentages in the mixture decreases the water absorption results of the bricks. However, increase of rice husk ash percentages increases the water absorption results. This is because the% absorption of fly ash sample used is only 2.47%; very much lesser than that of the rice husk ash which is equal to 25.65%. Firing time results no effect for water absorption. However, such results meet standard requirement for water absorption stipulated in ASTM C 902 under Class NX.

As per ASTM C 902, Class NX bricks are bricks that are not intended for exterior use but which may be acceptable for interior use where protected from freezing when wet.

Table 6. Water Absorptions of fly ash-rice husk ash bricks

Sample	Production Parameters			Water Absorption (%)	Average Water Absorption (%)
	% Fly Ash Utilization	Firing Temperature (°C)	Firing Time (Hours)		
1	80	800	6	34.48 32.14 34.39	33.67
2	60	800	8	55.27 62.50 61.59	59.79
3	60	800	4	45.86 59.69 52.00	52.52
4	40	800	6	69.89 60.23 70.53	66.88
5	95	800	4	17.36 12.22 17.32	15.63

The Table 7 below shows the data for abrasion resistance for the produced fly ash-rice husk ash bricks. Based on the table, increasing fly ash percentages decreases the abrasion resistances of the bricks. However, increasing the rice husk ash percentages increases the abrasion resistances. Further, firing time has no effect to abrasion resistances. Results for abrasion resistance in bricks are more than the standard values found in ASTM C 902.

Table 7. Abrasion resistances of fly ash-rice husk ash bricks

Sample	Production Parameters			Abrasion Resistance	Average Abrasion Resistance
	% Fly Ash Utilization	Firing Temperature (°C)	Firing Time (Hours)		
1	80	800	6	10.7632 31.7703 26.6043	23.0459
2	60	800	8	140.4878 222.4112 156.5522	173.1504
3	60	800	4	163.1965 151.7227 185.0461	166.6551
4	40	800	6	248.7091 357.2233 1254.9375	620.2900
5	95	800	4	6.8641 4.8318 9.6304	7.1088

Saturation coefficients of fly ash-rice husk ash bricks are shown in Table 8. According to the table, increasing fly ash percentages in the production decreases the resulting saturation coefficients of the bricks. Increasing rice husk ash percentages increases such saturation coefficients. On the other hand, firing time has no effect to such saturation coefficients. According to the ASTM C 902, the data for saturation coefficients passed the standard requirements for Classes NX and MX bricks. Class NX bricks are bricks that are not intended for exterior use but which may be acceptable for interior use where protected from freezing when wet whereas Class MX are those that are intended for exterior use where resistance to freezing is not a factor.

Table 8. Saturation Coefficients of Fly Ash-Rice Husk Ash Bricks.

Sample	Production Parameters			Saturation Coefficient	Average Saturation Coefficient
	% Fly Ash Utilization	Firing Temperature (°C)	Firing Time (Hours)		
1	80	800	6	0.9994 0.8918 0.9887	0.9600
2	60	800	8	1.9557 2.3011 2.1635	2.1401
3	60	800	4	0.6964 1.9682 1.5009	1.3885
4	40	800	6	4.4264 1.8741 1.9429	2.7478
5	95	800	4	0.8717 0.7607 0.9791	0.8705

Surface Morphological Characteristics of Fly Ash-Rice Husk Ash Bricks

Fig. 3.1 below shows the SEM morphologies of the 60%FA-35%RHA brick fired for 4 hours at 500 X, 2000X, 5000X and 15,000X magnifications. In general, it can be observed from the morphologies that said brick is made up of a combination of spherically and irregularly-shaped particles. These spherically-shaped particles are the fly ash particles whereas the irregularly-shaped particles are the rice husk ash particles. This is so because fly ash particles are predominantly spherical in shape (Khairul Nizar *et al.*, 2014; Davidovits, 2011; Bada and Potgieter -Vermaak, 2008) whereas rice husk ash particles are irregular in shape (Kazmi *et al.*, 2016; Eliche-Quesada *et al.*, 2017). Specifically, it can also be observed in both 5000X and 15,000X magnifications that spherically-shaped particles are more predominant than irregularly-shaped particles. This is because this brick was manufactured with 60% fly ash which is greater than that of 35% rice husk ash.

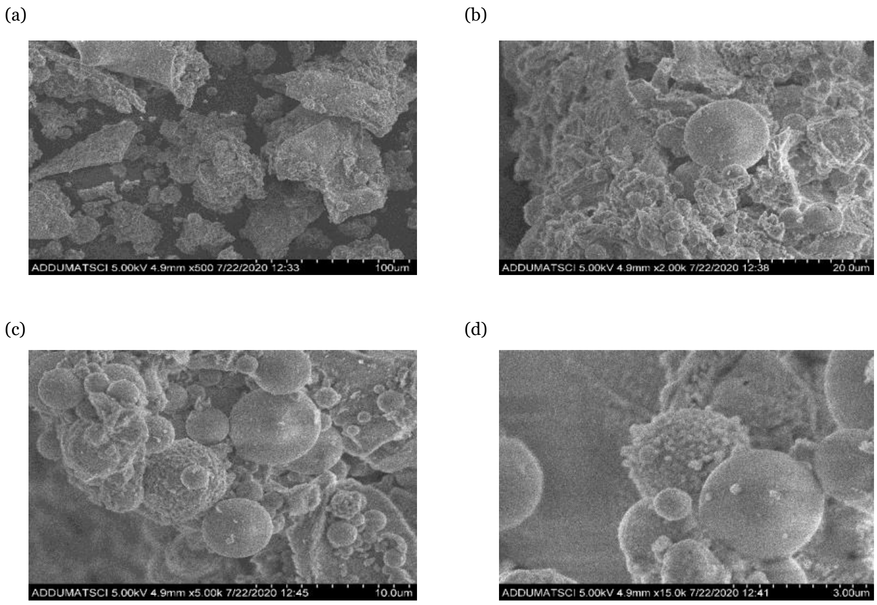
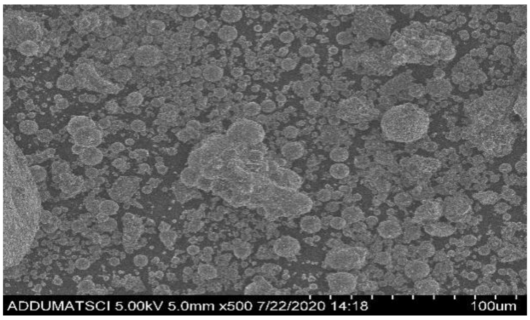
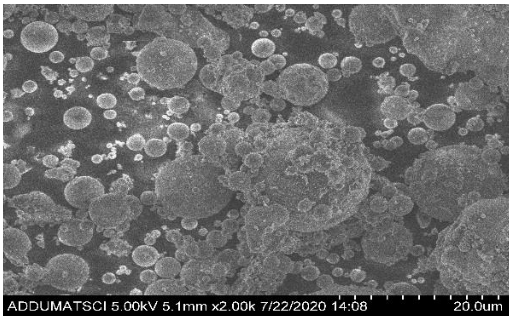


Fig. 3.1. (a) SEM Morphology of the 60%FA-35%RHA Brick fired for 4 hours at 500 X magnification, (b) SEM Morphology of the 60%FA-35%RHA Brick fired for 4 hours at 2,000 X magnification, (c) SEM Morphology of the 60%FA-35%RHA Brick fired for 4 hours at 5,000 X magnification and (d) SEM Morphology of the 60%FA-35%RHA Brick fired for 4 hours at 15,000 X magnification.

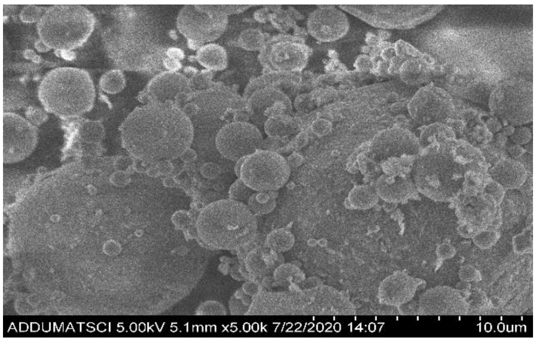
(a)



(b)



(c)



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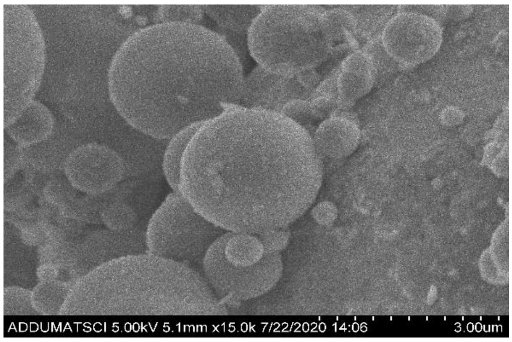

Fig. 3.2. (a) SEM Morphology of the 95%FA-0%RHA Brick fired for 4 hours at 500 X magnification, (b) SEM Morphology of the 95%FA-0%RHA Brick fired for 4 hours at 2,000 X magnification, (c) SEM Morphology of the 95%FA-0%RHA Brick fired for 4 hours at 5,000 X magnification and (d) SEM Morphology of the 95%FA-0%RHA Brick fired for 4 hours at 15,000 X magnification.

Fig. 3.2 above shows SEM morphologies of the 95%FA-0%RHA brick fired for 4 hours at 500X, 2,000X, 5,000X and 15,000X magnifications. Based on the morphologies below, it can be shown that the predominant particles are the spherically-shaped particles of the fly ash sample. This is so because said brick had no rice husk ash component.

Fig. 3.3 below shows SEM morphologies of the 80%FA-0%RHA brick fired for 6 hours at 500X, 2,000X, 5,000X and 15,000X magnifications. The morphologies show combinations of spherically and irregularly-shape particles. Thus, said brick is really made up mainly of fly ash and rice husk ash. Specifically, since said brick was manufactured at 80%FA and 15%RHA, it can be observed that spherically-shaped particles are more predominant than these irregularly-shaped particles.

Fig. 3.4 below shows the SEM morphologies of 40%FA-55%RHA brick fired for 6 hours at 500X, 2,000X, 5,000X and 15,000X magnifications. In general, the morphologies show that bricks are composed of spherically- and irregularly-shaped particles. Specifically, it can be shown in all magnifications that irregularly-shaped particles are more predominant this time. This is because% utilization of rice husk ash is greater than that of fly ash in the production.

Fig. 3.5 below shows the SEM morphologies of the 60%FA-35%RHA brick fired for 8 hours at 500X, 2,000X, 5,000X and 15,000X magnifications. In general, it can be shown that said brick is composed of mainly spherically- and irregularly-shaped particles. However, spherically-shaped particles are more predominant that these irregularly-shaped particles. This is because the% utilization of fly ash during the production was greater than that of the rice husk ash. Said brick sample has similar findings as the first sample although they differ with firing time applied. This imply that firing time may not have an impact at all as shown previously in the numerical results of the resulting mechanical properties.

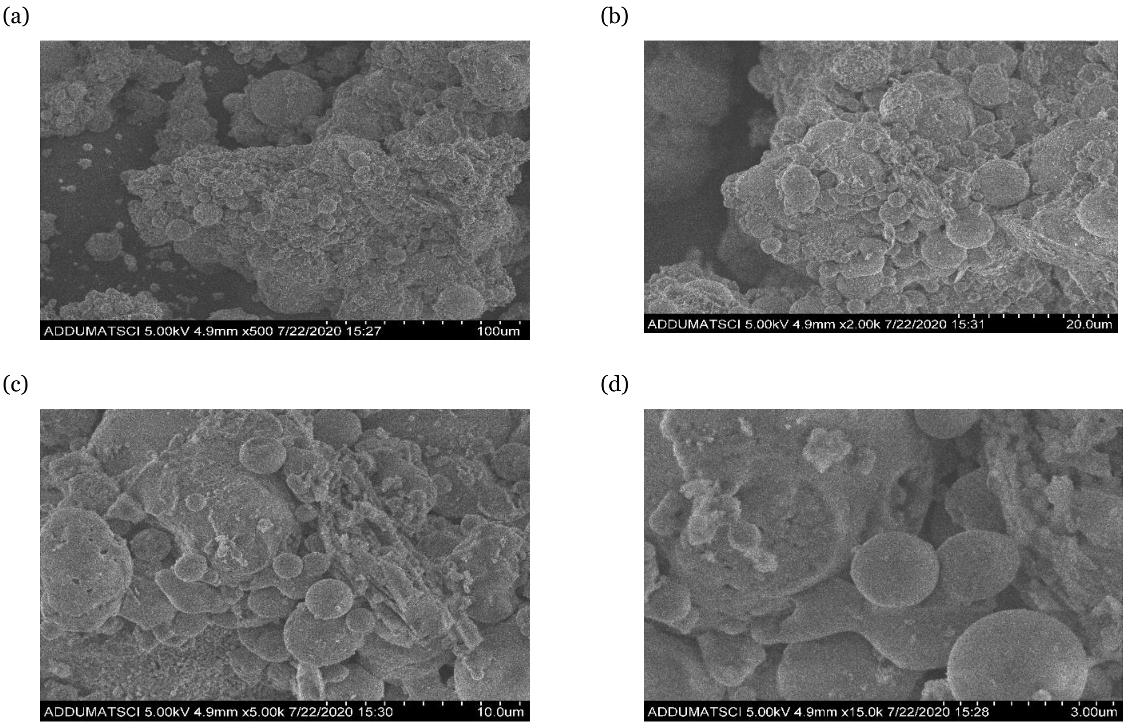

Fig. 3.3. (a) SEM Morphology of the 80%FA-15%RHA Brick fired for 6 hours at 500 X magnification, (b) SEM Morphology of the 80%FA-15%RHA Brick fired for 6 hours at 2,000 X magnification, (c) SEM Morphology of the 80%FA-15%RHA Brick fired for 6 hours at 5,000 X magnification and (d) SEM Morphology of the 80%FA-15%RHA Brick fired for 6 hours at 15,000 X magnification.

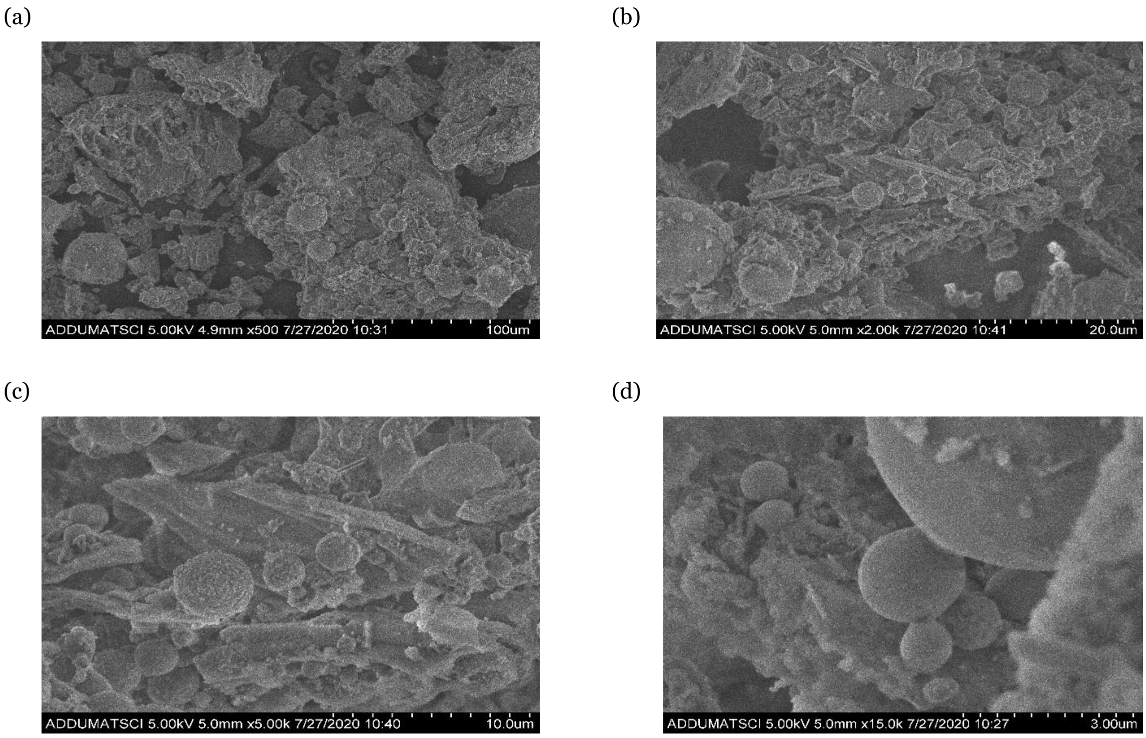

Fig. 3.4. (a) SEM Morphology of the 40%FA-55%RHA Brick fired for 6 hours at 500 X magnification, (b) SEM Morphology of the 40%FA-55%RHA Brick fired for 6 hours at 2,000 X magnification, (c) SEM Morphology of the 40%FA-55%RHA Brick fired for 6 hours at 5,000 X magnification and (d) SEM Morphology of the 40%FA-55%RHA Brick fired for 6 hours at 15,000 X magnification.

(a) (b)

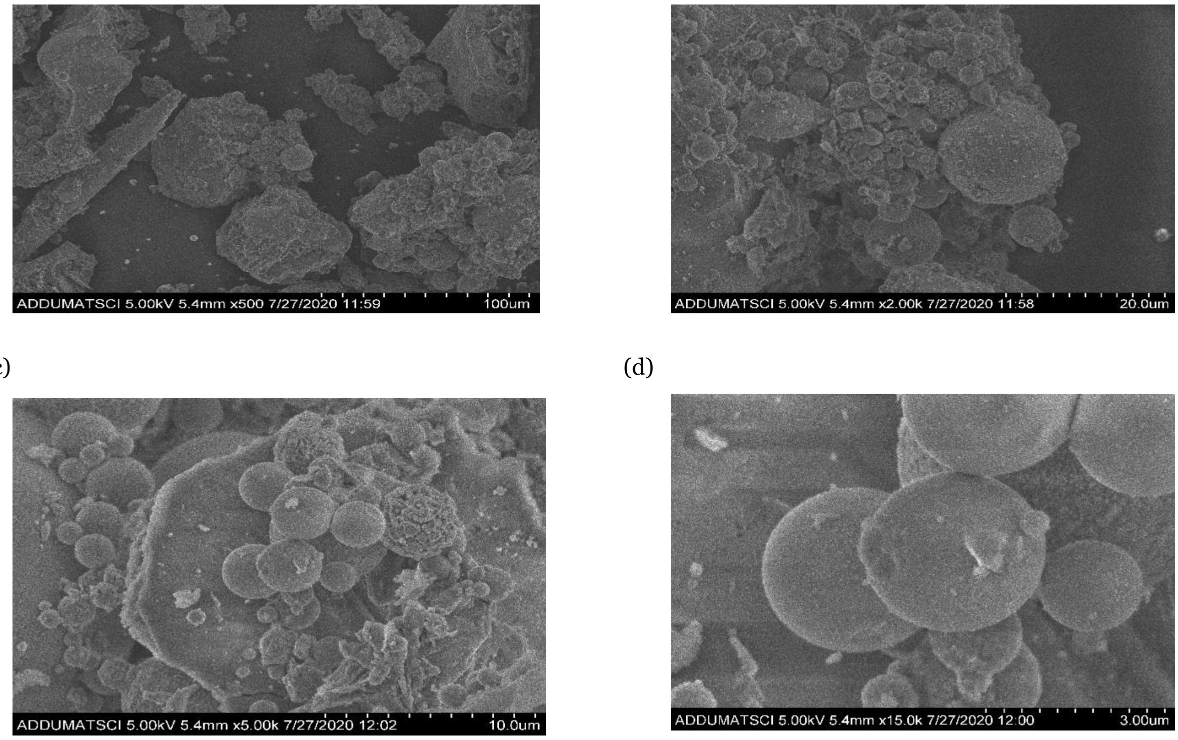

Fig. 3.5. (a) SEM Morphology of the 60%FA-35%RHA Brick fired for 8 hours at 500 X magnification, (b) SEM Morphology of the 60%FA-35%RHA Brick fired for 8 hours at 2,000 X magnification, (c) SEM Morphology of the 60%FA-35%RHA Brick fired for 8 hours at 5,000 X magnification and (d) SEM Morphology of the 60%FA-35%RHA Brick fired for 8 hours at 15,000 X magnification.

Conclusions and Recommendations

From the experimental results, it can be concluded that the bricks, which have been produced mainly of FA and RHA as evident by the predominant spherically- and irregularly- shaped particles shown by SEM, cannot be used for pedestrian and light traffic purposes as the mechanical properties did not meet the ASTM C 902 standard specifications completely. However, in the mechanical properties, it is observable that increasing FA percentage in the production increased the compressive strength of the bricks but decreased water absorption, abrasion resistance and saturation coefficient. Increasing RHA percentage decreased the compressive strength of the bricks but increased the other mechanical properties. Firing time had no effect at all. It can be recommended to use higher firing temperature, say 900° to 1000° C, and to use other parameters such as such as % water added, number of days of air drying, pressing pressure among others in the production of bricks; then compare the resulting mechanical properties of the produced bricks with the results of this study. It can also be recommended to conduct US EPA 1311 method or the Toxicity Characteristics Leaching Procedure for the FA-RHA bricks to assess if they are environmentally-safe to use or not for other construction purposes.

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