

## Brick Manufacturing From Water Treatment Sludge And Rice Husk Ash

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**Abstract:** For thousands of years, bricks have been made from clay. The water treatment plant sludge is extremely close to brick clay in chemical composition. So, the sludge could be a potential substitute for brick clay. The water treatment process generates a sludge that must be disposed of in an environmentally sound manner. The sludge generated in most of the treatment systems around the world is discharged into the nearest watercourse, which leads to accumulative rise of aluminum concentrations in water and human bodies. This practice has been linked to occurrence of Alzheimer's disease. Among all disposal options, the use of sludge in producing constructional elements is considered to be the most economic and environmentally sound option. One of the most common agricultural wastes, which contain high silica content, and might be incorporated with sludge in brick manufacturing, is rice husk ash (RHA). So, this trend also provides an environmentally sound manner to reuse rice husk ash (RHA). The study investigated the complete substitution of brick clay by water treatment sludge incorporated with rice husk ash (RHA). In this study, three different series of sludge to rice husk ash (RHA) proportions were studied, which exclusively involved the addition of sludge with ratios 25, 50, and 75% of the total weight of sludge-RHA mixture. Each brick series was fired at 900, 1000, 1100, and 1200 °C. The physical and mechanical properties of the produced bricks were then determined and evaluated according to Egyptian Standard Specifications (E.S.S.) and compared to control brick made entirely from clay. From the obtained results, it was concluded that by operating at the temperature commonly practiced in the brick kiln, 75 % was the optimum sludge addition to produce brick from sludge-RHA mixture. The produced bricks properties were obviously superior to the clay control-brick and to those available in the Egyptian market.

**Key words:** water treatment sludge – sludge disposal – clay – brick- rice husk ash.

### INTRODUCTION

Brick is one of the most important construction elements. The history of brick manufacturing goes back 8000 years when the fabrication of the earliest sun dried clay bricks was discovered. Sludge generated at water treatment plants should be treated and handled in an environmentally sound manner. Coagulant sludge is generated by water treatment plants, which use metal salts such as aluminum sulfate (alum) or ferric chloride as a coagulant to remove turbidity. The traditional practice of discharging the sludge directly into a nearby stream is becoming less acceptable because these discharges can violate the allowable stream standards (Sullivan, C., et al., 2010). The discharging of sludge into water body leads to accumulative rise of aluminum concentrations in water, aquatic organisms, and, consequently, in human bodies. Some researchers have linked aluminum's contributory influence to occurrence of Alzheimer's disease, children mental retardation, and the common effects of heavy metals accumulation (Prakhar, P.E. and Arup, K.S., 1998). It is recognized that the disposal of aluminum-laden solids from water treatment plants will receive a closer scrutiny in the coming years.

Several trials have been reported in Taiwan, UK, USA, Egypt, and other parts of the world to use water treatment sludge in various industrial and commercial manufacturing processes. Studies have been carried out on using sludge in brick, artificial aggregate, cement, and ceramic making. Also, some trials have been conducted to use sludge in land application. Due to the similar mineralogical composition of brick clay and water treatment plant sludge, the use of water treatment sludge in brick manufacture has been highly encouraged.

Several trials have been reported in this purpose. In a study that was conducted in the Netherlands, the researchers have manufactured bricks from clay to which water sludge was added (Feenstra, L., et al., 1997). The bricks were assessed in terms of production technique and environmental impact (leaching behavior). The results of the study were then taken as a basis for closer evaluation of the feasibility of this option. As a result, the process has now become reality. A research carried out in the UK, investigated the incorporating of two waste materials in brick manufacturing. The study used waterworks sludge and the incinerated sewage sludge ash as partial replacements for traditional brick-making raw materials at a 5% replacement level ( Anderson, M., et al., 2003). In another study that was carried out in Taiwan, researchers blended the water treatment sludge with the excavation waste soil to make bricks. The conclusion of the study indicated that 15% was the maximum water treatment sludge addition to achieve first-degree brick quality (Chihpin, H., et al., 2005). In Egypt, similar studies investigated the use of sludge as a complete or partial substitute for clay in brick manufacturing

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(Hassanain, A.M., 2008; Ramadan, M.O., et al., 2008; Hegazy, B.E., 2007). In this trend, different series of sludge and clay proportioning ratios were tried, which involved the addition of sludge with ratios between 50 and 100 % by weight. Each series was fired at different temperatures between 950 and 1100 °C. The physical properties of the produced brick were then determined and evaluated according to E.S.S. From the obtained results, it was concluded that 50 % was the optimum sludge addition to produce brick from sludge-clay mixture.

Agricultural wastes should, also, be handled and disposed of in an environmentally sound manner. The annual world production of rice crop is about 500 million tons, which represent 21% of the human food (Belonio, A.T., 2005). Several trials have been made to use rice husks and rice husk ash as a low cost concrete admixture because of its role as filler and pozzolan, in phenol adsorption from aqueous solution, in producing charcoal and supplementary cementitious materials, and in some other industrial uses such as brick making.

In Nigeria, Bricks were made from clay-sand mixes with different percentages of rice husk ash and burnt in a furnace for different firing times (Abdul Rahman, M., 1987). The firing durations at 1000°C were 2 hours, 4 hours and 6 hours. Test results indicated that lightweight bricks could be manufactured with rice husk ash without any deterioration in the quality of bricks. In another study, the effects of rice husk ash (RHA) on the various properties of lateritic soil-clay mixed bricks were studied (Abdul Rahman, M., 1988). The compressive strength of lateritic soil-clay mixed bricks increased almost linearly with increase in the percentage content of RHA. The latest approach study also, has been made in Taiwan (Chiang, K.Y., et al., 2009). Novel lightweight bricks have been produced by sintering mixes of dried water treatment sludge and rice husk. Samples containing up to 20 wt. % rice husk have been fired using a heating schedule that allowed effective organic burn-out. Rice husk addition increased the porosity of sintered samples. From the previous researches, it is clearly obvious that water treatment sludge and rice husk ash (RHA) could be used in manufacturing of clay brick.

**Objectives Of The Study:**

The study was aimed to make brick of water treatment plant sludge mixed with rice husk ash (RHA) with various ratios, through the crystallization process. The produced brick should meet the required values of compressive strength, water absorption, and efflorescence assigned by the Egyptian Standard Specifications (E.S.S. 1524/1993) for load bearing bricks. The produced brick was also aimed to compete with control clay brick, which was made under the circumstances of the study, and the common commercial brick types available in the Egyptian market.

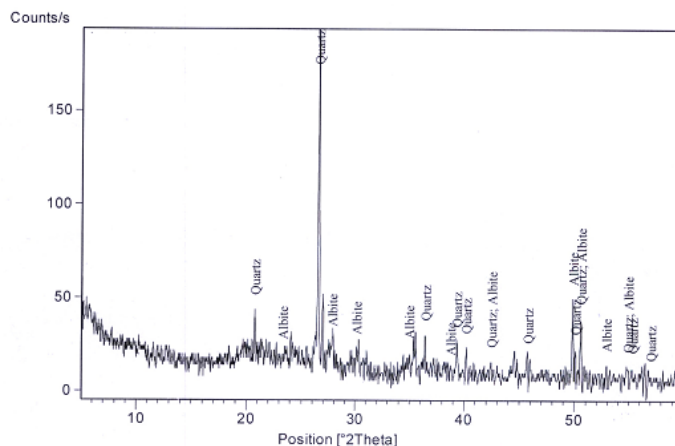
**Materials:**

The study involved the use of the coagulant sludge disposed of from the Giza Water Treatment Plant at Giza Governorate, Greater Cairo, in which aluminum sulfate was used in the coagulation process. The chemical composition of sludge was identified by using the X-ray fluorescence (XRF) spectrometer according to ASTM C114-00. The complete chemical composition of alum sludge is summarized in Table (1).

**Table 1:** Chemical Composition of WTP Sludge

Item	SiO <sub>2</sub>	Fe <sub>2</sub> O <sub>3</sub>	Al <sub>2</sub> O <sub>3</sub>	CaO	MgO	SO <sub>3</sub>	Na <sub>2</sub> O	K <sub>2</sub> O	Cl <sup>-</sup>	L.O.I
Ratio (%)	43.12	5.26	15.97	5.56	0.85	1.49	0.52	0.26	0.012	26.79

Table (1) shows that the major chemical compositions of the sludge were silicon, aluminum, and iron oxides, which are extremely similar to the major chemical compositions of the brick clay, but with higher alumina content. The phase composition was identified by using the X-ray diffraction (XRD) diffractometer according to ASTM C114-00. The phase composition of alum sludge is shown in Figure (1).



**Fig. 1:** XRD Patterns of the Sludge

The XRD scans were recorded from 5 – 60 °2θ. The XRD pattern of the water treatment plant sludge, shown in Figure (1), indicates the presence of two major crystalline phases, namely, quartz [SiO<sub>2</sub>] and albite [Na Al Si<sub>3</sub> O<sub>8</sub>]. These results indicate that the water treatment plant sludge presents, in its composition, minerals that are similar to those commonly occurring in brick clays.

The sludge was dewatered to achieve a concentration of suspended solids in sludge not less than 20 %. This process is accomplished sand filtering the sludge through a specially designed filter. The concentration of the suspended solids of the sludge, reaches 20 % after two days. The thickened sludge are then collected from the filter, distributed, spread and subjected to air drying and direct sunlight for at least 14 days on drying beds. The dried sludge is pulverized using a pestle and mortar. The powder is then sieved through a series of sieves. The sieving process is done to separate the impurities and large particles (> 0.075mm) of sand that may be included within the sludge.

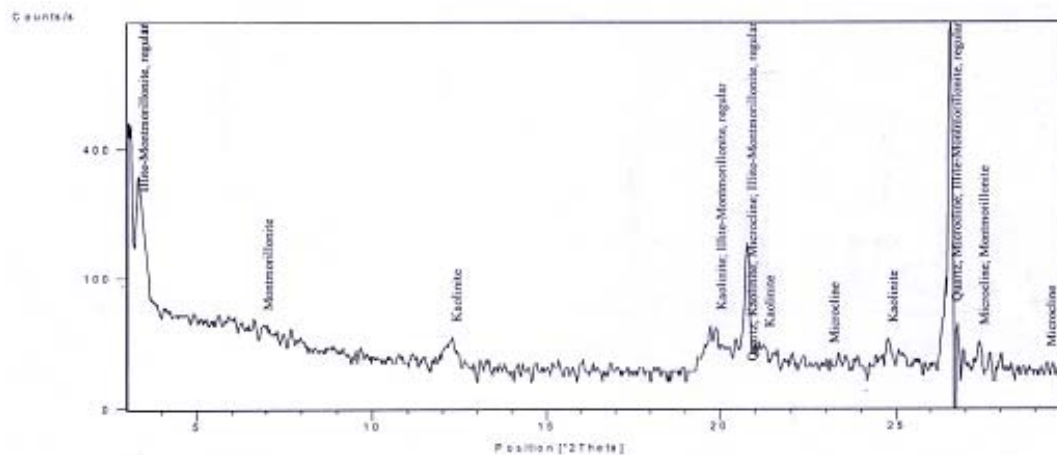
The removal of the organic content, which indicated by a relatively high value of loss on ignition (L.O.I) given in Table (1), was last stage of sludge preparation process. This was done by burning the sludge at moderate range of temperatures ranged from 150 to 350 °C for 1 and 2 hours period. It was found that, burning the pulverized sludge dust at 350 °C for 1 hour causes a loss in sludge weight equals 25 %. This removal ratio of organic content could be accepted.

The clay used in this study was obtained from a local brick factory at Imbahah, Giza Governorate, Greater Cairo. The typical compositions of such clay are quite variable in minerals proportions. The chemical composition of clay was identified by using the X-ray fluorescence (XRF) spectrometer according to ASTM C114-00. The complete chemical composition of alum sludge is summarized in Table (2).

**Table 2:** Chemical Composition of Clay

Item	SiO <sub>2</sub>	Fe <sub>2</sub> O <sub>3</sub>	Al <sub>2</sub> O <sub>3</sub>	CaO	MgO	SO <sub>3</sub>	Na <sub>2</sub> O	K <sub>2</sub> O	TiO <sub>2</sub>	P <sub>2</sub> O <sub>5</sub>	L.O.I
Ratio (%)	65.32	7.51	13.89	1.09	0.95	0.05	2.61	0.75	1.46	0.28	5.87

It is clearly obvious that is the major chemical compositions of the clay were silica, alumina, and ferric oxide, as shown in Table (2). This indicates the similar compositions of the water treatment plant sludge and the brick clay. The strength of the brick depends largely on the percentage of silica in the raw materials. So, it was anticipated that the clay is more suitable for brick making than the sludge due to its obviously higher silica content. Also, the burning of the clay before sintering was not required due to its low value of L.O.I. The phase composition of clay was identified by using the X-ray diffraction (XRD) diffractometer, according to ASTM C114-00. The phase composition of clay is shown in Figure (2).



**Fig. 2:** XRD Patterns of the clay

The XRD scans were recorded from 0 – 30 °2θ. The XRD pattern of the powder clay, shown in Figure (2), indicates the presence of five major crystalline phases, namely, kaolinite [Al<sub>2</sub> Si<sub>2</sub> O<sub>5</sub> (OH)<sub>4</sub>], montmorillonite [(Na<sub>x</sub> (Al,Mg)<sub>2</sub> Si<sub>4</sub> O<sub>10</sub> (OH)<sub>2</sub>!z H<sub>2</sub>O)], quartz [SiO<sub>2</sub>], microcline [K Al Si<sub>3</sub> O<sub>8</sub>], and illite-montmorillonite, regular [K- Al<sub>4</sub> (Si Al)<sub>8</sub> O<sub>20</sub> (OH)<sub>4</sub> !x H<sub>2</sub>O]. The clay is obtained in the form of large consolidated boulders, which require pulverizing and sieving before using in brick manufacturing, as in case of dried sludge. The clay is then oven dried to remove its moisture content.

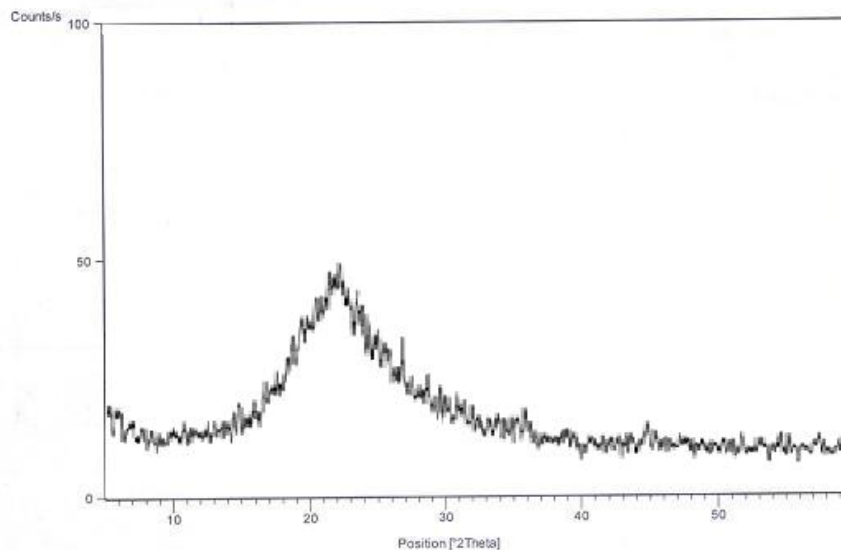
The rice husks used in this study was obtained from a local rice thresher at El-Qanater, Kalyobya Governorate, Greater Cairo. The rice husks is obtained as a by product of the harvested rice, which require incineration, pulverizing and sieving to produce rice husk ash (RHA) to use it in brick manufacturing, as

amorphous silica. In condensed matter physics, an amorphous or non-crystalline solid is a solid that lacks the long-range order characteristic of a crystal. It has been reported that at low temperatures (600 – 700 °C) silica in RHA is amorphous, and crystallization occurs when temperature goes above 700 °C (Farooque, K.N., et al., 2009). In this Study, rice husk ash (RHA) was obtained by incinerating rice husks at temperature of 600°C for 4 hours, and then it was left overnight to cool. The chemical composition was identified by using the X-ray fluorescence (XRF) spectrometer according to ASTM C114-00. The complete chemical composition of rice husk ash (RHA) is summarized in Table (3).

**Table 3:** Chemical Composition of Rice Husk Ash

Item	SiO <sub>2</sub>	Fe <sub>2</sub> O <sub>3</sub>	Al <sub>2</sub> O <sub>3</sub>	CaO	MgO	SO <sub>3</sub>	Na <sub>2</sub> O	K <sub>2</sub> O	TiO <sub>2</sub>	L.O.I
Ratio (%)	82.40	0.26	0.65	2.42	1.71	0.52	0.30	1.63	0.01	10.09

From Table (3), it is evident that rice husk ash (RHA) contains mainly silica, which is the major chemical composition of the brick clay. Rice husk ash indicated amount of alkalies (1.93 %) as a K<sub>2</sub>O and Na<sub>2</sub>O. Rice husk ash also indicated a loss on ignition 10.09 % which may be due to the presence of free carbon in the rice husk ash. These facts indicate that rice husk ash (RHA) could be an excellent substitute for brick clay. The phase composition was identified by using the X-ray diffraction (XRD) diffractometer, according to ASTM C114-00. The phase composition of rice husk ash (RHA) is shown in Figure (3).



**Fig. 3:** XRD Patterns of the Rice Husk Ash

The XRD scans were recorded from 5 – 60 °2θ. The XRD pattern of the rice husk ash (RHA), shown in Figure (3), indicates that silica in the rice husk initially exists in the amorphous form, but will not remain porous and amorphous, when incinerated for a prolonged period at a temperature above 700°C (Farooque, K.N., et al., 2009). These results indicate that the rice husk ash (RHA) presents, in its composition, amorphous silica that is similar to that commonly occurring in brick clays. The rice husk ash (RHA) is produced in the form of coarse ashes with large particle size, which require pulverizing before using in brick manufacturing, as in case of clay and dried sludge. The pulverizing of the rice husk ash (RHA) is carried out, using a ball mill, which consists of a 30 liters drum mounted on a pair of rollers and driven by an electric motor. The “balls” are made of steel and should be free to move inside the drum. The pulverizing process is sustained for several minutes, till the rice husk ash (RHA) transform completely into fine dust. After pulverizing, the produced pulverized rice husk ash (RHA) is ready to be used in brick manufacturing.

**Sample Preparation:**

In addition to the control brick, three different series of mixing ratios were tried. However, the batching proportions of raw materials required to produce lab-scale brick with nominal dimensions of (5 × 5 × 2) centimeters are shown in Table (4).

**Table 4:** Different Batching Proportions of Raw Materials

Brick Series	Percentage by Weight (%)		
	Sludge	RHA	Clay
Control Brick	0	0	100
Series-A	25	75	0
Series-B	50	50	0
Series-C	75	25	0

The study involved the trying of several mixing and preparation techniques. The best sample preparation technique was adopted. Mixing of the raw materials includes two main steps, dry mixing and the blending with water. To ensure homogeneity in the properties of the mixture, mechanical mixing is adopted.

The placement of raw materials in the mould as one clot and the compressing of the mixture, using a hydraulic piston, into the brick nominal dimensions was the followed practice. This process is an analog for the extrusion machine, which is used in modern brick factories.

Two steps were employed to dry the green molded bricks. The first step is the enclosing and stacking of the green bricks in an air-tight box for six days, till complete volumetric shrinkage takes place without cracking. The green bricks are then subjected to direct air drying and sunlight for another six days.

Each of the brick series, which mentioned previously in Table (4), were then fired at four different firing temperatures, 900, 1000, 1100, and 1200 °C giving a 16 different brick types. The produced bricks were tested for mechanical properties.

**Evaluation Of Brick:**

The mechanical and physical properties of the produced brick were then evaluated. These properties were namely, water absorption, efflorescence, apparent specific gravity, and compressive strength. The test methods were carried out according to (E.S.S. No. 48,619/ 2003) and the results of these properties are evaluated according to (E.S.S. No. 1524/1993), as shown in Table (5).

**Table 5:** E.S.S. 1524/1993 Brick Specifications

Purpose	Compressive Strength (kg/cm <sup>2</sup> )	Water Absorption (%)	Efflorescence
Load bearing	35	27	Slight
Non Load Bearing	15	30	Slight

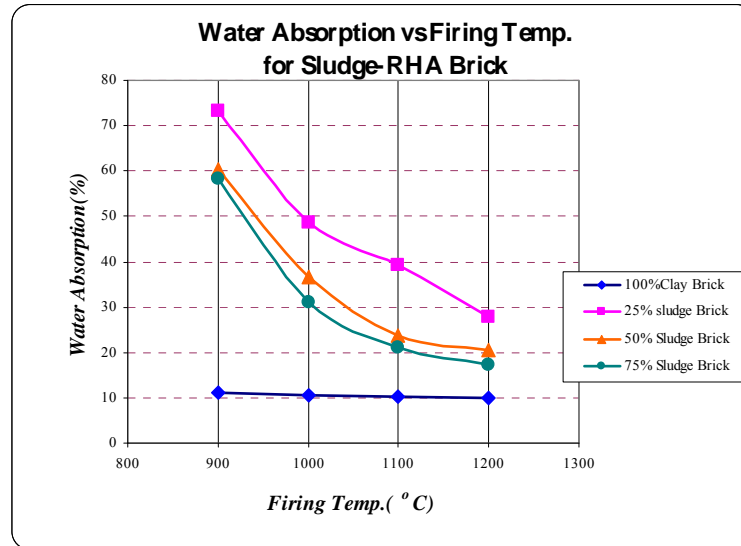
**RESULTS AND DISCUSSION**

The result of each test was the average of three bricks, to ensure the reliability of the results. All tests were performed on (5 × 5 × 2) centimeters prisms. The test results of the 16 different types of brick, which include the control clay brick, are listed below. The results were also compared to two of the commercial clay-brick types available in the Egyptian market, taking into consideration that all physical properties are comparable. With respect to mechanical properties, the use of (5 × 5 × 2) centimeters prisms should under estimate the obtained strength of the research brick types. The first, which will be referred to as "commercial brick sample (1)", is a solid clay-brick type, while the other, which will be referred to as "commercial brick sample (2)", is a perforated wirecut clay-brick type.

The durability of the brick is largely dependent upon their water absorption. The water absorption test results are shown in Figure (4). The water absorption test results of control clay brick ranged between 9.94 and 11.18 %. On the other hand, the water absorption test results of sludge-RHA brick ranged between 17.41 and 73.33 %. There were four sludge-RHA brick types that achieved water absorption less than 27 %, which comply with the requirements of the E.S.S. 1524/1993 for the load bearing walls. These brick types were of (Series B and C), which contains 50 and 75 % of sludge respectively, and fired at 1100 and 1200 °C. Also, there was one brick type that exhibited water absorption less than 30 %, which contained 25 % of sludge and fired at 1200 °C. This brick type met the requirements of the E.S.S. 1524/1993 for the non-load bearing walls. The effect of firing temperatures on water absorption is attributable to the fact that increasing firing temperature ensures the completion of the crystallization process and closes the open pores in the sinter. While the effect of the sludge ratio is explained by the fact that although increasing sludge ratio decreases the proportion of silica in the brick mixture, which reduces the strength of the sinter and increase the open pores, it decreases the proportion of RHA particles, which is distinguished by its flabby nature. The effect of the flabby nature of the RHA particles, which severely increases the open pores in the sinter, on increasing water absorption is much significant than that of reducing silica content.

Compared to the control clay brick type, all of the sludge-RHA brick types exhibited higher water absorption than that of the 100 % clay brick type for the same firing temperatures. Compared to the commercial brick types, there were only three of the sludge-RHA brick types that achieved lower water absorption than

Commercial Brick Sample (1), which attained 21.19 % water absorption. These three types were of (Series-B) and fired at 1200 °C; and of (Series-C) and fired at 1100 and 1200 °C. While all of the research sludge-RHA brick types exhibited higher water absorption than Commercial Brick Sample (2), which attained 10.77 % water absorption. These results indicate that there were five sludge-RHA brick types achieved acceptable water absorption for different uses.



**Fig. 4:** Water Absorption Test Results

The apparent specific gravity is in inverse correlation with the water absorption. The apparent specific gravity test results are shown in Figure (5). The apparent specific gravity test results of control clay brick ranged between 1.84 and 1.95. On the other hand, the apparent specific gravity test results of sludge-RHA brick ranged between 0.78 and 1.46. All of the brick types achieved apparent specific gravity less than 1.6, which lays in the category of light weight brick (Jackson, N. and Dhir, R.K., 1996). However, the effect of firing temperatures on apparent specific gravity is attributed to the completion of the crystallization process and closing of the open fine pores in the sinter by increasing firing temperature. During the crystallization process, the distance between the particles in the sinter decreases with increasing temperature. So, the apparent specific gravity increases with increasing firing temperature due to densification.

Compared to the control clay brick types, all of the sludge-RHA brick types achieved lower apparent specific gravity than that of the 100 % clay control-brick type for the same firing temperatures. Compared to the commercial brick types, all of the sludge-RHA brick types achieved lower apparent specific gravity than both Commercial Brick Sample (1), which attained apparent specific gravity of 1.53 and lays in the light weight category, and Commercial Brick Sample (2), which attained apparent specific gravity of 1.89. Generally, the apparent specific gravity of the of the sludge-RHA brick types is much lighter than that of the control brick types and the commercial brick types.

Brickwork sometimes develops an efflorescence of white salts brought to the surface by water and deposited by evaporation. These salts may have an external origin, like the water in soil in contact with the brickwork, or may derive from the mortar. However, the salts frequently originate in the bricks themselves. Visible efflorescence can be formed from very small amounts of salts. Efflorescence may be disfiguring but it is often harmless and disappears after a few seasons. However, efflorescent salts may contain a high proportion of sulfates and may cause sulfate attack on the cement mortar joints. The efflorescence was of "Nil" class for all of the control clay brick and sludge-RHA brick types, which comply with the requirements of the (E.S.S. 1524/1993). These results could be considered as an indicator for the very low values of soluble salts content of the brick. Also, the commercial brick types exhibited no efflorescence.

Compressive strength determines the potential for application of the bricks. Compressive strength is usually affected by the porosity, pore size, and type of crystallization. It is usually defined as the failure stress measured normal to the bed face of the brick. The compressive strength test results are shown in Figure (6). The compressive strength test results of control clay brick ranged between 58.09 and 69.44 kg/cm<sup>2</sup>. On the other hand, the compressive strength test results of sludge-RHA brick ranged between 28.78 and 79.96 kg/cm<sup>2</sup>, which comply with the requirements of the (E.S.S. 1524/1993) for the load bearing walls. There were nine sludge-RHA brick types met the requirements of the (E.S.S. 1524/1993) for the load bearing walls. On the other hand,

there were only three sludge-RHA brick types that achieved compressive strength between 27 and 35 kg/cm<sup>2</sup>, which comply with the requirements of the (E.S.S. 1524/1993) for the non-load bearing walls, but didn't meet the requirements of the (E.S.S. 1524/1993) for the load bearing walls. These brick types were of (Series A, B, and C) and fired at 900 °C.

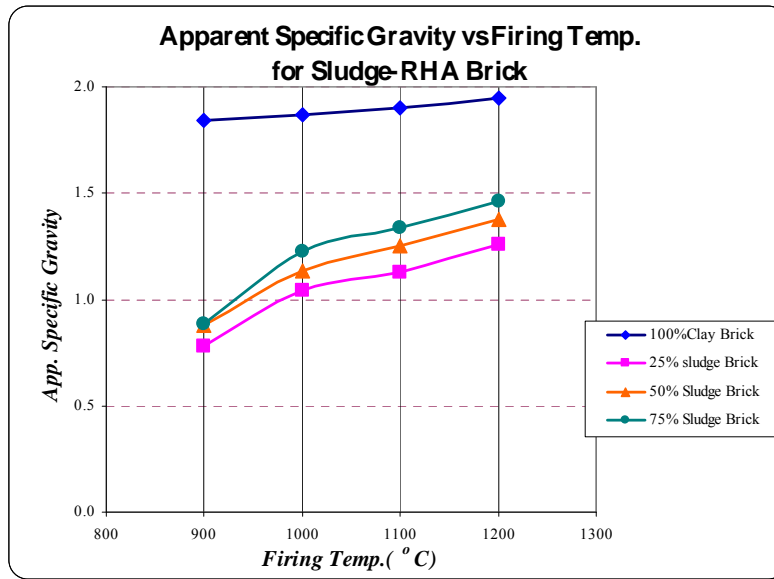


Fig. 5: Apparent Specific Gravity Test Results

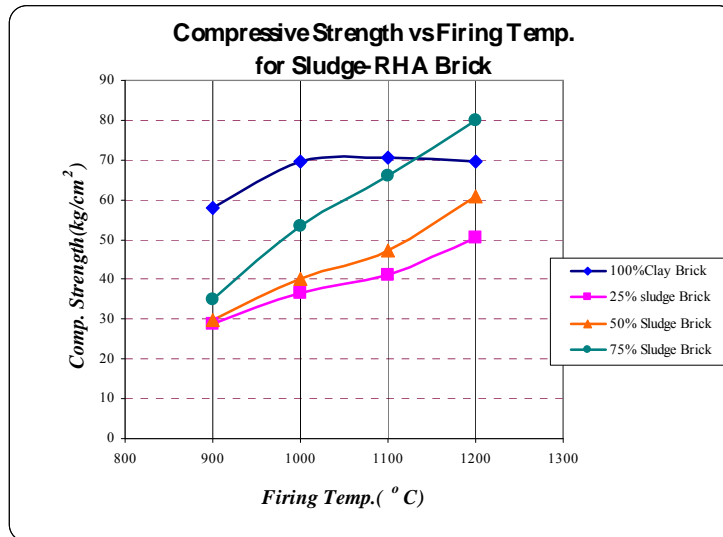


Fig. 6: The Compressive strength Test Results

The effect of firing temperatures on compressive strength may be attributable to the fact that increasing firing temperature ensures the completion of the crystallization process, closes the open pores in the sinter, and, consequently, increases compressive strength of the crystalline aluminosilicate brick. While the effect of the sludge ratio is explained by the fact that although increasing sludge ratio decreases the proportion of silica in the brick mixture, which increase the open pores and reduces the compressive strength of the sinter, it decreases the proportion of RHA particles, which is distinguished by its flabby nature. The effect of the flabby nature of the RHA particles, which severely increases the open pores in the sinter, on decreasing compressive strength is much significant than that of reducing silica content. As a result, increasing sludge ratio generally decreases the open pores in the sludge-RHA sinter and, consequently, increases the compressive strength.



Compared to the control clay brick, only one of the sludge-RHA brick types achieved higher compressive strength than that of the 100 % clay control-brick type for the same firing temperatures. This type contained 75 % of sludge and fired at 1200 °C. Compared to the commercial brick types, all of the sludge-RHA brick types achieved higher compressive strength than Commercial Brick Sample (1), which attained 27.51 kg/cm<sup>2</sup> compressive strength. While only one type of the research sludge-RHA brick types achieved higher compressive strength than Commercial Brick Sample (2), which attained 79.57 kg/cm<sup>2</sup> compressive strength. This type, again, was the one that contained 75 % of sludge and fired at 1200 °C. Generally, the compressive strength of the research sludge-RHA brick types is more than acceptable compared to that of the control clay brick types and commercial clay-brick types that available in the Egyptian market. It should be noted that the use of (5 × 5 × 2) centimeters prisms as brick will significantly reduce the compressive strength compared to similar sample of (25 × 12.5 × 6.5) centimeters size (Neville, A.M., 1989).

#### **Conclusions:**

The conclusions reached in this study were based on the experimental program executed in this research, and limited on both the tested materials and the testing procedures employed:

1. Water treatment plant sludge can be a successful partial substitute for brick clay incorporated with agricultural waste materials; which contain high silica content; under the conditions, mixing proportions, firing temperatures, and manufacturing methods used in this study.
2. The addition of some agricultural waste materials; which contain high silica content; such as rice husk ash can enhance the physical properties of sludge brick. The maximum percentage of water treatment plant sludge, which can be used in the mixture, is dominated by the practiced firing temperatures.
3. The research brick types were competitors to both the research control clay brick types and commercial clay brick types available in the Egyptian market.
4. The optimum sludge addition to produce brick from sludge and rice husk ash mixture was 75 %; by operating at the temperatures commonly practiced in the brick factories and based on the experimental program executed in this research, and limited on both the tested materials and the testing procedures employed.

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