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 water stream 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 because 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 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 ^{o}C, giving 16 different brick types. The physical properties of the produced bricks were then determined and evaluated according to E.S.S. and B.S. The results indicated that by operating at the temperature commonly practiced in the brick kiln, 50 percent sludge was the optimum ratio, in the sludge-clay mixture, to produce brick from and 80 percent was the maximum practical sludge ratio. The produced bricks properties were superior to those available in the Egyptian market.

KEY WORDS: water treatment plant sludge – sludge disposal – clay – brick.

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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, children mental retardation, and the common effects of heavy metals accumulation (Prakhar, 1998). 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, 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 manufacturing.

Research carried out in the UK, assessed the potential of incorporating aluminum and ferric coagulant sludge in various manufacturing processes including clay brick (Godbold et al, 2003). A mixture consists of about 10 percent of the water treatment sludge and sewage sludge and incinerated ash was added to about 90 percent of natural clay to produce the brick. Anderson et al, (2003), 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 (Chihpin et al, 2001) 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, (2005) 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.

MATERIALS

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).

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 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).

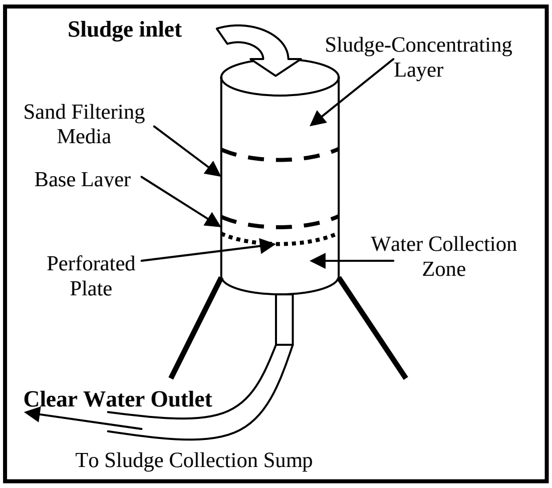

Figure (1): The Sludge Filter Used for Concentrating the Sludge

The concentration of the suspended solids of the sludge, which trapped in the sludge-concentrating layer, reaches 20 percent after two 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 ^{o}C for 1 and 2 hours period. It was found that, burning the pulverized sludge dust at 350 ^{o}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 sieving before using in brick manufacturing, as in case of dried sludge. The clay was oven dried to remove its moisture content.

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 cm are shown in Table (2).

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

Several mixing and preparation techniques were attempted. The best sample preparation technique was found to be similar to that adopted in actual manufacturing process. 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 lump and the compressing of the clay-sludge mixture, using a hydraulic piston, into the brick nominal dimensions was the followed practice. This process is analogous for the extrusion machine, which is used in modern brick factories.

The drying of green molded bricks was then carried out in two steps. The first step was done by enclosing and stacking of the green bricks in an air-tight box 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 ^{o}C giving a 16 different brick types. The produced bricks were tested for their mechanical properties.

TESTING BRICK PROPERTIES

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 were evaluated in accordance with **E.S.S. No. 48,619/ 2003** and **BS 3921:1985**.

RESULTS AND DISCUSSION

All of tests were performed on 5 × 5 × 5 cm 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, It should be noted that using 5 × 5 × 5 cm cubes should result in a lower value of brick compressive strength than that which would be obtained if 25 × 12 × 6.5 cm brick were used due to size effect **(Neville, 1989).**

The first reference brick was designated as "commercial brick sample (1)", was solid clay-brick type fired at 800 ^{o}C. The other brick sample, referred to as "commercial brick sample (2)", was perforated wirecut clay-brick type fired at 950 ^{o}C.

The durability of the brick, and consequently masonry, is basically 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 **E.S.S. 1524/1993**. Five brick types exhibited Water absorption less than 7.0 percent, which met the requirements of the **BS 3921:1985** for Engineering 'B' Bricks.

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 bricks 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. These types were that contained 80% sludge and fired at 950, 1000, and 1050 ^{o}C.

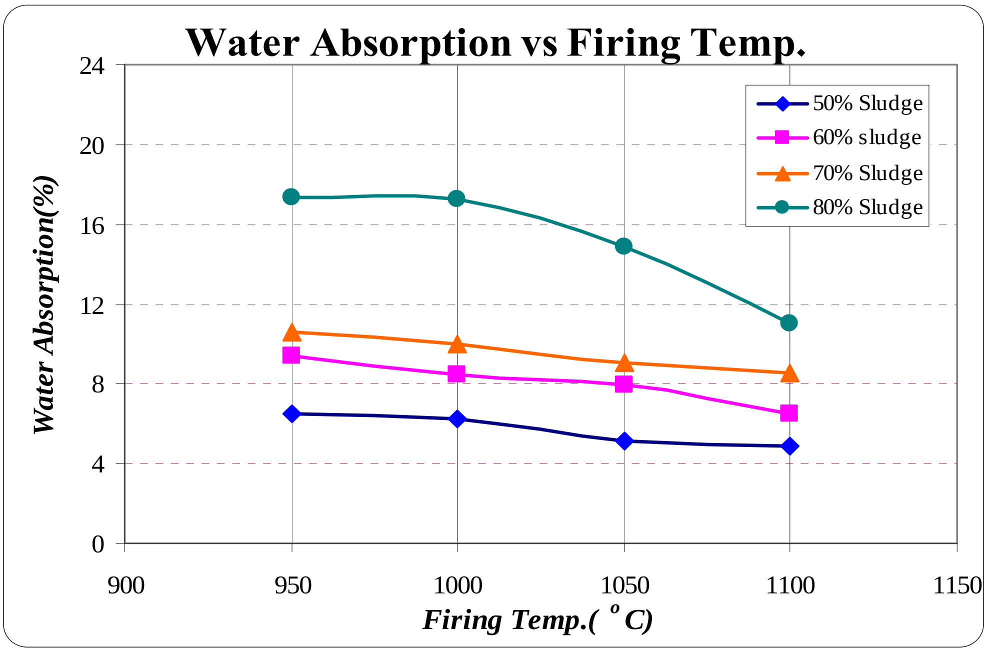

Figure (2): Water Absorption Test Results

The initial rate of suction (IRS) test is specified by **BS 3921: 1985** to help in the improvement of the brick-mortar bond. The IRS test results are shown in **Fig. (3)**. The results of initial rate of suction test ranged between 1.12 and 8.24 kg/m^2/minute. These values indicate high IRS There were only two brick types that had IRS less than 2 kg/m^2/min., which met the requirements of the **BS 5628: 1987**. However, the high IRS values should not represent any disadvantage. Brick units having I.R.S. exceeding 2 kg/m^2/min. should be pre-wetted prior to laying as specified by **ASTM C62**.

All research brick types achieved lower IRS than that of the Commercial Brick Sample (1), which reached 8.78 kg/m^2/min. IRS. Yet, only three units of the research brick achieved higher IRS than Commercial Brick Sample (2), which recorded 5.94 kg/m^2/min.

Like ceramics, fired bricks exhibit long-term expansion upon exposure to moist air, due to the chemical reaction between some compounds in ceramic body and moisture. Moist air expansion is a progressive phenomenon and continues indefinitely, although at a diminishing rate **(Jackson and Dhir, 1996)**. This

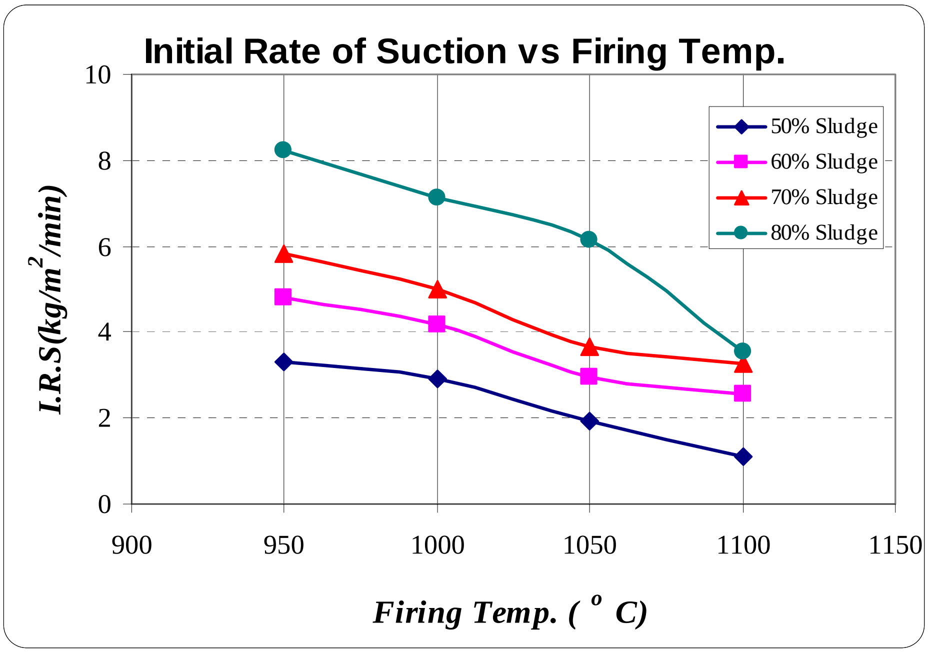

Figure (3): Initial Rate of Suction Test Results

expansion can be divided into permanent and reversible divisions. It is therefore recommended to use brick after certain standing time to allow for permanent expansion to take place.

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. It can be concluded from **Fig. (4)** that moist air expansion increased with the decrease of firing temperature and the increase of sludge ratio in the raw materials mixture. This may be attributed to the fact that increasing firing temperature completes the crystallization process and closes the open pores in the brick ceramic structure, reducing 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 the soil in contact with the brickwork, or may be derived 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 cause disfiguration to masonry, but it is often harmless and disappears after a few seasons. However, efflorescent salts may contain high sulfates and attack the cementing mortar joints.

The efflorescence was of **"Nil"** class for all of the studied sludge-clay bricks, to the requirements of the **E.S.S. 1524/1993**. These results could be considered as an indicator for the low values of soluble salts of the brick. In addition, the commercial brick types exhibited no efflorescence.

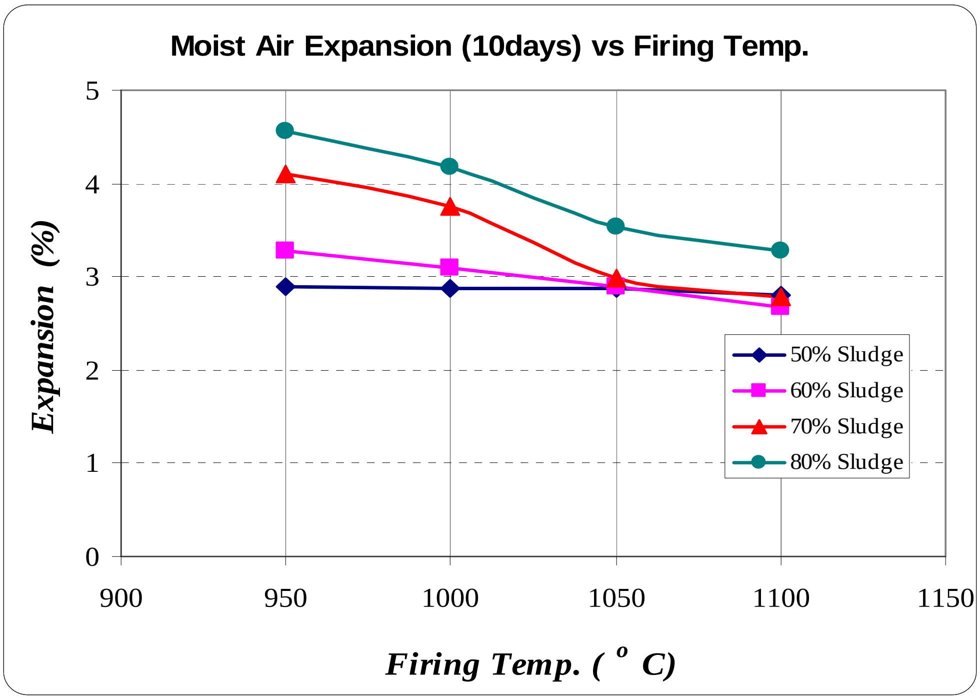

Figure (4): The Moist Air Expansion Test Results

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 **Fig. (5)**. The results of compressive strength test ranged between 23.49 and 118.94 kg/cm^2. These values indicate that almost all of the research brick types can be used in the load bearing walls according to the **E.S.S. 1524/1993**. Only bricks made with 80 percent sludge ratio and fired at 950 and 1000 ^{o}C respectively, did not achieve the Egyptian standard requirements for wall bearing bricks, and can be used only in the none load bearing masonry.

There were six brick types that exhibited compressive strength higher than 75 kg/cm^2, which met the requirements of the **B.S. 5628:1987** for Engineering 'A' bricks, 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/cm^2 compressive strength. Furthermore, three of the studied brick samples realized compressive strength higher than that of the Commercial Brick Sample

(2), which attained 79.1 kg/cm^2. As it was stated earlier, the use of (5 × 5 × 5) centimeters prisms as brick samples would reduce the value of the measured compressive strength compared to similar sample of (25 × 12.5 × 6.5) centimeters size **(Neville, 1989).**

Another compressive strength test was carried out to study the effect of sever exposure to moisture on strength. In this test the compressive strength of the samples was determined after being submerged in water for seven days and compared to the corresponding values of standard test. The reduction in compressive strength after being submerged was estimated. These results may be considered as an indication for softening under similar sever exposure conditions.

A notable reduction in the strength of the brick is anticipated, since the submerging of brick in water for 7 days may cause deterioration and scaling to the brick. The results of the reduction in compressive strength after 7 days submerging 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 investigated bricks, except one, lost less strength than Commercial Brick Sample (1), which was dropped by 55.4 %. Additionally, only four of the research brick samples lost strength more than Commercial Brick Sample (2), which declined by 36.7 percent.

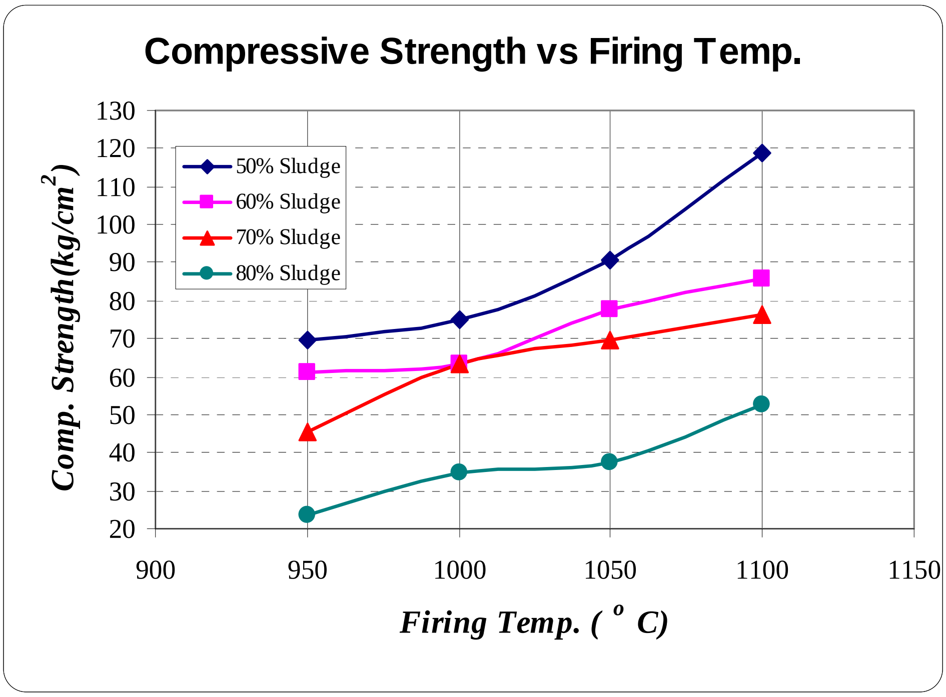

Figure (5): The Compressive strength Test Results

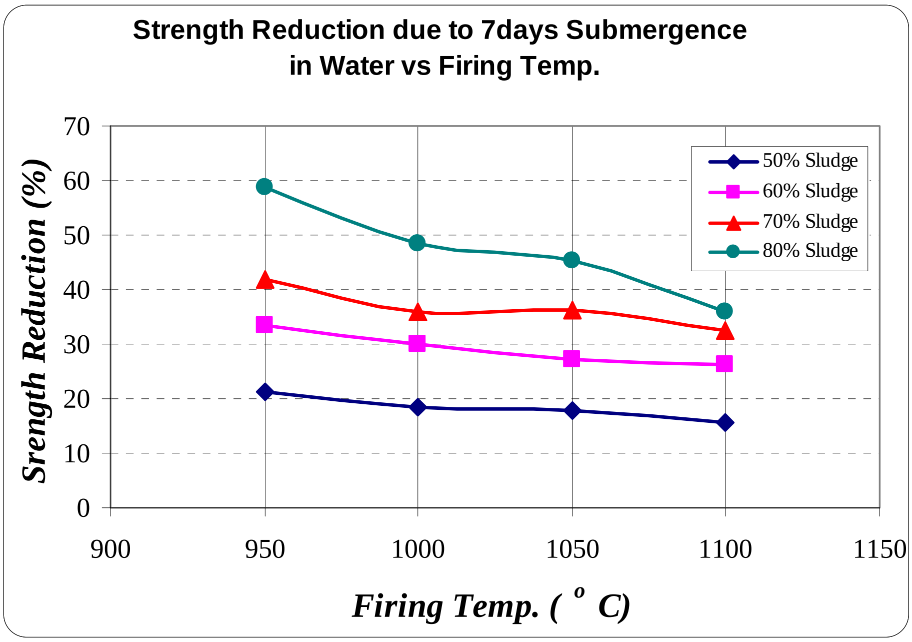

Figure (6): The Reduction in Compressive strength after submergence in Water for 7Days Test Results

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 reasonable sludge addition to produce sludge-clay brick.

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