REUSE OF WATER TREATMENT SLUDGE AND SILICA FUME IN BRICK MANUFACTURING

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Abstract: The work done in this study was devoted to the development of a procedure to produce brick from water treatment plant sludge and silica fume as a modern way for sludge reuse. Disposing the sludge to the nearest watercourse is the common practice all over the world, 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 it 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 brick clay and water treatment plant sludge, this study focused on the reuse of sludge incorporated with silica fume in brick making through the sintering process. The study investigated the complete substitution of brick clay by water treatment plant sludge incorporated with silica fume (SF). In this study, three different series of sludge to silica fume (SF) proportions were studied, which exclusively involved the addition of sludge with ratios 25, 50, and 75% of the total weight of sludge-SF mixture. Each brick series was fired at 900, 1000, 1100, and 1200 ^{o}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, 50 % was the optimum sludge addition to produce brick from sludge-SF mixture. The produced bricks properties were obviously superior to the 100 % clay control-brick and to those available in the Egyptian market.

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Introduction

The sludge disposed during the treatment of surface water 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 at all. The discharging of sludge into water body leads to accumulative rise of aluminum concentrations in water, aquatic organisms, and human bodies. High concentrations of aluminum have been linked to occurrence of Alzheimer's, and children mental retardation [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, Egypt and other parts of the world. Successful pilot and full-scale trials have been undertaken in brick manufacture, cement manufacture, commercial land application, and artificial aggregate making. The mineralogical composition of the "water treatment sludge" is particularly close to that of clay [2]. 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 [3]. A mixture consists of about 10 % of the water treatment sludge and sewage-sludge incinerated-ash was added to about 90 % of natural clay to produce the brick. Some other researchers also investigated the incorporating of two waste materials in brick manufacturing [4]. 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, 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 [5]. A satisfactory result was achieved when the ratio of the WTP sludge was less than 20% of the mixture. In another study, some researchers blended the water treatment sludge with the excavation waste soil to make bricks [6]. The conclusion of the study indicated that 15% was the maximum water treatment sludge addition to achieve first-degree brick quality. In Egypt, similar studies investigated the use of sludge as a complete or partial substitute for clay in brick manufacturing [7,8,9]. 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 ^{o}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.

Silica fume is a by-product of producing silicon metal or ferrosilicon alloys in smelters using electric arc furnaces. While these are very valuable materials, the by-product silica fume is of more importance to the concrete industry [10]. It falls into the general category of nuisance dust. Because of the name “silica fume” there are frequently questions raised regarding health issues of using this material in concrete. The general concern is with silicosis, which has been widely publicized within the construction industry. Because silica fume is amorphous and not crystalline, silicosis is not an issue. High dust concentrations may cause irritation to mucous membranes. Successful studies have been carried out on using silica fume in concrete making. Also, in an Indian study, active silica from silica fume (SF) was progressively incorporated in a whiteware composition in substitution of quartz [11]. This study indicated the possibility of using silica fume in brick manufacture due to its high content of amorphous silica.

Objectives of the Study

The main object of the study was to produce a lab scale brick units made of mixtures of water treatment plant sludge and silica fume with various ratios, through the sintering process, that meet the obligatory values of compressive strength, water absorption, and efflorescence assigned by the Egyptian Standard Specifications E.S.S. 1524/1993 [12]for load bearing bricks.

Also it was objected in this research to produce bricks that can compete with 100 % clay control-brick, which was made under the circumstances of the study, and most of the commercial brick types available in the Egyptian market.

Materials

The sludge used in the study was the coagulant sludge withdrawn from the clariflocculation tanks of the Giza Water Treatment Plant at Giza Governorate, Greater Cairo, in which aluminum sulfate was used in the coagulation process. The alum sludge is composed of about 1 % of suspended solids and 99 % of water, which is difficult to dewater. 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

Ingredient	Ratio by weight(%)
SiO_2	43.12
Fe_2O_3	5.26
Al_2O_3	15.97
CaO	5.56
MgO	0.85
SO_3	1.49
Na_2O	0.52
K_2O	0.26
Cl^-	0.012
L.O.I	26.79

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 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).

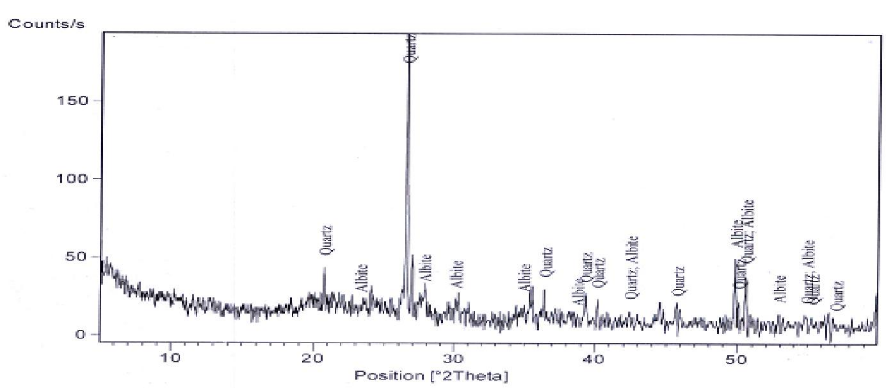

Figure (1): XRD Patterns of the Water Treatment Plant Sludge

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_2] and albite [Na Al Si_3 O_8]. 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 by filtering the sludge through a specially designed filter. The details of that filter are shown in Figure (2). The concentration of the suspended solids of the sludge, which trapped in the sludge-concentrating layer, 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. 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.

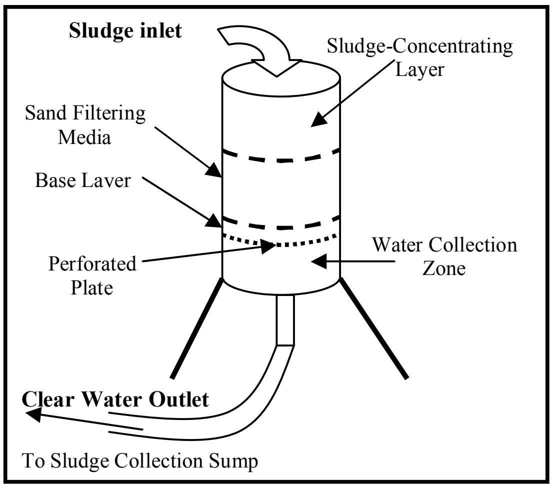

Figure (2): The Sludge Filter Used for Concentrating the Sludge

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 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 Imbabah, 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

Ingredient	Ratio by weight(%)
SiO_2	65.32
Fe_2O_3	7.51
Al_2O_3	13.89
CaO	1.09
MgO	0.95
SO_3	0.05
Na_2O	2.61
K_2O	0.75
TiO_2	1.46
P_2O_5	0.28
L.O.I	5.87

From Table (2), it is clearly obvious that is the major chemical compositions of the clay were silica, alumina, and ferric oxide. 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 very low value of L.O.I. indicates low organic content, which suggested that the removal or reduction of the organic content in the clay before sintering was not required. 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 (3).

The XRD scans were recorded from 0 – 30 °2θ. The XRD pattern of the powder clay, shown in Figure (3), indicates the presence of five major crystalline phases, namely, kaolinite [Al_2 Si_2O_5 $(OH)_4$], montmorillonite [(Nax $(Al,Mg)_2$ Si_4 O_{10} $(OH)_2$!z H_2O)], quartz [SiO_2], microcline [K Al Si_3 O_8], and illite-montmorillonite, regular [K- Al_4 (Si $Al)_8$ O_{20} $(OH)_4$!x H_2O]. 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 silica fume (SF) used in this study was the commercially available silica fume in the Egyptian market. The chemical composition was identified by using the X-ray fluorescence (XRF) spectrometer according to ASTM C114-00. The complete chemical composition of silica fume (SF) is summarized in Table (3).

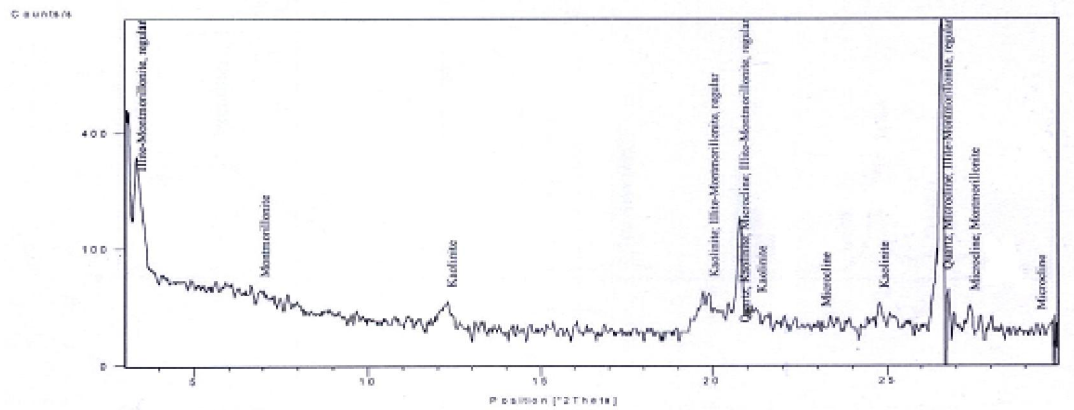

Figure (3): XRD Patterns of the clay

Table (3): Chemical Composition of Silica Fume

Ingredient	Ratio by weight(%)
SiO_2	96.19
Fe_2O_3	0.47
Al_2O_3	1.41
CaO	0.01
MgO	0.75
SO_3	0.02
Na_2O	0.31
TiO_2	0.01
L.O.I	0.81

From Table (3), it is evident that silica fume (SF) contains mainly silica, which is the major chemical composition of the brick clay and a small amount of alumina. As mentioned previously, the strength of the brick depends largely on the percentage of silica in the raw materials. These facts indicate that silica fume (SF) could be an excellent substitute for brick clay. The phase composition of SF was identified by using the X-ray diffraction (XRD) diffractometer, according to ASTM C114-00. The phase composition of silica fume (SF) is shown in Figure (4).

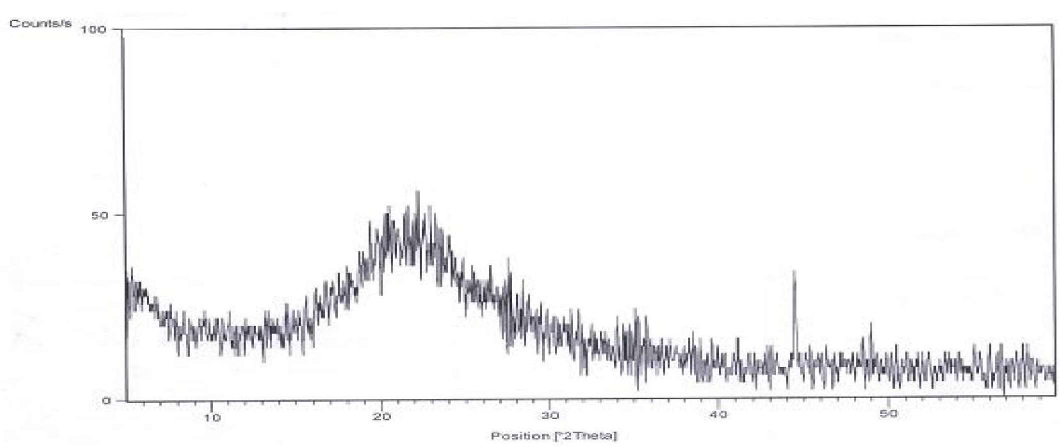

Figure (4): XRD Patterns of Silica Fume

The XRD scans were recorded from 5 – 60 $^{o}2\theta$. The XRD pattern of the silica fume (SF), shown in Figure (4), indicates that silica in the silica fume initially exists in the amorphous form, but will not remain porous and amorphous, when incinerated for a prolonged period at a temperature above 500° C [10]. These results indicate that silica fume (SF) presents, in its composition, amorphous silica that is similar to that commonly occurring in brick clays.

Sample Preparation

Four 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 Designation	Proportions by Weight (%)			
	Sludge	SF	Clay	Water (additional)
Control Brick	0	0	100	30
Series-A	25	75	0	40
Series-B	50	50	0	50
Series-C	75	25	0	50

Several mixing and preparation techniques were attempted. 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.

The drying of green molded bricks is then carried out in two steps. The first step is the enclosing and stacking of the green bricks in an air-tight box for not less than 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 four brick series, which mentioned previously in Table (4), were then fired at four different firing temperatures, 900, 1000, 1100, and 1200 ^{o}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, efflorescence, and compressive strength. The test methods were carried out according to E.S.S. No. 48,619/ 2003 [13] and the results of these properties are evaluated according to E.S.S. No. 1524/1993 [12], as shown in Table (5).

Table (5): 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

Results and Discussion

All tests were performed on (5 × 5 × 2) centimeters prisms, to ensure the reliability of the results. 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 (5). 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-SF brick ranged between 6.10 and 26.44 %, which comply with the requirements of the E.S.S. 1524/1993 for the load bearing walls. Compared to the control clay brick type, there were only two sludge-SF brick types that achieved lower water absorption than that of the 100 % clay brick type for the same firing temperatures, which contains 25 % of sludge (series A) and fired at 1100 and 1200 ^{o}C. 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, there were only four of the sludge-SF brick types that exhibited higher water absorption than Commercial Brick Sample (1), which attained 21.19 % water absorption. While only three types of the research sludge-SF brick types achieved lower water absorption than Commercial Brick Sample (2), which attained 10.77 % water absorption. These results are considered to be good enough to accept the water absorption ratio of the sludge-silica fume 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-SF 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.

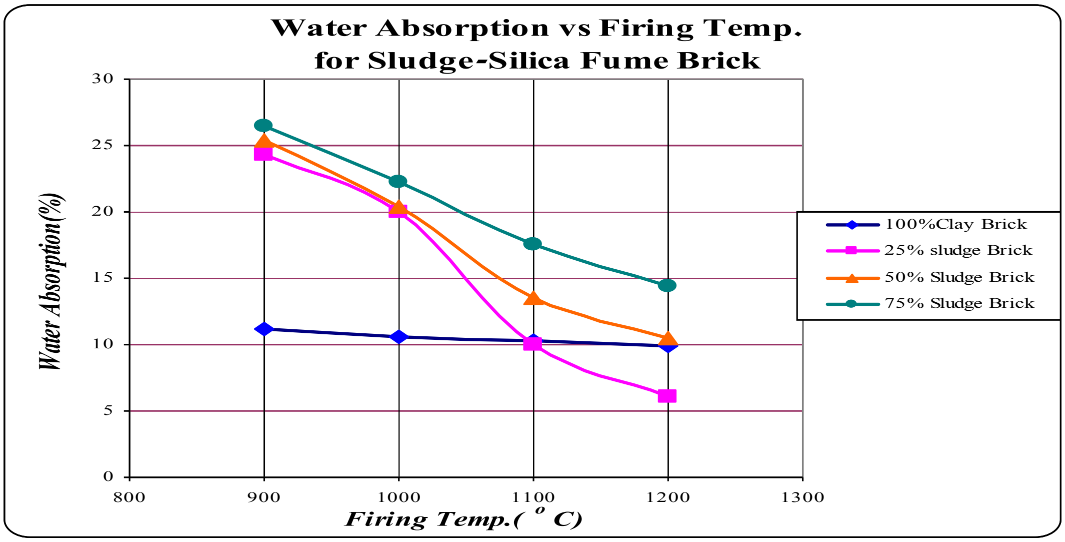

Figure (5): Water Absorption Test Results

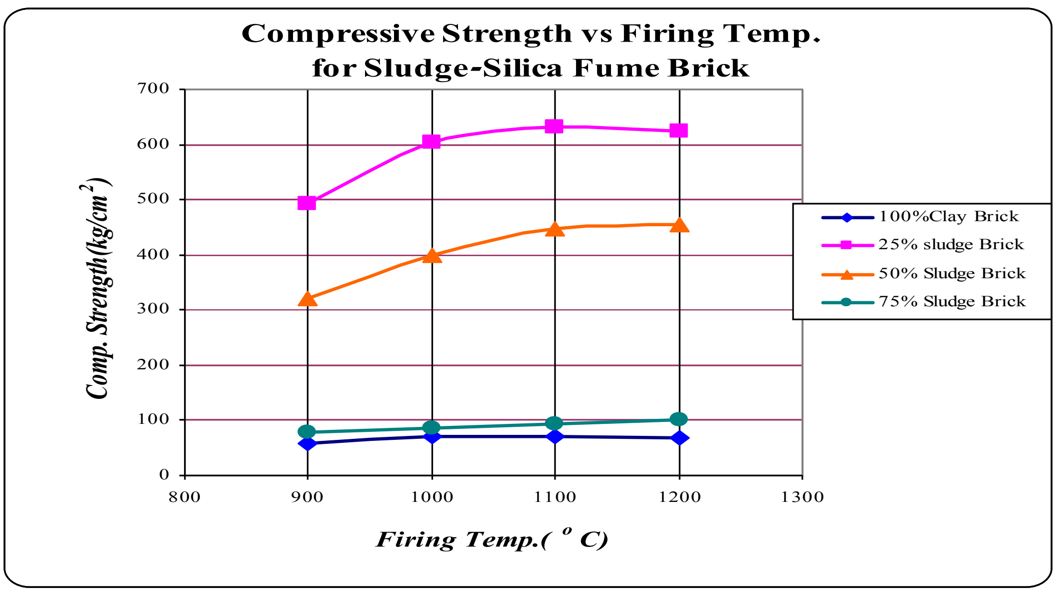

Figure (6): The Compressive strength Test Results

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^2. On the other hand, the compressive strength test results of sludge-SF brick ranged between 78.54 and 632.14 kg/cm^2, which comply with the requirements of the E.S.S. 1524/1993 for the load bearing walls. According to these results, the sludge-SF brick could be used in brickworks that require high strength. 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 increasing sludge ratio decreases the proportion of silica in the brick mixture, which, consequently, increases the open pores and reduce the compressive strength of the crystalline aluminosilicate sinter. Compared to the control clay brick, all of the sludge-SF brick achieved higher compressive strength than that of the control clay brick type for the same firing temperatures. Compared to the commercial brick types, all of the sludge-SF brick types achieved higher compressive strength than Commercial Brick Sample (1), which attained 27.51 kg/cm^2 compressive strength. While only one type of the research sludge-SF brick types achieved lower compressive strength than Commercial Brick Sample (2), which attained 79.57 kg/cm^2 compressive strength. Generally, the compressive strength of all the research sludge-SF brick types is superior to that of the control clay brick types and the 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 [14].

Conclusions

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:

1. Brick can be successfully produced from water treatment plant sludge incorporated with industrial waste materials; which contain high silica content; under the conditions, mixing proportions, firing temperatures, and manufacturing methods used in this study.
2. The water treatment plant sludge almost resembled the brick clay in its chemical composition but higher sintering temperatures are required, if used as a partial substitute for brick clay incorporated with industrial waste materials, due to its lower silica and higher alumina contents.
3. 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.
4. The physical properties of sludge brick can be enhanced by the addition of some industrial waste materials; which contain high silica content; such as silica fume, but the maximum percentage of water treatment plant sludge, which can be used in the mixture, is dominated by the practiced firing temperatures.
5. Generally, the test results of the research brick types were superior to both the research control clay brick types and commercial clay brick types available in the Egyptian market.
6. 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, 50 % was the optimum sludge addition to produce brick from sludge and silica fume mixture.

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References

[1] Prakhar, P.E. and Arup, K.S., 1998. Donnan Membrane Process: Principles & Application in Coagulant Recovery from Water Treatment Plant Residuals, Lehigh University, Bethlehem, PA 18015,.

[2] Lia, J.Y., and Liu, J.C., 2004. Co-conditioning and Dewatering of Alum Sludge and Waste Activated Sludge, Water Science and Technology, 50: 41-48,.

[3] Godbold, P., Lewin K., Graham A. and Barker P., 2003. The Potential Reuse of Water Utility Products as Secondary Commercial Materials, WRc Report No. UC 6081,.

[4] Anderson, M., Biggs, A. and Winters, C., 2003. Use of Two Blended Water Industry By-Product Wastes as A Composite Substitute for Traditional Raw Materials Used in Clay Brick Manufacture", Recycling and Reuse of Waste Materials, Proceeding of the International Symposium., p 417-426.

[5] Chihpin, H., Ruhsing, P.J., Sun, K.D., Liaw, C.T., 2001. Reuse of Water Treatment Plant Sludge and Dam Sediment in Brick-Making", Water Science and Technology, 44:273-277.

[6] Chihpin, H., Ruhsing, P.J., and Yaorey, L., 2005. Mixing Water Treatment Residual with Excavation Waste Soil in Brick and Artificial Aggregate Making", Journal of Environmental Engineering, 131: 272-277.

[7] Hassanain, A.M., 2008. Brick Manufacturing from Water Treatment Plant Sludge", M.Sc. Thesis, Civil Eng. Dept., Faculty of Eng., Benha Univ., Egypt.

[8] Ramadan, M.O., Fouad, H.A. and Hassanain, A.M., 2008. Reuse of Water Treatment Plant Sludge in Brick Manufacturing", Journal of Applied Sciences Research, 4:1223-1229.

[9] Hegazy, B.E., 2007. Brick Making from Water Treatment Plant Sludge", Journal of Engineering and Applied Science, 54:599-616.

[10] Holland, T.C., 2005. Silica Fume User's Manual", Silica Fume Association, Free Highway Association, FHWA-IF-05-016, USA.

[11] Prasad, C.S., Maiti, K.N. and Venugopal, R., 2003. Effect of Substitution of Quartz by Rice Husk Ash and Silica Fume on the Properties of Whiteware Compositions, Ceramics International, 29: 907-914,.

[12] Egyptian Standard Specifications E.S.S. 1524/ 1993, The Standard Specifications for Clay Bricks", 1993.

[13] Egyptian Standard Specifications E.S.S. 48,619/ 2003, "The Standard Methods for Testing of Building Bricks, Part 1: Standard Methods for Physical Tests of Building Bricks", 2003.

[14] Neville, A.M., 1989. Properties of Concrete, The English Language Book Society and Pitman Publishing, Third Edition, Vol. 3.

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