

Reuse of Water Treatment Plant Sludge in Brick Manufacturing

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Abstract: A large quantity of sludge is generated each year from water treatment plants in Egypt. Disposing the sludge to the nearest watercourse is the common practice in Egypt, which accumulatively rise the aluminum concentrations in water and consequently in human bodies. This practice has been linked to occurrence of Alzheimer's disease. Landfill disposal of the sludge is impractical because of the high cost of transportation and depletes the capacity of the landfill. The use of sludge in construction industry is considered to be the most economic and environmentally sound option. Due to the similar mineralogical composition of clay and water treatment plant sludge, this study focused on the reuse of sludge in clay-brick production. The study investigated the use of sludge as partial substitute for clay in brick manufacturing. In this study, four different series of sludge and clay proportioning ratios were studied, which exclusively involved the addition of sludge with ratios 50, 60, 70, and 80 percent of the total weight of sludge-clay mixture. Each series involved the firing of bricks at 950, 1000, 1050, and 1100 °C, giving 16 different brick types. The physical properties of the produced bricks were then determined and evaluated according to Egyptian Standard Specifications and British Standards. From the obtained results, it was concluded that by operating at the temperature commonly practiced in the brick kiln, 50 percent was the optimum sludge addition to produce brick from sludge-clay mixture. The produced bricks properties were superior to those available in the Egyptian market.

Key words: Water treatment plant sludge, sludge disposal, clay and brick

INTRODUCTION

The sludge disposed during the various water treatment processes can be a major concern for water treatment plants. Most of the water treatment plants in Egypt discharges the sludge into the river Nile with no treatment. The discharging of sludge into water body leads to accumulative rise of aluminum concentrations in water, aquatic organisms, and human bodies. Some researchers have linked aluminum's contributory influence to occurrence of Alzheimer's, children mental retardation, and the common effects of heavy metals accumulation^[1]. Consequently stringent standards of effluent discharge are coming into effect, and thus proper management of the sludge becomes inevitable. The use of water treatment sludge in various industrial and commercial manufacturing processes has been reported in UK, USA, Taiwan and other parts of the world. Successful pilot and full-scale trials have been undertaken in brick manufacture, cement manufacture, commercial land application. The mineralogical composition of the "water treatment sludge" is particularly close to that of clay and shale. This fact encourages the use of water treatment sludge in brick manufacture. Several trials have been reported in this purpose. Research carried out in the UK, assessed the

potential of incorporating aluminum and ferric coagulant sludge in various manufacturing processes including clay brick making^[8]. A mixture consists of about 10 percent of the water treatment sludge and sewage sludge, incinerated ash was added to about 90 percent of natural clay to produce the brick. Anderson *et al.*,^[1] also 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.

In Taiwan^[4] a study had been made to use a mixture of water treatment plant (WTP) sludge and dam sediment as raw materials for brick making through the sintering process. A satisfactory result was achieved when the ratio of the WTP sludge was less than 20% of the mixture. Chihpin *et al.*,^[5] 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.

The main object of the study was to produce a lab scale brick units made of mixtures of clay and water treatment plant sludge with various ratios that meet the obligatory values of compressive strength and water absorption assigned by the Egyptian Standard

Specifications^[7] for load bearing bricks. Also it was objected in this research to produce bricks that can compete with most of the commercial brick types available in the Egyptian market.

The author referred at some tests to the British Standards^[2] for clay brick to confirm the compliance of the produced brick with one of the most conservative international standard specifications.

MATERIALS AND METHODS

The sludge used in the study was the coagulant sludge withdrawn from the clariflocculation tanks of the Giza Water Treatment Plant in the southern part of Cairo, in which aluminum sulfate was used in the coagulation process. The alum sludge is composed of about 1 percent of suspended solids and 99 percent of water, which is difficult to dewater. The complete chemical composition of alum sludge is summarized in Table (1).

From Table (1), it is obvious that is 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 sludge was dewatered to achieve a concentration of suspended solids in sludge not less than 20 percent. This process is accomplished by filtering the sludge through a specially designed filter. The details of that filter are shown in Fig. (1).

The concentration of the suspended solids of the sludge, which trapped in the sludge-concentrating layer, reaches 20 percent after a couple of days. The thickened sludge are then collected from the filter, distributed, spread and subjected to air and direct sunlight for at least 14 days till air dried. 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 of sand that may be included within the sludge. The last stage of sludge preparation process involves the removal of the organic content, which indicated by a relatively high value of loss on ignition (L.O.I) given in Table (1). 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 percent. This removal ratio of organic content could be accepted.

The clay used in this study was obtained from local brick factory at El- Qanater, Kalioubya governorate. The clay is obtained in the form of large consolidated boulders, which require pulverizing and

Table 1: Chemical Composition of WTP Sludge

Ingredient	Ratio by weight(%)
SiO ₂	43.12
Fe ₂ O ₃	5.26
Al ₂ O ₃	15.97
CaO	5.56
MgO	0.85
SO ₃	1.49
Na ₂ O	0.52
K ₂ O	0.26
Cl	0.012
L.O.I	26.79

sieving before using in brick manufacturing, as in case of dried sludge. The clay is then oven dried is required to remove the moisture content of the clay.

Sample Preparation: Four different series of mixing ratios were tried. However, the dry weights of raw materials and the batching proportions required to produce one lab-scale brick with nominal dimensions of (5 × 5 × 5) centimeters are shown in Table (2).

Several mixing and preparation techniques were attempted. The best sample preparation technique was found to be similar to the actual adopted manufacture method. 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 clay in the mould as one clot and the compressing of the clay-sludge 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.

The drying of green molded bricks is then carried out in two steps. The first step is done by enclosing and stacking of the green bricks in an air-tight box or container for not less than 6 days, till complete volumetric shrinkage takes place without cracking. The green bricks are then subjected to direct air and sunlight for another 6 days.

Each of the four brick series, which mentioned previously in Table (2), were then fired at four different firing temperatures, 950, 1000, 1050, and 1100 °C giving a 16 different brick types. The produced bricks were tested for mechanical properties.

Evaluation of Brick: The evaluated mechanical and physical properties of the manufactured bricks were namely, water absorption, initial rate of suction, efflorescence, compressive strength, and the reduction in compressive strength after the submergence of the bricks in water for 7 days. These properties are evaluated according to^[6] as shown in Table (3).

Table 2: Different Batching Proportions of Raw Materials

Brick Series Designation	Proportions by Weight (%)			Dry Weights (gm)			
	Sludge	Clay	Water (additional)	Sludge	Clay	Total Dry Weight	Water (additional)
(Series-A)	50	50	30	105	105	210	65
(Series-B)	60	40	30	115	75	190	60
(Series-C)	70	30	30	125	55	180	55
(Series-D)	80	20	30	130	35	165	50

Table 3: E.S.S. 1524/1993 Brick Specifications

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

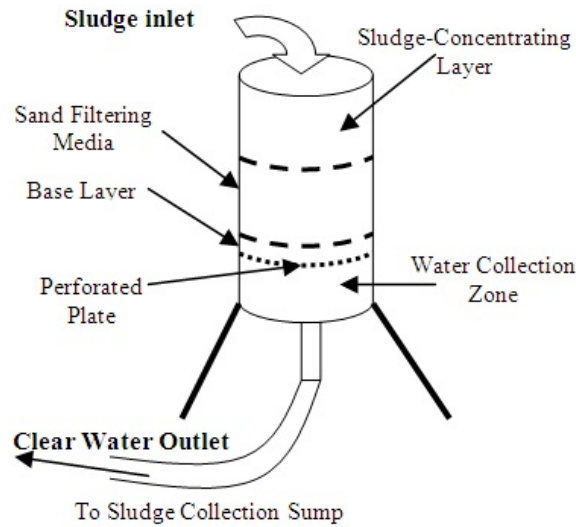


Fig. 1: The Sludge Filter Used for Concentrating the Sludge.

RESULTS AND DISCUSSION

All of tests were performed on (5 × 5 × 5) centimeters prisms, to ensure the reliability of the results. The test results of the 16 different types of brick, which manufactured through the study, 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 × 5) 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 Fig. (2). The results of water

absorption test ranged between 4.84 and 17.34 percent, which comply with the requirements of the^[7]. There were five brick types that exhibited Water absorption less than 7.0 percent, which met the requirements of the^[2] for Engineering Brick 'B'. 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 increasing sludge ratio decreases the proportion of silica in the mixture which reduce the strength of the sinter and increase the open pores. Compared to the commercial brick types, all of the research brick types achieved lower water absorption than Commercial Brick Sample (1), which attained 20.71 percent. While only three types of the research brick achieved higher water absorption than Commercial Brick Sample (2), which attained 11.33 percent.

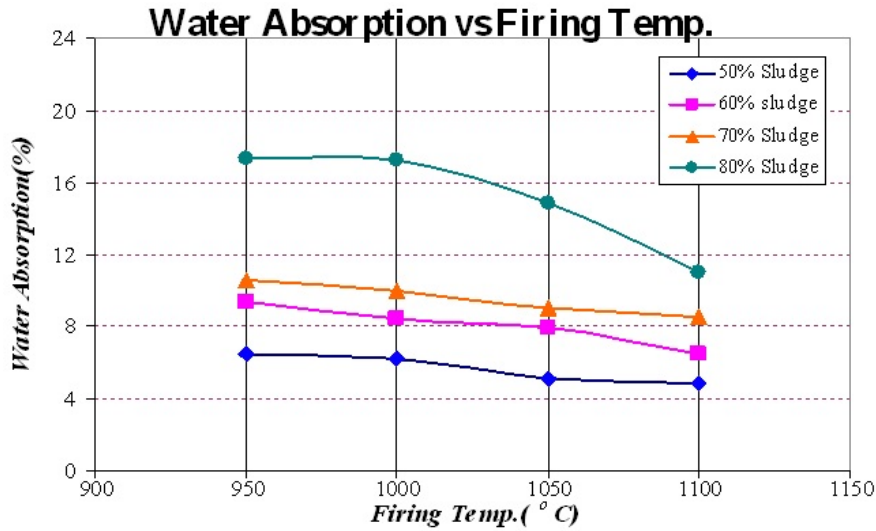


Fig. 2: Water Absorption Test Results

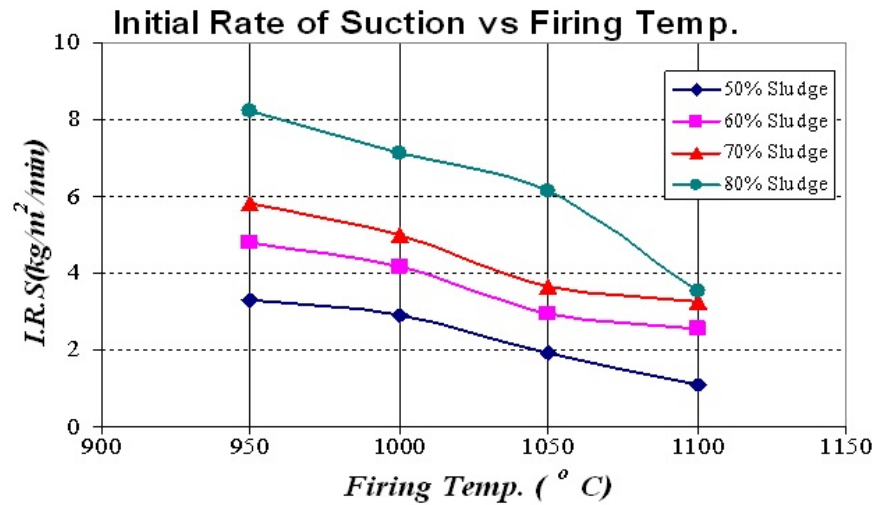


Fig. 3: Initial Rate of Suction Test Results

The initial rate of suction (IRS) test is specified by^[2] to help in the improvement of the brick-mortar bond. The I.R.S test results are shown in Fig. (3). The results of initial rate of suction test ranged between 1.12 and 8.24 kg/m²/minute. These values indicate high I.R.S. There were only two brick types that achieved I.R.S. less than 2 kg/m²/min., which met the requirements of the^[3]. The high I.R.S. values of the rest 14 research brick types do not represent a problem, since the brick units having I.R.S. values exceeding 2 kg/m²/min. should be pre-wetted prior to laying as suggested by^[2]. The effect of firing temperatures on initial rate of suction is attributed to the completion of the crystallization process and closing of the fine pores in the sinter by increasing firing temperature. While the

effect of the sludge ratio is explained by the fact that increasing sludge ratio decreases the proportion of silica in the brick mixture which requires higher temperatures for the completion of the crystallization. As a result, it reduces the strength of the sinter and increases the open fine pores. All of the research brick types achieved lower I.R.S. than Commercial Brick Sample (1), which attained 8.78 kg/m²/min. I.R.S. While only three types of the research brick achieved higher I.R.S. than Commercial Brick Sample (2), which attained 5.94 kg/m²/min. I.R.S.

Fired brick ceramics exhibit a long-term expansion on exposure to moist air. Moist air expansion is progressive and continues indefinitely, although at a diminishing rate, such that the total expansion increases

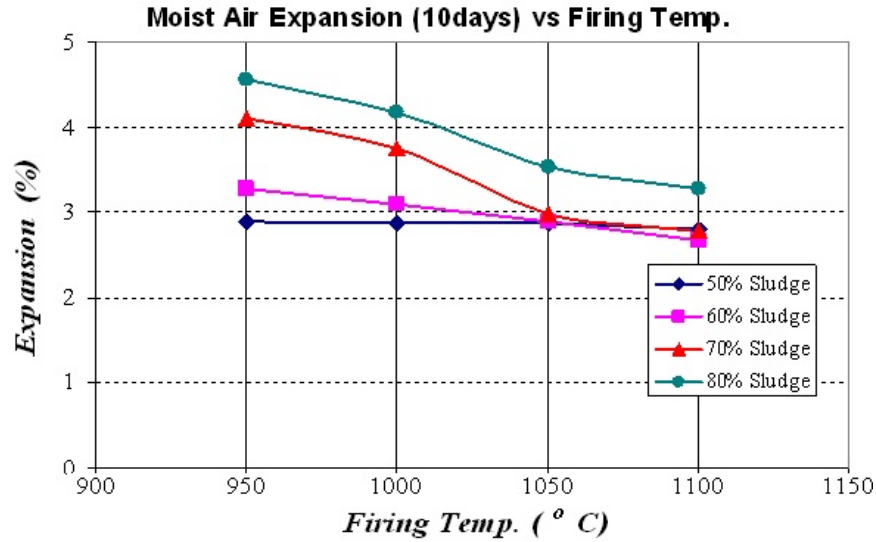


Fig. 4: The Moist Air Expansion Test Results

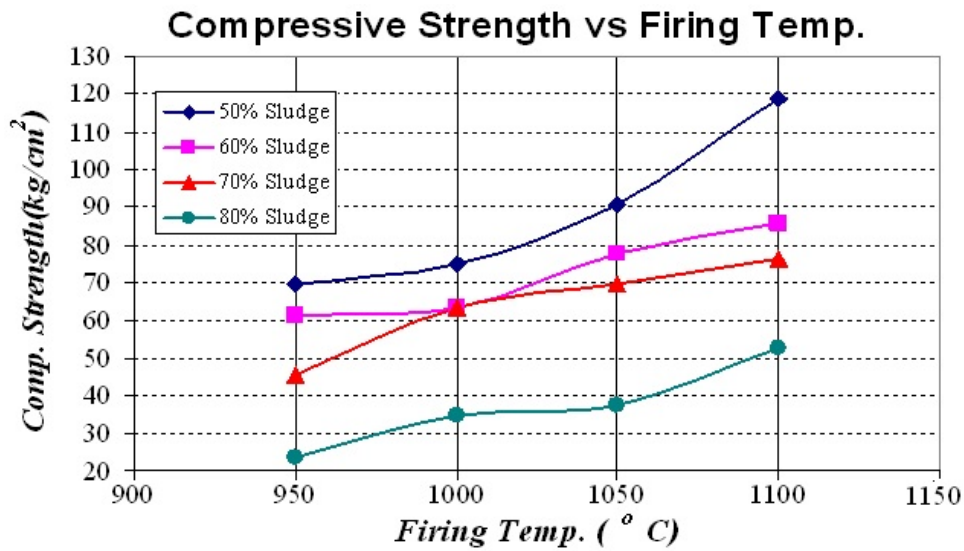


Fig. 5: The Compressive strength Test Results

as the logarithm of time^[9]. The moist air expansion test results are shown in Fig. (4). The results of moist air expansion test ranged between 2.68 and 4.57 percent. These values are considerable, but they will not significantly increase with time. The minimal effect of firing temperature on moist air expansion is attributed to the fact that increasing firing temperature completes the crystallization process and closes the open pores in the brick ceramic, which reduce the moist air expansion and the porosity. On the contrary, the effect of the sludge ratio is attributed to the fact that increasing sludge ratio results in increasing the porosity and consequently increasing the moist air expansion.

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 sludge-clay brick types, which comply with the requirements of the^[7].

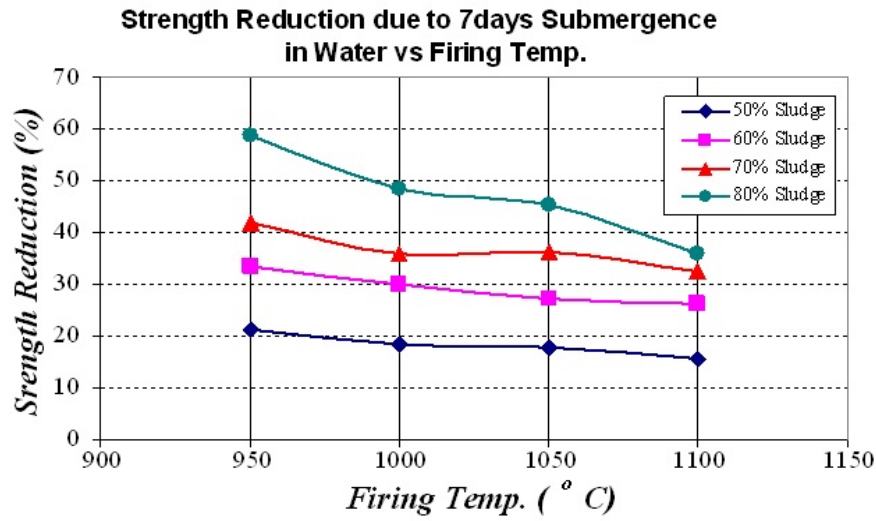


Fig. 6: The Reduction in Compressive strength after submergence in Water for 7Days Test Results.

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 Fig. (5). The results of compressive strength test ranged between 23.49 and 118.94 kg/cm². These values indicates that all of the research brick types can be used in the load bearing walls according to the^[7] except the two brick types that contain 80 percent sludge ratio and fired at 950 and 1000 °C respectively, which can be used only in the none load bearing walls according to the^[7]. There were six brick types that exhibited compressive strength higher than 75 kg/cm², which met the requirements of the^[3] B.S. 5628:1987 for Engineering Brick 'A', and they could be used in brickworks that require high strength. The significant effect of firing temperature on compressive strength is attributed to the completion of the crystallization process and effective sintering at high temperatures. On the contrary, the effect of the sludge ratio is attributed to the low silica content in sludge and consequently the decrease in the compressive strength by increasing sludge ratio. All the research-brick types achieved higher compressive strength than Commercial Brick Sample (1), which attained 21.97 kg/cm² compressive strength. Also, three of the research brick types achieved compressive strength higher than Commercial Brick Sample (2), which attained 79.14 kg/cm² compressive strength. It should be noted that the use of (5 × 5 × 5) centimeters

prisms as brick will significantly reduce the compressive strength compared to similar sample of (25 × 12.5 × 6.5) centimeters size^[10].

Another ordinary compressive strength test is carried out, but the only difference is that this test was performed to determine the reduction in compressive strength after submergence of brick in water for 7 days. The results of this test may be considered as an indication for softening under such severe exposure conditions. A considerable reduction in the strength of the brick is anticipated, since the submergence of brick in water for 7 days may cause deterioration and scaling to the brick. The results of this test may predict the behavior of the brick on the long term. The results of the reduction in compressive strength after 7 days submergence in water are shown in Fig. (6). The percentage of the strength reduction for all research brick types, after 7 days submergence in water, ranged between 15.7 and 58.7 percent. All the research-brick types achieved lower strength reduction than Commercial Brick Sample (1), which attained 55.4 percent of strength reduction, except one type. Also, only four of the research brick types achieved strength reduction higher than Commercial Brick Sample (2), which attained 36.7 percent of strength reduction.

Conclusion: Based on the experimental program executed in this research, and limited on both the tested materials and the testing procedures employed, the following conclusions had been reached:

- Brick can be successfully produced from water treatment plant sludge under the conditions, firing temperatures, and manufacturing methods used in this study.

- The water treatment plant sludge almost resembled the brick clay in its chemical composition but higher sintering temperatures are required, if used alone as a complete substitute for brick clay, due to its lower silica and higher alumina contents.
- Incineration of water treatment plant sludge is needed before using in brick manufacturing to evaporate the major part of its relatively high organic content, which indicated by its high loss on ignition (L.O.I) value.
- The physical properties of sludge brick can be enhanced by the addition of clay, but the maximum percentage of water treatment plant sludge, which can be used in the mixture, is dominated by the practiced firing temperatures.
- Generally, the test results of all the research brick types are superior compared to the commercial clay brick types available in the Egyptian market.
- By operating at the temperatures commonly practiced in the brick factories, 50 percent was the optimum sludge addition to produce sludge-clay brick.

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