Alternative biomass furnace wall material from biomass furnace ash

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Abstract: Biomass furnace ash (BFA) generated from drying of grains in mechanical dryers were blended with cement in varying ratio of 1:4, 1:5, 1:6, 1:7 and 1:8 by volume. Each composition was cured in an ambient condition for 7, 14 and 28 days and determined their properties such as density, porosity, compressive strength and thermal shock resistance. Cold crushing strength increased with increasing cement content and curing time. Likewise, density increased with increasing cement content and curing time while porosity showed the other way. All the sample compositions exceeded 30 cycles without any crack when subjected to thermal shock resistant cycles of heating and cooling using a firing temperature of 1000°C in an electric muffle furnace.

Keywords: biomass, rice husk, ash, furnace, mechanical dryer

Citation: Flores, E. D., R. P. Gregorio, and A. E. Badua. 2017. Alternative biomass furnace wall material from biomass furnace ash. Agricultural Engineering International: CIGR Journal, 19(1): 50–55.

1 Introduction

Rice husk is one of the most generated agricultural wastes in the rice producing countries all over the world. Asia alone produces 770 million tons of rice husk from which about 193 million tons of ash can be generated annually (IRRI, 2013). These large amounts of agricultural wastes are burnt and dumped in an open field causing serious damage to the surrounding environment. Rice husk combustion in ambient atmosphere emits smoke and leaves 25 percent ash (Rao et al., 2012) as a byproduct residue that is easily swayed by wind due to its low density, giving risk to human health when inhaled and in contact with eyes. With this societal and environmental concern, some valuable application of rice husk has been done as alternative solution to its disposal problem. Rice husk has been utilized mostly as an alternative fuel for household cooking and energy, in small and large capacity boilers for processing of paddy and steam generation, in brick kilns and furnaces (Kumar et al., 2012; Chungsangunsit et al., 2009).

In Philippines, the use of biomass furnace in mechanical drying of grains and other agricultural crops has been valued by farmers because of its lower fuel cost compared to imported petroleum-based furnace. With this, the Philippine's Department of Agriculture (DA), through its mechanical grain drying program, has distributed more than 2500 units of mechanical grain dryers coupled with direct-fired biomass furnace to rice growing farmers' associations and cooperatives nationwide. The program has been completed but DA is expected to install more dryers and biomass furnaces in the key grain areas of the country. These biomass furnaces attached to mechanical grain dryers use rice hull as fuel.

The PHilMech biomass furnace consumes rice hull at 18.8 to 48.5 kg h^{-1} (Martinez et al., 2010) and the drying operation usually lasts for 8 to 12 h with each batch, depending on the initial moisture content and volume of the grains. Therefore, larger volume of residues after burning of rice husk in the biomass furnace is anticipated during the drying operation. The ash from the rice husk

Received date: 2016-08-08 **Accepted date:** 2016-12-08

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burned in the biomass furnace or BFA is a large volume of wastes (Dela Torre, 2011) that needs to be addressed. Alternative ways to utilize these wastes should be explored so that it can become more beneficial and valuable for other agricultural and industrial uses. Utilization of these wastes as a matrix for the development of material will further reduce its disposal problem and promote value added products while experiencing a clean environment in sustainable manner. Furthermore, the common combustion chamber of biomass furnaces for mechanical dryers (flatbed type) are made of conventional refractory concrete that normally breaks after several exposures to high temperatures during drying operation. The wall of the combustion chamber of a biomass furnace should withstand at least 760°C (1400°F) firing temperature. Beyond this firing temperature, the wall should have a multilayered lining composed of two to three layers of refractory (PNS/PAES, 2010). However, refractory is expensive and often not available in the local areas to immediately repair and replace the biomass furnace combustion chamber in case of breakdown (Flores and Martinez, 2010).

Thus, in this study, the use of BFA for the production of alternative furnace wall material which can withstand the required firing temperature for biomass furnace combustion chamber has been explored. Moreover, the effect of mixing ratio and curing time on the properties of the materials were investigated. The mixing composition and curing time which provided the best properties to use in the actual construction of combustion chamber wall for biomass furnace were determined.

2 Materials and methods

2.1 Sample preparation

Samples are collected from the rice husk burned at 650°C to 850°C inside the combustion chamber of biomass furnace during drying in flatbed dryer at PHilMech drying center, Muñoz Science City, Nueva Ecija, Philippines. Then the samples were mixed with cement in varying ratio of 1:4, 1:5, 1:6, 1:7 and 1:8 by volume. The percentage mix proportions are shown in Table 1.

Each composition was initially dry-mixed for 1 min then gradually added with water (constant water/BFA-cement ratio of 0.90 v/w is applied) and subsequently wet-mixed for 5 min (Figure 1a). Afterwards, the samples were prepared and casted in a θ 50 × 50 mm height steel mold. Demolding of the specimen was done after 24 h, then allowed to cure at ambient temperature for 7, 14 and 28 days before its characterization (Figure 1b).

Table 1 Mix proportions of sample specimen

Mixing ratio (v/v) (cement: BFA)	Materials		
	BFA, wt%	Cement, wt%	Water, vol %
1:4	54.46	45.54	90
1:5	60.00	40.00	90
1:6	66.67	33.33	90
1:7	71.43	28.57	90
1:8	75.00	25.00	90

a. Mixing of sampling specimen

b. Demolded sample specimens for analysis

Figure 1 Preparation of BFA-cement sample specimens for analysis

2.2 Sample characterization

2.2.1 Bulk density and porosity

The bulk density and porosity of the specimens were determined from their weights and dimensions. The bulk density in grams per cubic centimeter was determined by dividing the dry weight (W_d) of the specimen by its exterior or bulk volume (V_b).

The porosity was expressed as the percentage relationship between the pore volume and the bulk volume of the specimens. The pore volume (V_p) of the specimens in cubic centimeters was calculated by subtracting the dry weight (W_d) from the saturated weight (W_s). The saturated weight of the specimen was obtained after soaking the dry specimen for 12 h. The bulk density and porosity of the sample specimens were calculated using Equations (1) and (2) (ASTM, 2015).

$$\text{Bulk density} = \frac{W_d}{V_b}\text{, g cm}^{-3} \quad (1)$$

$$\text{Porosity} = \frac{V_p}{V_b} \times 100\text{, \%} \quad (2)$$

2.2.2 Cold crushing strength

Cold crushing strength was done using an Instron Universal testing machine, 5 kN capacity at the University of the Philippines Los Baños College of Engineering and Agro-industrial Technology (UPLB-CEAT), Los Baños, Laguna, Philippines. The test was done to determine the compression strength to failure of each sample specimen. The samples were placed between two plates of the compression strength tester, followed by the application of a uniform load at a speed rate of 10 mm min^{-1}. The load at which a crack appears on the sample was noted and the cold crushing strength (*CCS*) was calculated using equation (3) (ASTM, 2015).

$$CCS = \frac{Load\ to\ fracture}{Surface\ area\ of\ the\ sample}\text{, kg cm}^{-2} \quad (3)$$

2.2.3 Thermal shock resistance

The thermal shock resistance experiment was done at the physical laboratory of Agricultural Mechanization Division of PHilMech. Each sample was placed in an electrically heated furnace using a firing temperature of 1000°C (Figure 2).

Each sample was then withdrawn from the furnace and held for 10 min. The procedure was repeated until an appearance of a crack is visible. The number of cycles to cause a crack for each sample was recorded and taken as a measure of its thermal shock resistance. The firing temperature used was beyond the 760°C minimum required by PNS/PAES for combustion chamber wall lining and the actual measured temperatures inside the combustion chamber at the range of 650°C to 850°C and 700°C to 900°C for direct and in-direct fired biomass furnace, respectively (Dela Torre, 2011).

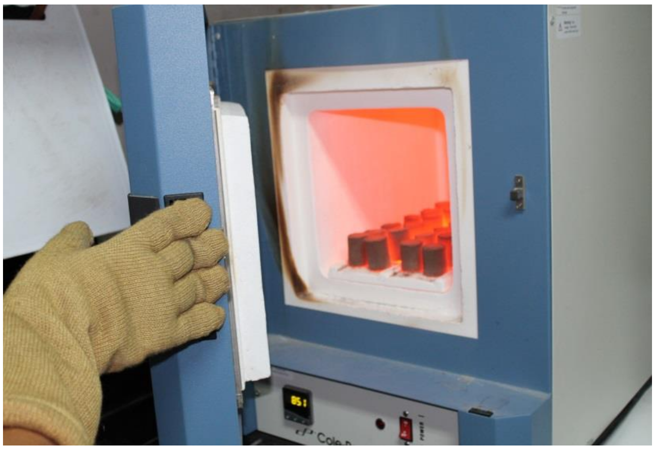

Figure 2 Thermal shock resistance experiment using electrically heated furnace

2.3 Analysis of data

Data was analyzed using multi-factor analysis of variance (ANOVA) and Duncan's multiple range test (DMRT) for the mean difference observed. Each set of data was run and evaluated using the Design Expert 8.0 software.

3 Results and discussion

3.1 Effect of curing time and mixing composition on the properties of the materials

3.1.1 Porosity

The effect of curing time and mixing composition on the porosity of the materials is depicted in Figure 3. Results showed that the increase of BFA in the mixing composition makes the material more porous. This indicates a more empty spaces or void in the mixing composition. It was also observed that higher percentage of porosity gained at early stage of curing time and tends to decrease at later curing stage. As the curing time increases, the hardening process eventually tends to fill the voids and make the pore radius finer (Kartini et al., 2015). Highest porosity of 78.16% was observed at 1:8 mixing composition with 7 days curing time while lowest porosity of 41.76% was obtained at 1:4 mixing composition with 28 days curing time.

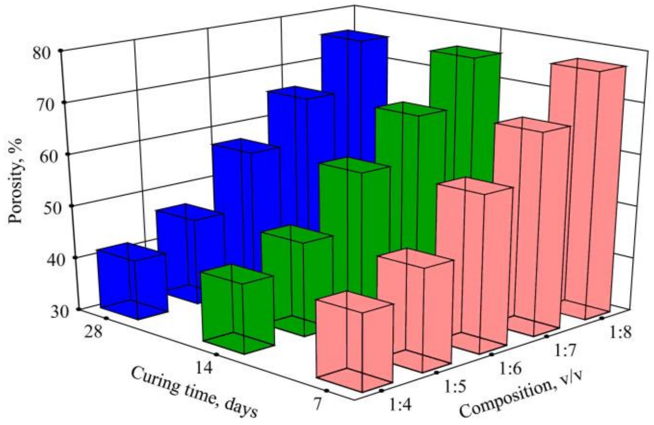

Figure 3 Effect of curing time and mixing composition on the porosity of the materials

3.1.2 Bulk density

The effect of curing time and mixing composition on the bulk density of the materials is shown in Figure 4. It was observed that the bulk density decreased with the increasing percentage of BFA and decreasing curing time.

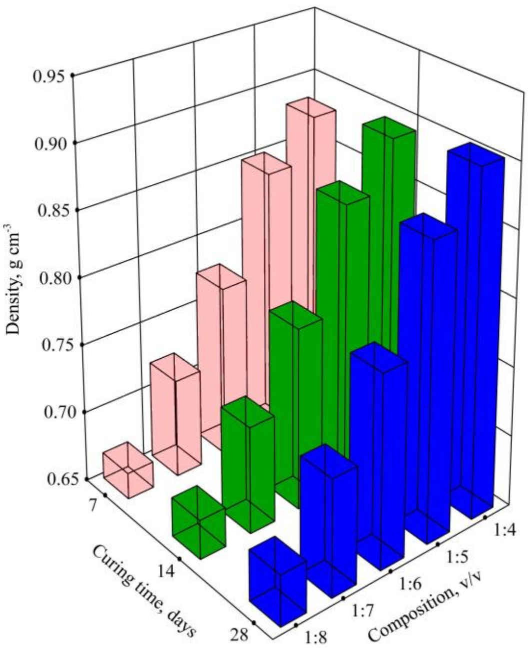

Figure 4 Effect of curing time and mixing composition on the density of the materials

The addition of biomass furnace refuse with an early stage of curing time tends to increase the porosity of the samples, as mentioned earlier. A more porous material has more voids and lesser solid matter content than material with lower porosity. Pores in the material filled with air serve as good insulator and barrier to heat. The larger the proportion of air, the greater the thermal insulation power of the material which in turn, ensures lower thermal heat conductivity and higher resistance to thermal shock load (Omotoyinbo and Oluwole, 2005; Chesti, 1986). Lowest density of 0.670 g cm^{-3} was observed at 1:8 mixing composition with 7 days curing time while highest density of 0.906 g cm^{-3} was measured at 1:4 with 28 days curing time.

3.1.3 Cold crushing strength

The effect of mixing composition and curing time against cold crushing strength of the materials is described in Figure 5. Results showed that the increase of BFA in the mixing composition with decreasing curing time implies decrease in cold crushing strength of the materials. The reduction in strength could be attributed to the decreased in density and increase in porosity with increasing biomass furnace refuse and decreasing curing time. The presence of pores in the material affects the strength due to lesser cross sectional area exposed to an applied load. A material with higher porosity are lighter and have lower load bearing capacity than one of the same material with lower porosity, because less solid material in the sample is available to carry the load. Moreover, the slight increase of strength with increasing curing time might be due to the extent of hydration process. This resulted in a larger amount of the reaction product that leads to the reduction of porosity and enhanced strength as the curing time increases (PrasanPhan et al., 2010) for all mixing composition. Highest strength of 18.95 kg cm^{-2} was observed at 1:4 mixing composition with 28 days curing time while lowest strength of 3.33 kg cm^{-2} was measured at 1:8 mixing ratio with 7 days curing time.

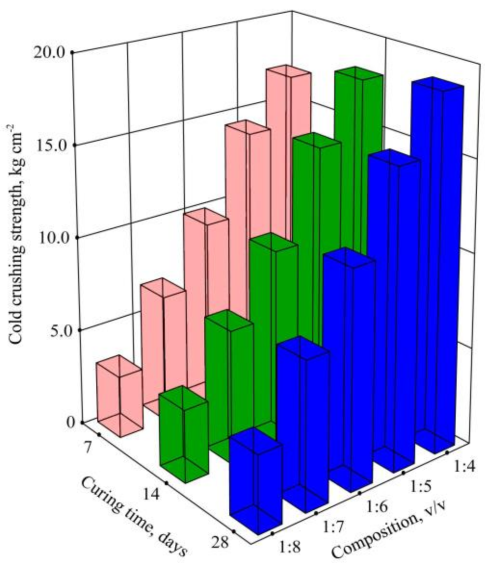

Figure 5 Effect of curing time and mixing composition on the cold crushing strength of the materials

3.1.4 Thermal shock resistance

The thermal shock resistance of the materials with five various mixing compositions and curing of 7, 14 and 28 days were determined and presented in Table 2. These materials were subjected to heat and cooling process using a firing temperature of 1000ºC. It was expected that materials with higher porosity has more resistance to thermal shock load. Results however showed that all the prepared materials exceeded 30 cycles and fell within the categorical equivalent of "excellent" based on the adopted principle in determining thermal shock resistance (Hassan, 2005). The test was stopped after each test reached 31 cycles. The variation of results might be observed if the spalling test were continued until cracks were observed for each material.

Table 2 Thermal shock resistance of materials with various mixing ratio and curing time

Mixing ratio (v/v)	Curing time, days		
	7	14	28
1:4	>30	>30	>30
1:5	>30	>30	>30
1:6	>30	>30	>30
1:7	>30	>30	>30
1:8	>30	>30	>30

Note: excellent, >30; good, 25-30; fair, 20-25; acceptable, 15-20; poor, 10-15 and very poor, less than 10.

3.2 Utilization of developed biomass furnace wall material for actual drying operation

Based on the results of the investigation, the BFA-cement mixing ratio of 1:4 and 28 days curing time was the ideal conditions used in the actual preparation of biomass furnace wall. This condition provided the material with the highest strength and enough resistant to thermal shock loads. The constructed wall of biomass furnace was attached to a flatbed dryer and used for custom drying services (Figure 6). The established mixing ratio was also used in the rehabilitation of biomass furnaces of flatbed dryers distributed under the DA rice production program.

Figure 6 Construction of wall for biomass furnace of flatbed dryer

4 Conclusions and recommendations

In this study, the use of BFA for the preparation furnace wall material combined with cement and adequate amount of water was investigated. Properties such as density, porosity, cold crushing strength and thermal shock resistance were determined and the following conclusions were drawn:

- The percent porosity of the material was observed to increase with increasing BFA content and decreasing curing time. Highest porosity of 78.16% was observed at 1:8 mixing composition with 7 days curing time while lowest porosity of 41.7% was obtained at 1:4 with 28 days curing time.
- The density (g cm^{-3}) of the material was observed to decrease with increasing BFA content and decreasing curing time. Highest density of 0.906 g cm^{-3} was obtained at 1:4 mixing composition with 28 days curing time.
- The cold crushing strength (kg cm^{-2}) of the material decreased with increasing BFA content and decreasing curing time. Highest compressive strength of 18.95 kg cm^{-2} was measured at 1:4 mixing composition with 28 days curing time.
- The thermal shock resistance of all the prepared materials exceeded 30 cycles of heating and cooling process using a firing temperature of 1000ºC temperature.
- Conclusively, by considering the strength and durability of the materials with enough resistance to thermal shock loads, the mixing ratio of 1:4 and 28 days curing time would be the ideal combination for the preparation of biomass furnace wall. The constructed furnace was attached to flatbed dryer and used for custom drying services around neighboring farmers' community.

To make the material stronger for more rigid applications, its density should be increased. The use of other locally available natural additives such as clay as cement replacement can also be explored for the development of refractory materials.

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