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Engineering characteristics of the compressed-stabilized earth brick

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ABSTRACT

Utilization of lime and rice husk ash for soil stabilization produced considerable strength gain and other geotechnical properties of the stabilized soils. Its application could be also superior for construction materials as compressed-stabilized earth (CSE) or unfired-brick. This paper presents the investigation result of the application of lime and rice husk for unfired brick or compressed stabilized earth. The compressive and three-point flexural strength tests including compressive strength after water submersion were carried out in this present study. The investigation results show that compressive and flexural strength of clay brick are improved by adding of lime and RHA. The best quantity of lime and RHA in this study, is obtained by ratio 1:1 of lime and RHA. The addition of sand in stabilized clay resulted in more improvement in the water retention ability.

1. Introduction

Sun-baked and fired clay bricks are conventionally used for mainstream masonry wall construction but they suffer from the rising price of energy and other related environmental problems such as high energy usage and carbon dioxide emission. The use of stabilized unfired clay bricks for masonry construction may solve these problems. The unfired clay brick technology relies on the use of an activated industrial by-product and natural clay. It is anticipated that the final pricing of the unfired clay masonry building brick will therefore be reduced. The added environmental advantages of utilizing industrial by-products in the region will further improve the region profile on sustainability. The chemical admixtures such as lime, cement, and/or fly ash are widely used as a mean of chemically transforming unstable soils into structurally sound construction foundation. In clay-bearing soils, those stabilizers induce a textural change in greater ease of compaction and handling as well as moderate improvements in the resulting strength.

Rice husk ash (RHA) is potential siliceous materials. Incineration of the rice husks is the common method to converse into RHA. Rice husks are major agricultural by-product obtained from the food crop of paddy. The existence is abundance all over many tropical countries, such as Indonesia, Thailand, Philippines, and India. Generally, it is considered a valueless product of rice milling processes. The RHA has been classified into high carbon char, low carbon ash and carbon free ash [1]. Several researches on the utilization of rice husk ash (RHA) for soil improvement have been successfully carried out to enhance geotechnical properties of various soils type [2–7]. Those researchers show significant use of the rice husk ash in combination with lime and/or cement to enhance the soil bearing capacity and geotechnical properties of soils. In cement–rice husk ash mixtures, Rahman [3] recommended a mix proportion 6% RHA–6% cement and 6% RHA–3% cement for base and sub-base materials, respectively. In the lime–rice husk ash stabilized soil, the amount of lime and rice husk ash were 6–12%, depending on the type of soils, to improve the strength and durability of the soil [5,7]. Noor et al. [8] notices that RHA addition of greater than 10% by weight does not contribute to the improvement in strength, while higher lime addition (>10% by weight) will have detrimental effects on the strength properties of the stabilized soil [9]. To obtain maximum compressive and tensile strength, the mixture ratio of rice husk to lime was designed to be 1:1 by weight [10]. Both of the lime-stabilized and cement-stabilized residual soils enhance the strength by mixing the RHA. In term of comparing the strength development, lime is the more effective stabilizing agent compared to cement [11]. The reaction between the soil and additives produce calcium silicate hydrate (CSH) gel that is responsible for the strength development in lime–RHA–residual soil. The past studies conclude that the addition of RHA enhances not only the strength but also the durability of lime-stabilized-soil.

Study on the unfired-brick or compressive stabilized earth has been carried out by several researchers [12–14]. The bricks were produced from stabilized clay with cement and/or other industrial wastes such as fly ash, or ground-granulated blast furnace slag (GBBS). The researches demonstrate that the compressive strength, flexural strength, moisture content, rate of water absorption,

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percentage of void, density and durability assessment were all within the acceptable engineering standards for clay masonry units. Reddy and Gupta [14] indicates that the use of cement–soil mortars (with 10–15% clay fraction and 15% cement) is preferable when *t* is compared to the most commonly used pure cement mortars of 1:6 proportion.

Majorly in Indonesia, especially in Yogyakarta, the rice husk ash is in abundance as by-product of traditional brick industries. The rice husk is commonly utilized in combustion process of the clay brick. This current study extends the principle of soil stabilization to the building industry for unfired clay brick making. Thus, this paper is relevant to those involved in the use of industrial by-products to improve soil and geotechnical properties, including civil and construction engineers. Furthermore, this paper may also be of interest to professionals working in developing countries. This research was addressed to the following objectives: (1) to obtain the best lime and rice husk ash mixtures for unfired-brick, (2) to investigate the water absorption of unfired brick, and (3) to study the compressive and flexural strength of the unfired-brick.

2. Methodology

2.1. Materials

The common brick materials are clay soils. In this study, the soil used was taken from the ex-farming area, in Godean, Yogyakarta, at the depth of 40–80 cm below the ground surface. The specific gravity of the soil was 2.4. The soils can be identified as organic soil that consists of 20% clay particles, 33% silt, and 47% fine sand. The particle size distribution of the soil is illustrated in Fig. 1. The consistency limits of the soil were 41%, 25%, and 16% respectively for liquid limit (LL), plastic limit (PL) and plasticity index (PI). Thus, the soil can be symbolized as *ML* or *OL* refers to Unified Soils Classification System. Since the ratio of $LL_{oven\text{-}dried}$ and $LL_{not\text{-}dried}$ is lower than 0.75, thus far, it is classified as sandy organic-clay with low plasticity.

The sand was collected from the deposit of the Merapi Volcano in Yogyakarta, Indonesia. The sand is commonly used as construction materials in Yogyakarta. The particle size distribution of sand is shown in Fig. 1. The coefficient of uniformity (C_u) and coefficient of curvature (C_c) of the sand is 4.3 and 0.6 respectively, thus it can be classified into poorly graded sand based on the Unified Soils Classification Systems with *SP* symbol.

2.2. Lime and rice husk ash

The hydrated lime was used as stabilizing agent in this research. Major chemical constituent of the lime is calcium hydroxides ($Ca(OH)_2$). To reduce the carbonation effect due to humidity, the lime was kept in the airtight plastic drum. The other stabilizing material is rice husk ash. For this research, only the gray colour ashes are collected. Then the gray ones were ground using Los Angeles abrasion machine and 40 mild steel bars with a size of 10–12 mm in diameter and 200–300 mm in length. The amount of 5 kg RHA was placed into the machine, and ground for about 3 h, which is equivalent to 5000 revolutions. This period produces suitable fineness and proper surface area of RHA respectively about 12.4% and 25 mm^2/g. The fineness of RHA was determined by particles retained on 45 μm sieve, and, the specific surface area was measured by using Blaine fineness apparatus. The test procedure was carried out as avowed in ASTM C204. [15]. The ground RHA is then transferred into a plastic bag and stored in an airtight container at room temperature to prevent atmospheric humidity absorption. Chemical composition of the RHA and lime was examined using X-ray Fluorescence method (Table 1). The RHA was comprised of 89.08% SiO_2, 1.75% Al_2O_3, 0.78% Fe_2O_3, and 1.29% CaO. According to the chemical composition as specified by ASTM C618 [16], the RHA could be classified as Class N pozzolana since the sum of SiO_2, Al_2O_3, and Fe_2O_3 was 91.61% with SO_3 of 0.01% and Na_2O of 0.85%.

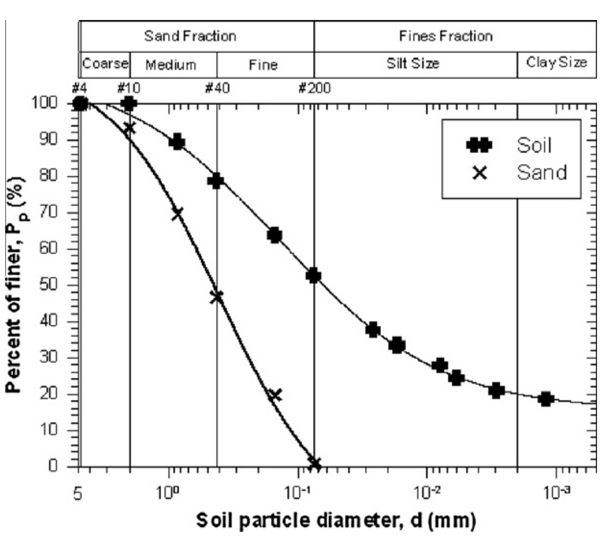

Fig. 1. Particle size distribution of the soil and sand used in the study.

2.3. Mixtures proportion and sample preparation

To reduce the effect of shrinkage, clay as the basic material of brick is commonly mixed with sand. In this study, a trial-mix of soil and sand were carried out to obtain optimum value of sand used based on their compaction characteristics. The variation of clay and sand mixtures were evaluated using standard Proctor compaction test. The optimum proportion of soil–sand mixtures is about 70% soil and 30% sand which has highest the maximum dry density among the trial-mix. The optimum moisture content and maximum dry density the soil–sand mixture are 19% and 17.4 kN/m^3 respectively. For a comparison, a clay soil specimen was also investigated.

The lime required for stabilization (LRS) was determined according to the method developed by Eades and Grim [17]. The test determines the lime-fixation which is the percentage of lime required to produce a saturated solution of lime in a suspension of soil in water and thereby to satisfy fully ion exchange. The saturation of the suspension is approached by the determination of the pH of solution, whereby a value of 12.40 indicating saturation. As a result, 5% lime is amount of lime required for stabilizing the tested soil–sand mixtures. The addition of RHA varies in this study to obtain the best lime–RHA reactivity. The ratio of lime and RHA are designed as 1:1, 1:2, 1:3, 2:1, and 3:1 by weight. Table 2 presents the tests scheme and mixture design of the research. The quantities of admixtures were prepared in the percentage of dry weight of soil.

The specimen size for the compressive strength and water absorption tests were 230 mm length by 110 mm width with the thickness of 55 mm. A beam with rectangular section of 150 mm by 150 mm specimen size and 600 mm length was prepared for the beam flexural strength test. Based on the value of maximum dry density and known volume of each specimen, the required amount of dry soil was weighed and poured into a mechanical mixer. Then the desired amount of lime and RHA thoroughly mixed with lime and rice husk ash in the mixer before the quantity of water was gradually added. The mixtures were then properly mixed for ±5–10 min. For each specimen, a constant weight of the mixed material was filled in the mould of compressive and flexural strength test respectively. Then, the raw materials were compressed in a hand-operated compression machine. The automatically controlled loading pressure of the press was 15 MPa. After the compression, the specimens were dismantled from the mould (Fig. 2) and moist-cured for 28 days by covering them with plastic sheet at the room temperature of ±30 °C. This method can prevent loss of moisture about 1–3% prior test for assuring pozzolanic reaction in the soil stabilization system.

2.4. Tests Scheme

Two major laboratory tests were performed in this study. Two specimens were prepared for each test. Compression test of the brick was carried out to determine the compressive strength of the specimens. The testing procedure was performed according to the Indonesian Standard SNI 15-2094-2000 [18] which is similar to ASTM C67-05. The three points bending flexural test was performed according to the Indonesian Standard SNI 03-6458-2000 [19] to obtain the flexural characteris-

Table 1
Chemical composition of the additives.

Constituents	RHA (%)	Lime (%)
SiO_2	89.08	0.00
Al_2O_3	1.75	0.13
Fe_2O_3	0.78	0.08
CaO	1.29	59.03
MgO	0.64	0.25
Na_2O	0.85	0.05
K_2O	1.38	0.03
MnO	0.14	0.04
SO_3	0.01	0.02
P_2O_5	0.61	0.00
H_2O	1.33	0.04
Loss on ignition	2.05	40.33

Table 2
Testing scheme and mixture design.

Proportion of materials			Specimen No.	Laboratory tests		
Clay	Sand	Lime:RHA ratio		CS	BF	WA
100%	–	–	C0	•	⦿	•
100%	–	5%:5%	C11	•	⦿	•
		5%:10%	C12	•	⦿	•
		5%:15%	C13	•	⦿	•
		10%:5%	C21	•	⦿	•
		15%:5%	C31	•	⦿	•
70%	30%	–	CS	•	•	•
		5%:5%	CS11	•	•	•
		5%:10%	CS12	•	•	•
		5%:15%	CS13	•	•	•
		10%:5%	CS21	•	•	•
		15%:5%	CS31	•	•	•

Note: •: tested, ⦿: not-tested, CS = compressive strength test, BF = beam flexural three point test, WA = water absorption test.

Fig. 2. Sample of the specimens after compacted.

tics of the specimens. The testing procedure was similar to the ASTM D1365-05. The arrangement of the specimen for the testing is illustrated in Fig. 3. The crack pattern and width were recorded to measure the modulus of rupture. The test provides values for the modulus of rupture (*MR*) of the material. The main advantage of a three point flexural test is the ease of the specimen preparation and testing. Calculation of *MR* is given as following:

If the fracture occurs within the middle third of the span length:

$$MR = \frac{PL}{bd^2} \quad (1)$$

If the fracture occurs outside the middle third of the span length by not more than 5% of the span length,

$$MR = \frac{3Pa}{bd^2} \quad (2)$$

where *MR* is flexural modulus of rupture, (kPa), *L* is span length, (mm), *b* and *d* are width and depth of test beam (mm) respectively, *a* is distance between line of fracture and the nearest support (mm), and *P* is maximum applied load (kN).

Total water absorption capacity of the brick material is established by the water absorption (*WA*) test. The dry specimens were subjected to 24 h submersion. The absorption of moisture can be determined from the moist weight of specimens after submersion as per Indonesian Standard SNI 15-2094-2000 [18]. After 28 days of moist cured, the specimens were weighed and the dimension was measured. And, they were placed in the water tank for 24 h. The amount of absorbed water during immersion was calculated using the following equation.

$$WA = \frac{M_w - M_d}{M_d} \times 100\% \quad (3)$$

where M_d is the mass of the dry specimens before submersion (g) and M_w is the wet mass of the specimen after being removed from the water tank (g).

After submersion, the wet specimens were loaded on the compression machine to undergo the compressive strength.

3. Results

3.1. Compressive strength of the stabilized earth brick

The compressive strength of the clay and clay–sand mix specimens is illustrated in Fig. 4a and b respectively. The figures also show the influence of lime and RHA ratio on the compressive strength of the soil mixtures under dry and wet conditions. Wet condition here means the specimen was subjected to waster submersion before testing, while dry specimens were situated in moist cured at room temperature. In general, the compressive strength of the dry specimens is higher than the compressive strength of the wet specimens. This characteristic demonstrates a loss of strength during submersion as presented in Table 3. The results explained that the loss of strength decreased with the increase of the lime–RHA ratio. The addition of lime and RHA increases the compressive strength, and then the compressive strength reach a maximum ratio at 1:1. After this limit, the compressive strength decreased.

In this experiment, a total mass loss was observed for untreated specimens immediately after submersion in water, whereas, the stabilized specimens retained their mass during submersion. This behaviour shows that the specimen was not durable to water immersion. Since the untreated specimens were ruined during submersion, unconfined compressive strength test could not be employed. The experiment results show that the treated clay–sand mix specimens has a higher compressive strength after submersion compared to treated-clay specimens.

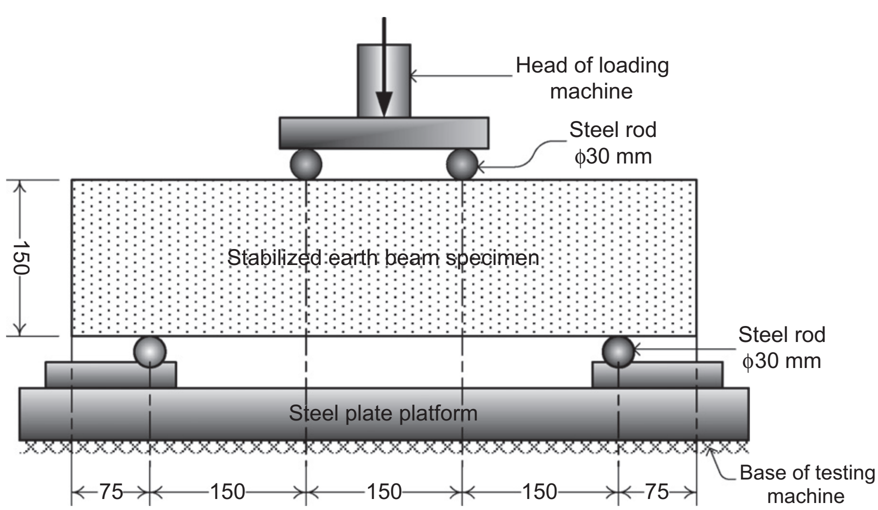

Fig. 3. Arrangement of specimen for flexural strength test.

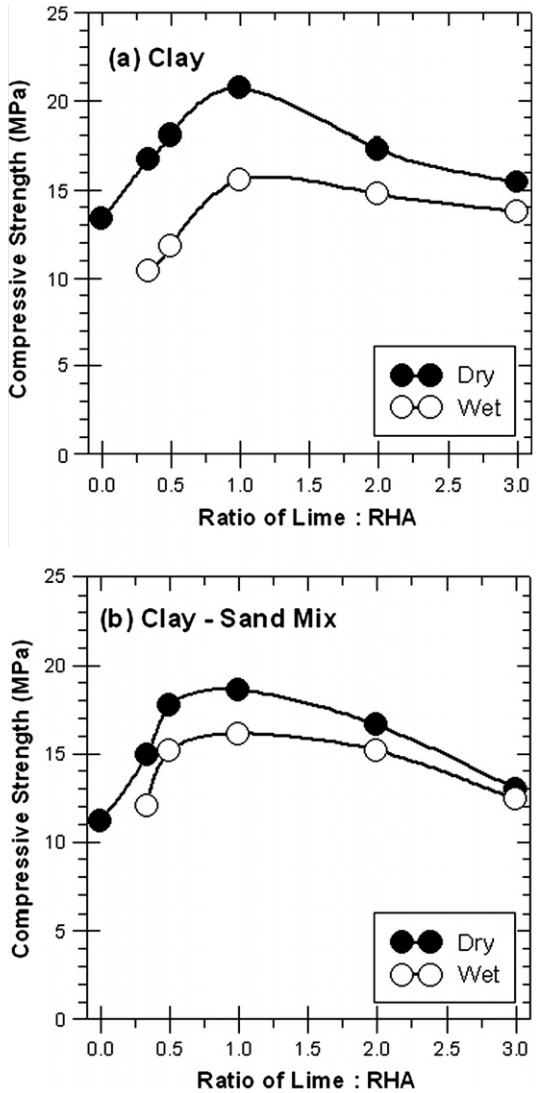

Fig. 4. Effect of lime and RHA ratio on the compressive strength (a) clay specimen, (b) clay–sand mix specimen.

Table 3
Compressive strength (MPa) and strength loss (%).

Lime:RHA ratio	Dry		Wet		Strength loss	
	Clay	Clay–sand	Clay	Clay–sand	Clay	Clay–sand
0	13.3	11.2	–	–	–	–
1:3	16.7	14.9	10.4	12.0	38	20
1:2	18.1	17.7	11.8	15.1	35	15
1:1	20.7	18.6	15.5	16.1	25	13
2:1	17.3	16.6	14.8	15.2	15	9
3:1	15.4	13.0	13.8	12.4	11	5

3.2. Water absorption of the stabilized earth brick

Water absorption test can be used as an indicator for the specimen's resistance to immersion. Fig. 5 depicts variation of the absorbed water for the stabilized clay and clay–sand mixtures which contain of lime–RHA. In general, the amount of the absorbed water decreases as the lime and RHA ratio increases. This behaviour shows that lime plays a significant role in clay and lime–RHA mixtures. For the stabilized clay specimens, the quantity of absorbed water decreases significantly, corresponding to the increases of the lime and RHA ratio. The clay–sand mix specimens show lesser water absorption than the stabilized clay specimens. This phenomenon is alluding to explain that the stabilized clay–sand mix is more impermeable than the stabilized clay specimens. The Indonesian Standard SNI 15-2094-2000 [18] requires the maximum water absorption of 20% as a standard for masonry brick. Based on the test results, all stabilized specimens with lime–RHA mixtures meet the masonry brick requirement.

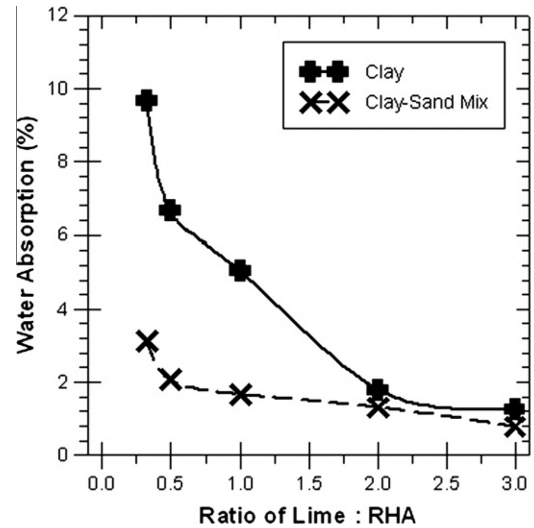

Fig. 5. Variation of amount of the absorbed water with ratio of lime and RHA.

3.3. Flexural strength characteristic of the stabilized-earth beam

It is the ability of a masonry brick, beam or slab to resist failure in bending. The typical load and deflection from beam-flexural test is shown in Fig. 6. The stabilized earth beam shows very small deflection at failure that ranges from 2 mm to 6 mm. The untreated clay–sand specimen has the lowest load carrying capacity among others, but it reaches greater deflection at failure. Addition of lime–RHA mixture enhances the load carrying capacity due to flexural. The highest flexural load is attained at lime–RHA ratio of 1:1.

In this test, most specimens undergo fracture at outside the middle third of the span length. The crack emerges from the lower support and propagates to the upper side of the one third of the span length. The area under the load and deflection curve gives the energy absorption capacity (E_a) of a specimen tested. A significant energy capacity of the load–deflection curve, is achieved by the addition of lime–RHA mixtures. Untreated specimen shows low energy absorption even when it undergoes longer displacement. The highest energy absorption is attained at the ratio lime–RHA of 1:1. The addition of RHA in lime–RHA mixtures shows a noticeable contribution as compared to the addition of lime in energy absorption of the compressed earth brick. A higher energy absorption indicates that more energy is required to develop more crack .

The other parameter obtained from the load–deflection relationship is modulus of rupture (*MR*). For a given crack width of specimen, the calculated modulus of rupture (*MR*) is illustrated in (Fig. 7). The figure shows variation of the *MR* with the ratio of lime and RHA. Addition of lime and RHA enhanced the flexural resistance, but after certain ration 1:1 of lime–RHA, the flexural resistance decreased. The relationship in (Fig. 7) shows clearly that ratio of lime and RHA at 1:1 shows the highest modulus of rupture. This result confirmed the results given in Fig. 3b, that maximum compressive strength is gained at ratio 1:1 of lime and RHA.

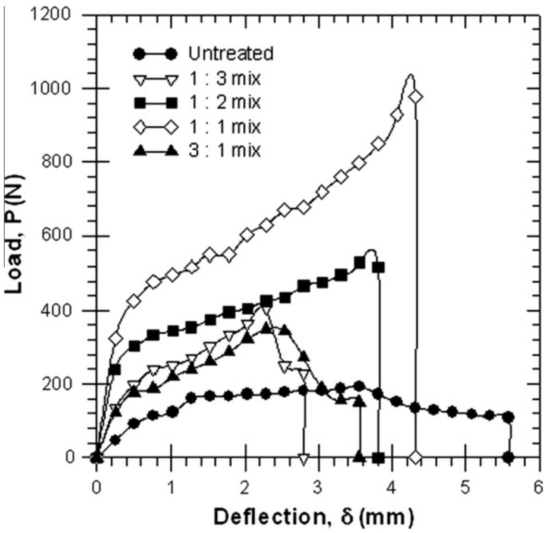

Fig. 6. Typical load–deformation result from flexural strength test.

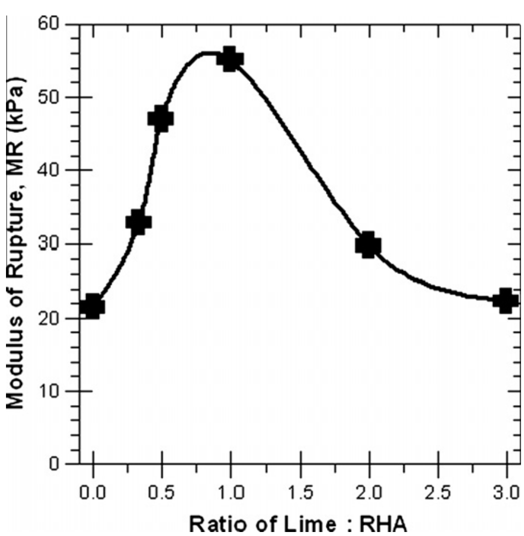

Fig. 7. Effect of lime and RHA ratio on the modulus of rupture.

4. Discussion

It is reassuring to note from the experiment results that performance of clay brick is improved by mixing its mixture with sand, and the properties are better by adding lime and RHA (Fig. 4a and b). The reason for the improved performance of the sand mixed clay is that increase the density of the specimens. In the sand–clay matrix, the sand particle size is coarser and the clay is finer; the finer particle will fill the void of the coarser particles. So, it would result in denser soil mixtures, impermeable and lesser water absorption (Fig. 5). In humid circumstance, lime and RHA consume quantities of water to react exothermically and produce cemented materials as calcium silicate hydrate (CSH). The cementitious materials will bind the clay particles together, imparting strength to the soil mixture. Muntohar [20] remarks that the reaction form bigger particles as known as flocculation–agglomeration. The CSH gel formed may also fill the void spaces and result more impermeable structure. Presence of water will increase the quantity of gel formed. This helps to bind the particles more effectively and also result in an appreciable gain in strength with the addition of RHA to the lime–soil system. RHA contains highly reactive amorphous siliceous and aluminous materials in a finely divided form. These materials, in the presence of water react with calcium hydroxide of lime during hydration to form compounds (C–S–H gel) possessing cementing properties. The reaction product responsible for the strength development in lime–RHA-residual mixture is calcium silicate hydrate [CSH] gel which after prolonged curing transforms into a more crystallized calcium silicate hydrate [4,21]. The increase in the energy absorption capacity is noticeably related to the increase in peak strength caused by cementation resulted from chemical reaction in the soil–lime–RHA systems.

As presented in the results, lime and RHA ratio of 1:1 (5% lime and 5% RHA) achieves better performance on the compressive strength and flexural resistance. For a low ratio of lime and RHA, where the quantities of RHA is higher than amount of lime in the mixtures, there is an insignificant increase in strength from addition RHA which could be due to moisture absorption (Fig. 5) render it to be inactive or due to insufficient presence of calcium in the lime–RHA system. The unreacted RHA will be abundant in the lime–RHA system. Increasing the quantity of lime in the mixtures may improve the RHA binding capacity and it may also result in increase of the compressive and flexural strength. Various lime–RHA ratio have been reported [21,22] as optimum for developing maximum strength and widely varying strength. Depending to the many factors such as degree of alkalinity or pH, reactivity index of RHA, mostly the optimum lime–RHA ratio ranges from 1:1 to 1:2. Noor et al. [8] mentioned that greater RHA addition contributes little improvement in strength. Decreasing of compressive strength and flexural strength properties for higher lime–RHA ratio could be affected by detrimental effect of lime unreacted lime as portlandite formation. The compound results in the reduction of mechanical resistance and the increase of the porosity [9,21]. Even if the porosity increases, the water absorption decreases (Fig. 5) since the CSH gel binds the soil particle to be more impermeable.

5. Conclusion

The results obtained suggest that there is a potential for the use of blended binders with clay for the manufacture of unfired clay materials in the building industry and various stabilized soil applications. There is a potential in using blended binders for the making of unfired clay bricks. The strength characteristics of the unfired clay bricks were improved by the presence of both lime and RHA whose combined action strongly bound the soil particles. Adding sand to the mixing materials in stabilized clay resulted in more improvement in the water retention ability of brick. The following conclusions are therefore drawn from the laboratory investigation carried out:

1. Performances of clay brick in compressive and flexural strength improved by mixing the mixture with sand, and they become better by adding lime and RHA. The optimum quantity of lime and RHA to gain highest strength, in this study, is obtained at the ratio 1:1 of lime and RHA.
2. The addition of lime and RHA mixture ratio decreased the ability of the compressed stabilized earth to absorb water. The compressed-stabilized earth meets the requirement of the Indonesian Standard SNI 15-2094-2000 for production of brick.
3. In general, the compressive strength due to submersion in water remains 62–95% of the normal (dry) compressive strength specimen.

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