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The Effects of Raw Rice Husk and Rice Husk Ash on the Strength and Durability of Adobe Bricks

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Abstract

Adobe houses are an important form of housing among many low income communities in developing countries. Unfortunately one drawback of adobe bricks is that their strength and durability against water are poor, which can lead to material deterioration and structural collapse. To improve the properties of adobe, the soil used to build bricks is sometimes stabilized with either natural or artificial additives. Rice husk is a natural additive commonly used in both raw and ash form as a stabilizer for several masonry materials due to its pozzolanic property. This study investigates and compares the influence of Raw Rice Husk (RRH) and heap burned Rice Husk Ash (RHA) as stabilizers on the compressive strength, stability, water absorption and volumetric shrinkage of adobe specimens. Whether the stabilizer was RRH or RHA, these materials were used in the proportion of 2% of dry weight of soil. Results showed significantly improved performance for the specimens containing RRH, but none for the RHA. This suggests that the excessive burning temperature in heap reduced the cementation properties of RHA. Based on these results, the study concludes that the application of raw rice husk as a stabilizer is more effective than heap burned rice husk ash for the construction of local adobe houses in areas affected by flood and rain.

Keywords: Adobe Brick; Soil Stabilization; RRH; RHA.

1. Introduction

Adobe construction is a type of earthen construction in which sun dried bricks are laid to form the walls of houses. Since soil is often freely available, this affordable construction is the method of choice for many low-income communities in developing countries [1, 2]. For example in Sindh Province of Pakistan about 39% of all housing is adobe houses while the percentage in Peru is 60% and in India about 73% [3, 4]. People often construct these houses by roughly estimating measurements and using traditional manual techniques [5]. The adobe houses are highly vulnerable to hydrological hazards. Guha-Sapir [6] reports that approximately 57.1% of the total disaster victims in 2011 were the result of hydrological hazards, and of those hydrological hazards, 66.8% were triggered by floods. The report mentioned Pakistan, India and Thailand as some examples of countries where flooding frequently occurs.

Flooding exerts lateral forces on the vertical and horizontal elements of houses, which results in their structure being subjected to lateral displacement [7, 8]. Particularly when adobe bricks soak in flood water, then capillary action, material disintegration and swelling can occur, whereas on drying the brick shrinks [9-11]. The rains on the other hand increases the dead weight of roof which imposes the excessive compressive loads on the wall. As in Pakistan, after heavy downpours and flood in year 2010, the wall collapse and roof deformation of 45% of the mud houses was recorded due to the increased dead weight of the roof [12].

The material’s poor strength and durability are the reason behind the vulnerability of adobe houses in floods and rains

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[9-11, 13]. In order to improve adobe's strength and durability against water, the soil is stabilized either with natural or with artificial additives [11, 14]. The artificial binders such as bitumen, asphalt, cement and lime are investigated and the results showed the improvement in the properties of adobe [15, 16]. Whereas the effects of natural additives are also investigated in improving the lacking properties of adobe; studies found the positive effects of natural stabilizers on the properties of adobe [13, 17-19]. Studies also found the negative effects of natural stabilizers particularly the effects of straw stabilizer on the strength of adobe bricks [14, 20]. The Raw Rice Husk (RRH) is one type of natural stabilizer which is used to stabilize concrete and other masonry materials. RRH provides the cementation properties as it retain the siliceous materials which form Pozzolans. On the burning of RRH, the Rice Husk Ash (RHA) produces which also retain the siliceous materials [21, 22]. The form of silica in the RHA varies with the burning temperature; the temperature up to 700-800 °C produces RHA with non-crystalline silica, while on the excessive temperature, the form of silica changes to crystalline silica from non-crystalline silica. The effects of RHA depends on the form of silica, the silica in a crystalline form may provide little or no cementation properties [23, 24]. The cementation properties in the RRH and RHA improves the material-stabilizer bond which ultimately improves the strength and durability of material [22, 25].

The ratio at which RRH and RHA effectively reacts in improving the adobe's properties cannot be accurately determined. As in the study Oskouei, Afzali [26], the maximum compressive strength was obtained for the specimens containing 0.3% RRH of the soil weight. Whereas, Akinyele, Olateju [17] investigated RRH in uncrushed and crushed forms and found the maximum improvement in the properties for the specimen containing 2% uncrushed RRH, 4% medium crushed RRH and 2% fully crushed RRH. In the study Watile, Deshmukh [27], the maximum improvement in compressive strength was observed on 2% RRH and the research Lertwattanaruk and Tungsirisakul [28] found the decrease in compressive strength with the increase of RRH above 3% by weight of soil.

For the RHA, Isah [29] found the maximum increase in compressive for the specimens stabilized with 10% to 12.5% RHA by mass. Whereas, the RHA at 5%, 10% and 15% showed the reduction in compressive strength in the study conducted by Vora, Patel [30]. While the 2% RHA also showed the maximum increase in the properties of adobe in the study Agbede and Joel [31]. This suggests that the reactivity of stabilizers varies with the texture and the proportion of soil particles [32].

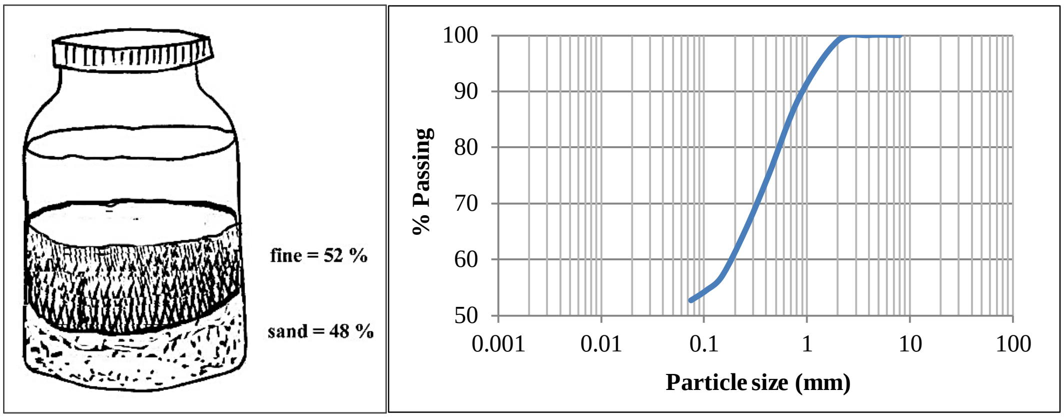
Therefore the study investigated the effects of RRA and RHA on a same soil and in a same mixing ratio to explore its influence on the adobe's strength and durability. Since the study focuses on the local adobe houses, the local methods were used to prepare stabilizers as well as the testing samples.

2. Materials and Methods

2.1. Materials Collection

The soil used for experiments was excavated from the site located in Phitsanulok province Thailand. The amount of sand was added to the excavated soil as it was found clayey with low portion of sand particles. As per field sedimentation test results, the soil after adding sand consists of 48% sand and 52% fines as shown in (Figure 1'A'). Whereas the particle size distribution graph (Figure 1'B') showing 52.7% soil passed through 0.075 mm sieve which indicates the presence on 47.3% sand in a soil. Thus for the preparation of specimens, this soil was used as it is a suitable soil for adobe brick [33].

The RRH was collected from the nearby rice mill; about 16.5% of collected rice husk 'by weight' was slightly compacted to reduce its pointed ends as shown in (Figure 2'A'). To produce the RHA (Figure 2'B'), the remaining RRH, therefore, 83.5% RRH was burnt in heap in an open field. After burning, 19.3% RHA of the weight of RRH was produced. These stabilizers were weighed by the total weight 'wt.' of dry soil and were added in the soil in a dry state; the percentage of dry soil and stabilizers in the mixture is presented in (Table 1). The water was added gradually in the dry mixture until the optimum plasticity for mixtures was observed and was kneaded manually for the proper consistency of the mixture.



(A) **(B)**

Figure 1. Soil particles and its grading (A) Sedimentation test results (B) Grading of sand particle

(A) **(B)**

Figure 2. Stabilizer rice husk (A) and rice husk ash (B) used for investigation

Table 1. The proportion of dry mixture

Group	Mixture	Dry soil (wt. %)	Stabilizers (wt. %)
G-1	Soil	100	0
G-2	Soil + RRH	98	2
G-3	Soil + RHA	98	2

2.2. Preparation of Specimens

The specimens for each experiment were cast manually from three groups of mixtures therefore G-1, G-2 and G-3. The wooden mold was used to cast 15 stacked prism specimens '5 from each mixture group' and 30 prism specimens '10 from each group of mixture'. Total of 75 prism specimens '25 from each group' were molded in the dimension of $200\times150\times100$ mm^3 and of those prisms, 45 partially dried prism specimens were used to prepare the stacked prisms of three courses. All the molded specimens of each group were dried and cured for 28 days under the semi-covered sheds at 29 (+ 5) °C average temperature and 69 (+5) % average relative humidity. The specimens at the age of 28 days were measured as presented in (Table 2) while (Figure 3) showing the cured specimens of each group.

Table 2. Mean average dimension of cured specimens

Mixture group	Dimension: L x W x H (mm³)	Volume (mm³)	CV * (%)
Stacked Prism Specimens			
G-1	174 x 127 x 254.8	5630570.4	2.10
G-2	188.2 x 135.6 x 279.2	7125161.6	1.59
G-3	190.4 x 131.4 x 262.4	6564870.1	1.55
Prism Specimens			
G-1	190.4 x 145.65 x 72.25	2003619.6	1.22
G-2	198.6 x 148.8 x 76.3	2254793.2	1.10
G-3	188.1 x 142.55 x 74.28	1990913.9	1.80

* Coefficient of Variation

G-1 **G-2** **G-3**

Figure 3. Adobe specimens at the age of 28 days

2.3. Unconfined Compressive Strength Test Method

The stacked prism specimens were prepared for unconfined compressive strength test following the procedure of 'AS-3700' as briefed in the document Australian earth building handbook [33]. The parameters of all the 15 specimens therefore, H/W ratio "refer to (Table 3)" was complied with the testing requirement and tested in compression testing machine model Tecnotest KL200 as shown in (Figure 4'A'). The speed rate of a machine was set to 0.5-1.0 Mpa/min while the load applied was even. The maximum ultimate load 'P', specimen's cross-section area 'A' and correction factor 'Ka' was computed in (Equation 1) to calculate the unconfined compressive strength 'C' in Mpa.

$$C = Ka \times (P \div A) \tag{1}$$

Table 3. Parameters of stacked prism specimens

Stacked prism	H/w ratio	Ka
G-1	2.01	
G-2	2.06	0.70
G-3	2.00	

2.4. Stability Test by Submersion Test Method

In the standing water of flood, the adobe brick soaks and disintegrates. The stability test will determine the time at which the specimen disintegrates in the standing water. This method was formerly approached to determine the stability of stabilized adobe specimens in the static water [34-36]. To determine the stability, five prism specimens from each group were submerged completely in the water. The water up to the height of 180 mm was filled in the plastic buckets of five US gallons to submerge the specimen completely in water as illustrated in (Figure 4'B'). After submersion, each specimen was assessed by three people by using their visual sense and touch sense. The 1st assessment was made after 45 minutes of submersion to check its suitability for construction [34]. The 2nd assessment was made after one hour of submersion and the rest in the interval of 24 hours until the severe deterioration was observed. Based on the assessment the specimens were rated as explained below.

- 'ND' No deterioration: When no visual and by touch damage is observed.
- 'LD' Light deterioration: When only a slight dent is observed on the specimen.
- 'MD' Moderate: When the slight dent on the specimen and the slight change in the color of water is observed.
- 'SD' Severe deterioration: When the major dent is observed on the specimen and the water becomes muddy and brown in color due to decomposition of submerged specimens.

2.5. Water Absorption Test Method

The purpose of examining the water absorption is to determine the capability of specimen in resisting the water penetration and to calculate the total volume of voids in the specimen. The lesser it absorbs the water, the less will be the volume of voids, and the more it will be considered as a durable brick. However, the absorption rate of 15% or less than 15% is applicable to be considered as a durable brick for construction [37]. To calculate the water absorption for prism specimens, the method recommended in Australian earth building handbook was followed [33]. The cured five prisms from each group were immersed in the water for 24 hours. Each plastic bucket of five US gallons weighed 0.7 kg was filled up to the level of 100 mm and the specimen was soaked in a separate bucket "refer to (Figure 4'C')". All buckets were placed under the semi covered sheds at the average temperature of 29 (+ 5) °C and 69 (+5) % average relative humidity. After 24 hours of submersion, each bucket was drilled from the bottom to drain off the water with extra care to prevent the loss of decomposed material. As soon as the water drained completely, the bucket with specimen was weighed to get the immersed weight "Wa = immersed weight with bucket – weight of bucket". All the buckets were placed at the same place under the same temperature and humidity for drying the specimens to get the optimum dry weight "Wb = optimum dry weight with bucket – weight of bucket". The percentage of water absorbed by each specimen 'W' was calculated by computing the values in (Equation 2).

$$W\% = (Wa - Wb) \div Wb \times 100 \quad (2)$$

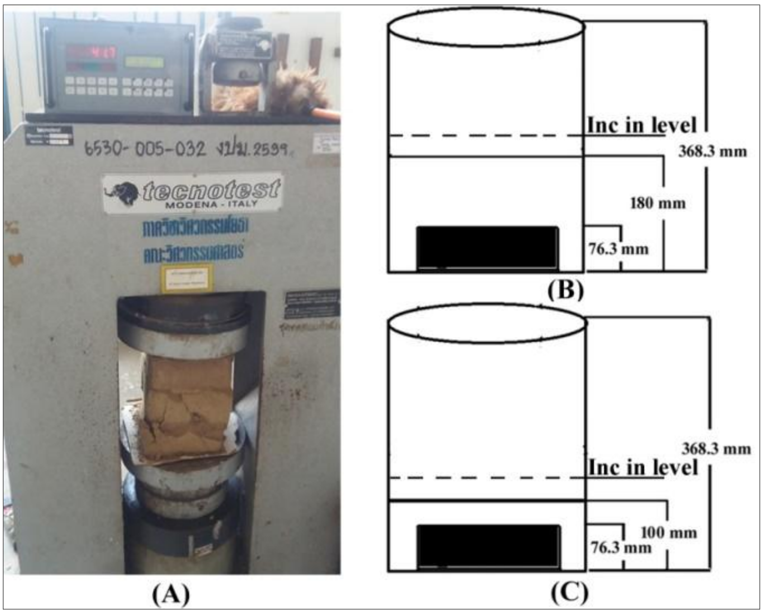


Figure 4. Experimental setup

3. Results and Analyses

3.1. Compressive Strength Test

The mean average compressive strength value of specimens from each group presented in (Table 4) showing the specimens containing RRH increased the compressive strength 'C' while the RHA stabilized specimens reduced the compressive strength 'C'. It also can be seen from the results that the RRH stabilized specimens obtained more failure strain 'Ɛc' and less modulus of elasticity 'Ec' than the un-stabilized specimens. Whereas the RHA stabilized specimens obtained the less failure strain 'Ɛc' and highest modulus of elasticity 'Ec' than the un-stabilized specimens. It indicates that the RRH has retained the positive effects on the strength and elasticity of adobe specimens. These positive effects of RRH on the adobe can also be observed from the graph (Figure 5) showing stress-strain relation under compressive load plotted for all three investigated specimens. The RRH stabilized specimen (G-2) comparatively showing the maximum increase in strain with the increasing stresses. Therefore it is deduced that; with the addition of RRH the ductility improved in the adobe specimens. While with the addition of RHA, the elasticity of specimen reduced and thus the specimen exhibited brittle nature under compressive load.

Table 4. The mean average results summary from compression test

Stacked prism	C (MPa)	σ_c (MPa)	CV (%)	Ɛc (mm/mm)	CV (%)	Ec (MPa)
G-1	1.36	1.94	2.91	0.03	6.31	64.66
G-2	1.69	2.42	2.86	0.056	6.96	43.21
G-3	1.23	1.75	1.86	0.0099	6.67	179.79

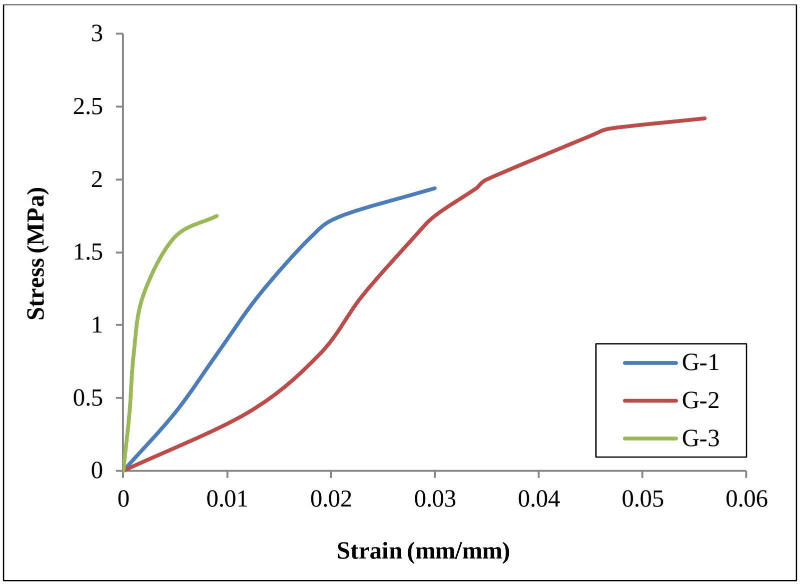


Figure 5. Stress-strain relation under compressive loads

Besides the factor of strength, the determination of compressive strength of adobe also depends on its behaviour and failure under loads [5, 38]. The specimens of each group were observed on the crack propagation on its lateral side during the application of loads as illustrated in (Figure 6). Each specimen of group G-1 exhibits the wide cracks which were perpendicular and parallel 'somehow angular' to the loads. The perpendicular crack appeared on the joint of 2nd and 3rd course which is the indication of weak joint. Whereas the cracks on the specimens G-2 and G-3 were parallel to the load and no perpendicular cracks were observed on its joint till the ultimate load.

At the ultimate load, the group G-1 and G-3 deformed in a brittle mode with very few wider cracks. The deformation observed on specimen G-3 was sudden and more severe than G-1 specimens "refer to (Figure 7)". Due to the sudden deformation of G-3, no perpendicular crack was observed on the joints of specimens. Whereas on G-2 specimens, the exfoliation was observed on the lateral side of top course, while the core of specimens remained coherent as shown in (Figure 7). From the failure of specimens under compressive loads, it is clear that the RRH increased the green strength, as a result no brittle deformation was observed under the loads. Additionally, RRH provided the stronger bond between the courses of specimens and thus no perpendicular crack appeared on the joint. The RHA on the other hand reduced the materials' resistance to compressive loads and thus the specimens deformed suddenly in a brittle mode.

The observed effect of RRH is due to the strong bond between husk fiber and soil particles which results to the efficient distribution of induced loads throughout the material matrix. From the failure mode of RRH stabilized specimen it was observed that the stabilizer RRH delayed the failure on the application of load and also the specimen did not deform completely. This is because of the flexibility of RRH stabilizer and the interaction of RRH with soil particles, with its addition the material matrix worked as a structural mesh under the compressive loads and thus prevented the specimen from complete deformation. Whereas the RHA reduced its reactivity in forming the bond with soil which results in the lower strength and complete deformation of specimen under compressive loads.

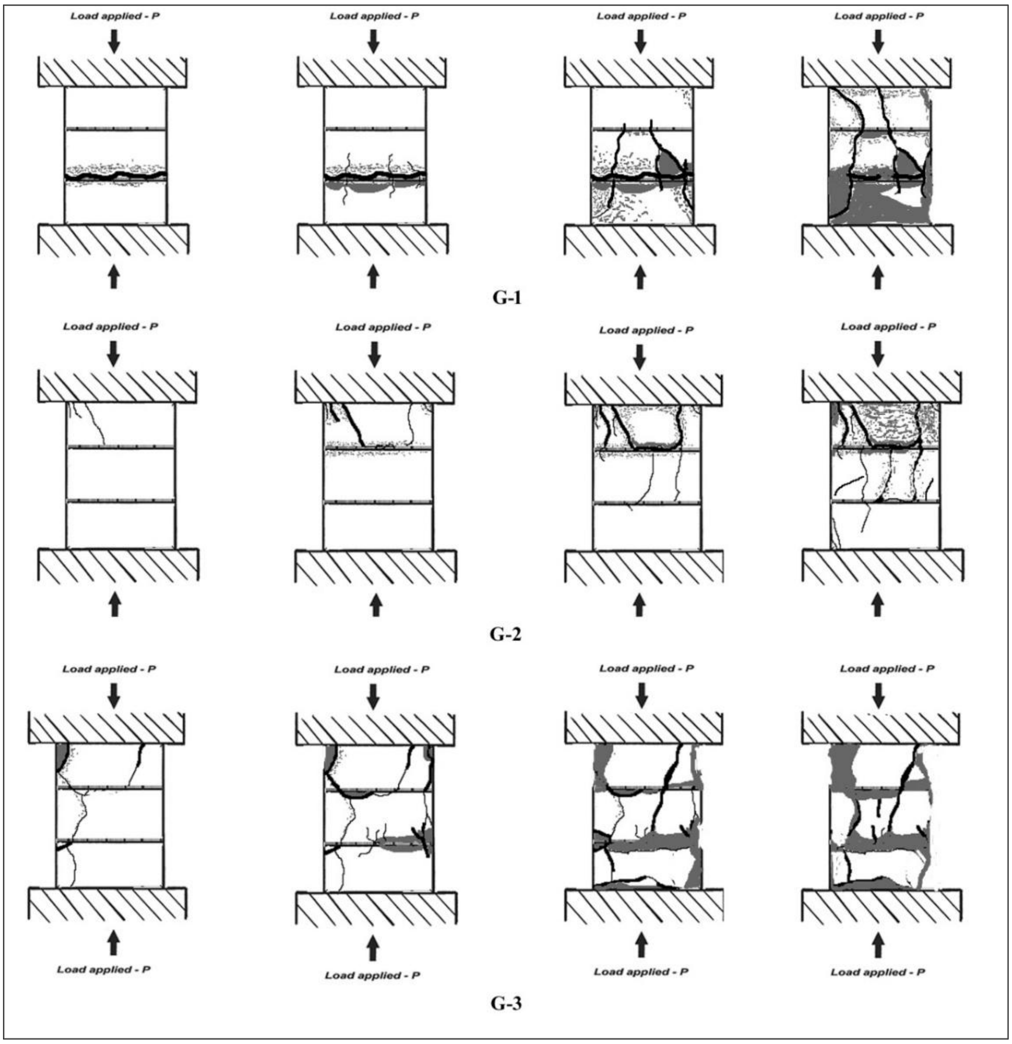
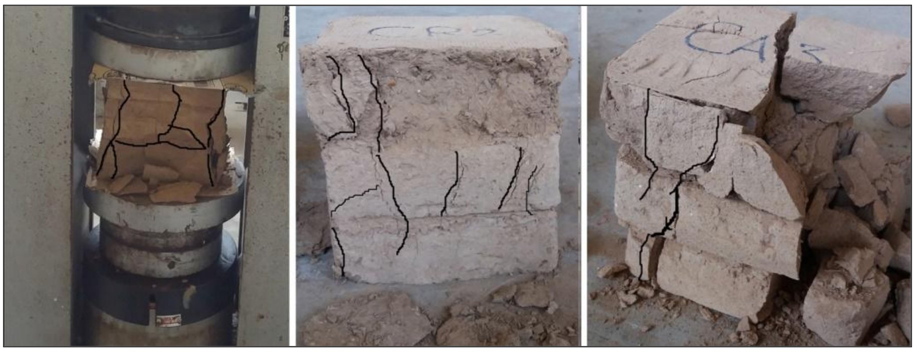


Figure 6. Cracking of specimens on the application of compressive loads



G-1 **G-2** **G-3**

Figure 7. Failure of specimens at ultimate load

3.2. Stability Test by Submersion

The mode average results of five specimens of each group presented in (Table 5) indicating the suitability of specimens G-1 and G-2 for construction as it showed no deterioration "ND" after 45 minutes of submersion. On the mean time the specimens of group G-3 showed light deterioration "LD" which indicates the ash stabilized specimens is not suitable for construction. The G-1 after one hour showed light deterioration "LD" and within 24 hours of submersion it deteriorated severely "SD". While G-2 specimens remained "ND" after one hour of submersion, it deteriorated lightly "LD" on the 1st day, moderately "MD" on the 2nd and also on 3rd day and on the 4th day, the severe deterioration "SD" was observed. Whereas, the G-3 specimens showed moderate deterioration "MD" and severe deterioration "SD" at one hour and in 24 hours of submersion respectively.

Table 5. Mode average stability test results

Assessment time	G-1	G-2	G-3
45 minutes	ND	ND	LD
1 hour	LD	ND	MD
1 day	SD	LD	SD
2 days	-	MD	-
3 days	-	MD	-
4 days	-	SD	-

The form of specimens was observed at the stage of severe deterioration after draining the water from buckets. From (Figure 8), it is clear that the un-stabilized specimens "G-1" and RHA stabilized specimens "G-3" loses its form as the specimens completely decomposed. While the RRH stabilized specimens "G-2" showing the integrated form of specimen.

The Increase in the life of RRH specimen under the static water and the appearance of its integrated form at the stage of severe deterioration indicating that, the husk fiber grasped the soil matrix together which prevent the specimen from complete deformation. From the revealed results of RHA stabilized specimens, it can be presumed that the RHA does not retain the bonding property which results in the complete disintegration of material.

G-1 G-2 G-3

Figure 8. Specimens' form at the stage of severe deterioration

3.3. Water Absorption

The water absorption "W" percentage presented in (Table 6) showing the durability for G-2 specimens as it absorbed water less than 15%. While the specimens G-3 and G-1 are not considered as a durable brick because the absorption rate is more than 15%. From the results, it is clear that the RRH reduced the volume of voids in specimens which results to the less penetration of water. The RHA reduced the volume of voids in specimens to some extent as it absorbs less water than plain soil specimens.

All the specimens were observed after 24 hours of submersion. From (Figure 9), it can be seen that the material of G-1 and G-3 specimens loses its binding property on 24 hours immersion in the water. The G-2 on the other hand remained in a molded form on 24 hours immersion in water.

From this observation it is attributed that the soil with the addition of RHA loses its bond on 24 hours soaking which indicating the RHA stabilizer is poor in binding the material matrix. However, the results of RRH stabilized specimen insuring the sufficient cementing property of RRH which provides the stronger bond to the material matrix due to this the form of specimen on submersion remained integrated. The factor of reduction in water absorption is also associated with cementing property of stabilizer. The stabilizer with good cementing property holds the soil particles together, which increases the homogeneity of materials and makes the material less porous [39]. Results indicating the good cementing property in RRH specimen, which makes the specimen less porous and thus the stabilizer prevented the specimen from the absorption of excessive water. However, the results indicating poor cementing property of RHA stabilizer as it did not increase the durability by absorbing the water more than 15%.

Table 6. Mean average results of water absorption

Prism	W (%)	CV (%)
G-1	20.63	2.83
G-2	13.61	2.57
G-3	17.69	2.73

G-1 G-2 G-3

Figure 9. The specimens' form after 24 hours of soaking

The volumes of RRH stabilized specimens after 24 hours soaking was measured to observe the swelling of material. The measurement shows the specimen's volume increased by 10.58%. Comparing the swelling percentage with the shrinkage percentage which is presented in (Table 7), it is clear that the specimen swelled less than it supposed to swell. Thus it indicates that the rice husk on soaking prevented the material from excessive swelling. Since the specimens of other groups deteriorated within 24 hours this volume was not compared with the specimens of other groups.

3.4. Volumetric Shrinkage of Prism

The volumetric shrinkage of 10 prism specimens from each group therefore, G-1, G-2 and G-3 is calculated in percentage on the shrunk volume of specimens which is given in (Table 2). From the results presented in (Table 7), it can be seen that the G-1 and G-2 obtained nearly same shrinkage percentile, while G-2 among them obtained less shrinkage percentage.

The reduction in volumetric shrinkage is because of the chemical reaction between stabilizer and clay content present in the soil which decreases the plasticity of material [40]. Based on the results, the plasticity of the soil reduced with the incorporation of RRH stabilizer. Whereas RHA showed no reaction on the plasticity of soil and thus did not contribute in reducing the shrinkage. Additionally no cracks was observed on all the group of specimens as they were cured in sheds and were covered at its early age with thin polythene sheets to prevent the specimens from rapid dry as rapid dry may lead to the shrinkage cracks [41].

Table 7. Mean volumetric shrinkage result Table

Prism	Shrinkage (%)	CV (%)
G-1	33.21	1.18
G-2	24.84	1.09
G-3	33.64	1.88

4. Discussion

The study investigated to compare the influence of raw rice husk (RRH) and heap burnt rice husk ash (RHA) on the compressive strength, stability in water, water absorption and shrinkage of adobe bricks. These stabilizers were investigated due to its known pozzolanic property. Study revealed the positive effects of RRH as it improved the bond between stabilizer and soil particles, while RHA loses the cementation property and thus showed no reaction. With the addition of RHA, the adobe specimens reduced the strength and stability. This observed effect of RHA could be due the traditional production method of RHA therefore heap burning method, where there are the maximum chances of increase in temperature above 700-800 °C and as a result, the RHA loses its binding property [24]. The heap burned RHA as a stabilizer for adobe construction due to its approachable production method could become the choice for low-income communities if it has showed the positive effects in improving the properties. Thus the RRH is recommended as a stabilizer over RHA for the construction of adobe houses.

Additionally, the results obtained in this study showing the coefficient of variation (CV) as high as 6.96 %, which is thus acceptable as the specimens were molded manually [2].

5. Conclusion

The impact of 2% rice husk and 2% heap burnt rice husk ash on the adobe's strength and durability was investigated. The field and laboratory tests were conducted on the manually prepared specimens. From the results, the conclusions drawn are as follows:

1. The rice husks improved the compressive strength, elasticity and resistance of specimens under the compressive load. On the contrary, the rice husk ash reduced the compressive strength and resistance of specimens under compressive load.
2. The specimens containing rice husk when soaked in water improved the durability of adobe as it survived four

days in the static water and reduced the capillary action by filling the pore space in adobe specimens. Whereas, the rice husk ash reduced the durability of adobe specimen as it started deteriorating within 45 minute. However the capillary action in rice husk ash stabilized specimens was observed less than the un-stabilized specimens.

3. The rice husk on soaking prevented the specimens from excessive swelling and shrinking. Whereas, the un-stabilized and rice husks ash stabilized specimens on soaking disintegrated within 24 hours and on drying, the rice husk ash showed no reactivity in increasing or decreasing the shrinkage.

4. Although the raw rice husk and rice husk ash due to the presence of silica retained the similar properties, but the stabilizers showed the opposite results. The negative results of rice husk ash are due to the formation of crystalline silica as it was produced in a heap under uncontrollable temperature.

Based on the investigation results, the study provides the guideline that the adobe if stabilized with raw rice husk can improve the performance of adobe structure during flood event. The improved behaviour under compressive loads makes it suitable for the construction of load bearing walls especially where the frequency of rain is high. It also can increase the life of structure by delaying the deterioration of brick in the stagnant flood water. Whereas the rice husk ash burnt in heap is not suitable to use as a stabilizer for adobe as it reduced the overall performance of material. Therefore, the stabilizer rice husk is determined as an appropriate stabilizer for the construction low-cost adobe houses in the areas affected by rain and flood. Further research shall be conducted to compare the effects of rice husk with other local stabilizers such as straw, jute, sugar cane bagasse etc. This will provide the guide for the local people to get the suitable stabilizer for adobe houses.

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