Assessment of Ceramic Tiles Sludge as a Brick Manufacturing Material

Sabry A. Ahmed, M.E. Metwally and S.E. Zakey
Faculty of Engineering, Zagazig University
Zagazig, P.O. Box 44519, Egypt.

***Abstract*— The ceramic tiles industry produces many wastes such as ceramic sludge, broken under quality tiles and ceramic dust. Recycling of such wastes in the construction industry shares in the environmental protection against the pollution caused by their accumulation; in addition to saving the great need of row materials required for such industry. In this study, the ceramic sludge (CS) was mixed with dune sand to produce sand-CS bricks at contents of 30, 40, 50, 60, 70 and 100 % CS by the dry weight of the mix. The brick specimens made from these mixes were burned at 950 ^{0}C for 6 hours and tested for compressive strength, unit weight and water absorption. Furthermore, two mixes with 70 and 100 % CS were selected to study the effect of burning temperature and time on the properties of corresponding bricks. Burning of these mixes specimens was carried out at 800, 900 and 950 ^{0}C for 4, 6 and 8 hours. The results showed that the optimum content of CS was 70 % and the optimum burning was found at 950 ^{0}C for 6 hours, at which the compressive strength, unit weight and water absorption of sand-CS bricks were 19.53 MPa, 1.37 ton/m^3 and 12.40 %, respectively. The corresponding values for bricks with 100 % CS were 15.20 MPa, 1.28 ton/m^3 and 14.15 %, respectively.**

Keywords— ***Ceramic Tiles Sludge; Sand-Ceramic Sludge Bricks; Burning Temperature And Time*.**

I. INTRODUCTION

The disposal of industrial wastes comprises one of the major worldwide environmental problems. In numerous countries, the limitations of number of dumping landfill sites and the general disposal methods have rendered the environment unfriendly. The use of industrial wastes in brick manufacturing has attracting growing interest of researcher in recent years and is becoming a common practice [1-5]. With increasing demands of the construction industry, bricks quality and cost become more important day by day in Egypt.

In Egypt, every year huge growing amounts of ceramic wastes in the form of ceramic sludge, broken under quality tiles and ceramic dust are produced from ceramic tiles industry. Re-use of ceramic wastes in concrete and brick manufacturing showed a valuable results [6-10]. El–Fadaly et al. [11] investigated the possibility of recycling some ceramic wastes including cyclone dust, sludge and filter dust in manufacturing of floor tiles composed of 50 % clay, 45 % feldspar and 5 % talc. They were added to the mix at 2.5 to 10 % of its dry weight. The tested specimens were pressed at 225 bar then fired in an industrial kiln at 1190 ºC for 35 minutes. The results showed that the physico-mechanical properties of tiles were enhanced by the addition of cyclone dust, while deteriorated by the addition of sludge although they were still within the acceptable range of such products. On the other hand, the addition of filter dust to the floor tiles constituents had nearly no effect on their physico-mechanical properties.

Andreola et al. [12] re-used the ceramic glazing sludge deriving during the purification process of waste-water obtained from the glazing tile phase in the manufacturing of a high sintered floor/wall covering tiles. Results of technological tests and scanning (SEM) analysis showed a dense microstructure with crystalline phases similar to commercial glass-ceramic. Also, the product was achieved with energy saving due to lowering the firing temperatures to 1000°C instead of 1200°C.

Abdel-Ghafour [13] used the ceramic sludge solid waste as a replacement of clay to produce green building bricks. He found that incorporating 15% ceramic sludge to clay decreased the plasticity coefficient with insensitive behavior upon drying; in addition to suitable physical and mechanical properties of the fired bricks.

Nandi et al. [14] studied the possibility of using ceramic sludge resulting from a waste-water treatment of ceramic tiles and the recycled glass to obtain a ceramic engobe for the production of single-fire ceramic tiles. Seven mixes were prepared with 20-80 % by weight ceramic sludge and 12-48 % recycled glass in combination with calcite, dolomite, ulexite and saltpeter as raw materials. The results showed that the incorporation of these wastes would allow for the obtainment of ceramic frits for producing ceramic engobes.

The present paper aims to study the effect of adding ceramic sludge on the properties of sand bricks for economical and environmental benefits. Dune sand–CS bricks were produced with 30, 40, 50, 60, 70 and 100 % CS of the dry weight then burned at 950 ^{0}C for 6 hours. To achieve the aim, the properties of bricks in terms of compressive strength, unit weight and water absorption were measured according to British standard procedure. Furthermore, the effect of the burning temperature of 800, 900 and 950 ^{0}C and burning time of 4, 6 and 8 hours on the properties of sand-CS bricks were measured at 70 and 100 % CS.

II. EXPERMINTAL WORK

The materials used in this study were sand and ceramic sludge. The sand was dune sand from Sinai desert, it had a yellow color and its particles were very fine; passing through sieve No. 30. Its specific gravity and fineness modulus were 2.8 and 2.5, respectively. The chemical composition of sand is shown in Table I. The ceramic sludge (CS) is one of the ceramic tiles industry wastes, which produced during washing of burned tiles by water through special pressed water filters.

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 5 Issue 10, October-2016

Its chemical composition is shown in Table I and its bulk density was 1.4 ton/m^3. The ceramic sludge was grinded to the limit that it passed through sieve No. 50.

TABLE I. CHEMICAL COMPOSITION OF DUNE SAND AND CS.

Oxide Component	Weight (%)	
	Dune sand	*Ceramic sludge (CS)*
SiO_2	88	44.83
TiO_3	-	1.23
Al_2O_3	2.2	27.72
$Fe_2O_{3\ total}$	4.7	3.57
MnO	-	0.05
MgO	0.19	0.85
CaO	1.5	5.88
Na_2O	0.40	1.50
K_2O	0.19	1.52
P_2O_5	-	0.55
SO_3	-	0.13
Cl^-	0.14	0.03
LOI	1.88	8.4

To study the effect of CS content on the properties of sand-CS bricks six mixes were prepared with 30, 40, 50, 60, 70 and 100 % CS of the dry weight of mix. The flow test was used to adjust the quantity of water required to maintain a target slump of 65-85 mm flow diameter. Brick specimens cast from these mixes were subjected to 950 ^{0}C for 6 hours then the compressive strength, bulk density and water absorption were measured.

The effect of burning temperature and time on the properties of sand-CS bricks was carried out on the specimens of mix contained the optimum content of CS, which showed the highest compressive strength, and also on the specimens made of 100 % CS. Specimens of these mixes were subjected to burning temperature of 800, 900, 950 ^{0}C for 4, 6 and 8 hours.

The steel mold shown in Fig. 1 was used to produce hollow brick specimens with standard dimensions of 25x12x6 cm [15]. Casting of specimens was carried out by filling the mold with the mix in three layers; each layer was subjected to manual compaction. The steel cover was adjusted on the mold and pressed by hand to immerse the steel fingers in the mix. The extra mix was got out from the space between the steel cover and the mold sides, and removed. The whole mold was put in the compression testing machine and compressed till the steel fingers reached the mold base. The brick specimen was removed from the mold and stored in the laboratory until complete drying.

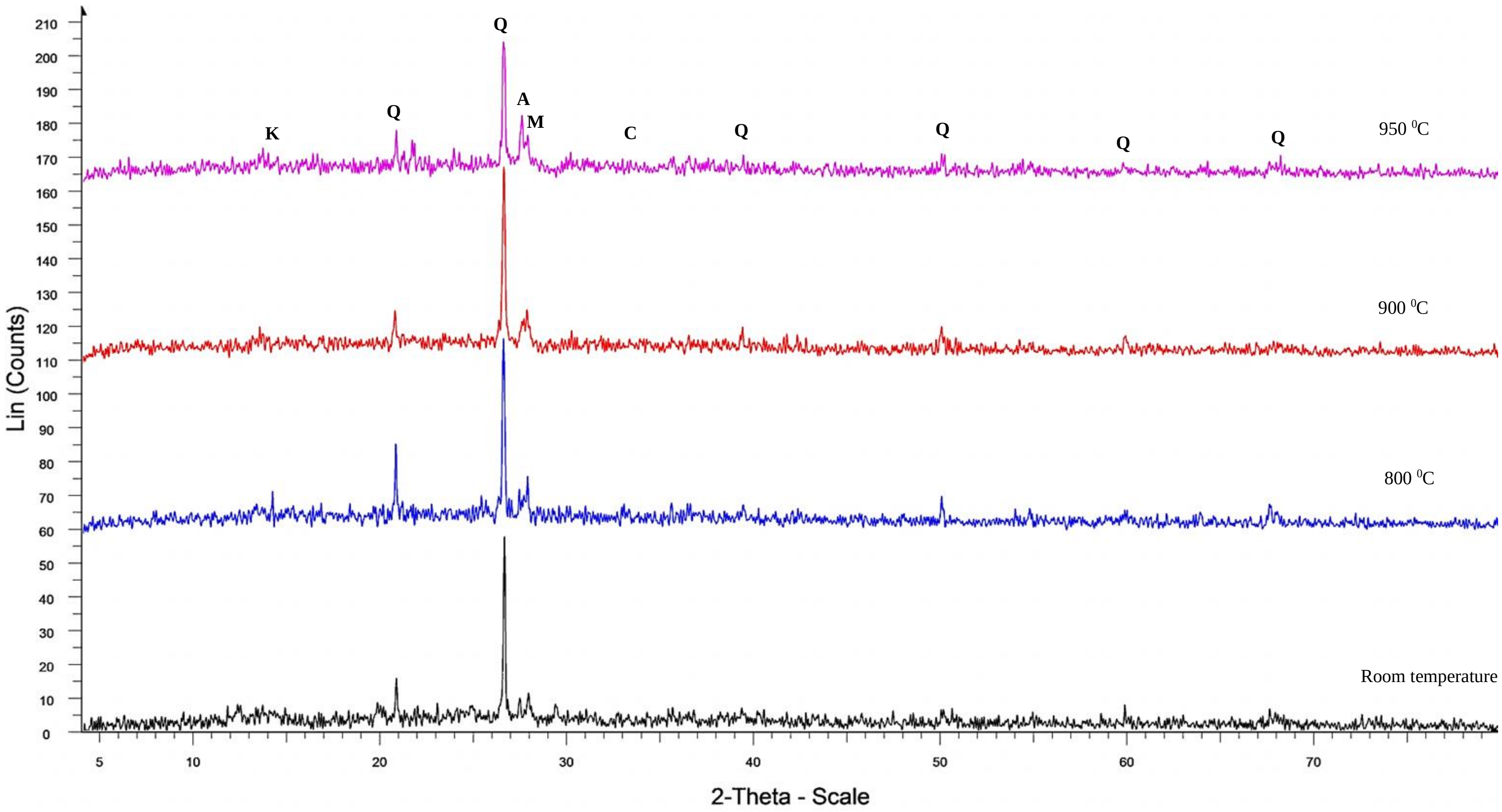
Compressive strength, unite weight and water absorption tests were carried out on the brick specimens according to the British standard test procedure; BS EN 772-1: 2011 [16], BS EN 772-13: 2000 [17] and BS EN 772-21: 2011[18], respectively. Also, the XRD was employed to analyze the change of phases at different temperatures.

Fig. 1. Steel mold.

III. RESULTS AND DISCUSSIONS

The mineralogical composition of ceramic sludge was characterized using XRD for one sample at room temperature (without curing) and also for another three samples burned at 800, 900 and 950 ^{0}C for six hours, see Fig. 2. The main phases in the different cases are summarized in Table II. As clearly observed the main phases in the unburned sample were quartzes low (SiO_2), microcline ($KAlSi_3O_8$), albite ($NaAlSi_3O_8$), kaolinite ($Al_2Si_2O_5(OH)_4$) and calcite ($CaCO_3$). The calcite was the minor phase. The main phases in the samples subjected to burning at different temperatures were quartzes low, microcline, albite and minor ratio of cristabalite (SiO_2) of 4.2 % in case of sample subjected to 950 ^{0}C only. Table 2 shows that for temperature $\geq$ 800 ^{0}C there was a complete dissolving of calcite and kaolinite. Also, there was a noticeable reduction in the quartze low and albite ratios with the increase in burning temperature. They were 40.7 and 34.3% at 800 ^{0}C and decreased to 24.9 and 26.1 % at 950 ^{0}C, respectively, due to melting. On the other hand, microcline ratio was increased from 25.0 % at 800 ^{0}C to 44.8 % at 950 ^{0}C as a result of the increase in its crystalline phase content. These crystals were embedded in the melting matrix.

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 5 Issue 10, October-2016



K: Kaolinite, Q: Low Quartz, A: Albite, M: Microclin, C: Calcite

Fig. 2. Mineralogical composition of CS at different temperatures.

TABLE II. MAIN PHASES OF CS WITH AND WITHOUT BURNING.

Oxide Component	Chemical Name	Without Burning	Burning Temperature (ºC) for 6 hrs.		
			800	*900*	*950*
Quartize Low	SiO_2	26.6	40.7	37.9	24.9
Microcline	$KAlSi_3O_8$	24.0	25.0	27.9	44.8
Albite	$NaAlSi_3O_8$	24.0	34.3	34.1	26.1
Cristablite	SiO_2	-	-	-	4.2
Kaolinite	$AlSiO_2O_5(OH)_4$	18.6	-	-	-
Calcite	$CaCO_3$	6.8	-	-	-

The compressive strength of sand-CS bricks made with different contents of CS is shown in Fig. 3. There was a gradual increase in the compressive strength with increasing the CS content from 30 to 70 %, while a little decrease was observed at 100 % CS. For example, the compressive strength of brick specimens made with 30% CS was 6.6 MPa and increased to 19.53 MPa at 70 % CS then decreased to 15.20 MPa at 100% CS. The increase in compressive strength with increasing the CS content may be due to the decrease in silica content and the increase in contents of mineral oxides. The mineral oxides acted as fluxes, which decreased the melting temperature and led to more liquid phase content and more close of opening pores thus create more stiff structure. At 100% CS there was a decrease in the compressive strength due to the complete absence of sand; presence of sand in the mix improves the strength of bricks by its physical action.

Figure 4 presents the relationship between the unite weight of sand-CS bricks and the CS content. As can be seen there was a gradual decrease in the unit weight with increasing the CS content. For example the unite weight at 30% CS was 1.58 ton/m^3 and gradually decreased to 1.28 ton/m^3 at 100 % CS. This can be discussed by the gradual decrease in the sand content, which had a higher unit weight of 2.8 ton/m^3 relative to that of CS, which was 1.4 ton/m^3.

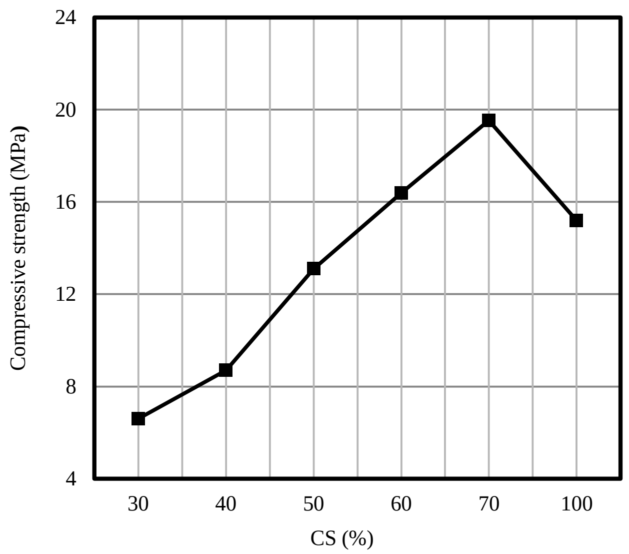


Fig. 3. Compressive strength of sand-CS bricks.

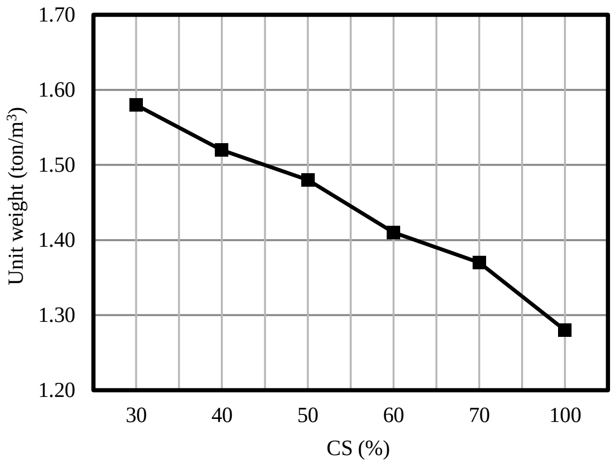


Fig. 4. Unit weight of sand-CS bricks.

Figure 5 illustrates the relationship between the water absorption of sand-CS bricks and the CS content. The results showed a marginal increase in the water absorption with increasing the CS content till 70 % then sharp increase at 100%. From 30 to 70 % CS the water absorption was increased from 11.7 to 12.4 %, however at 100 % CS it reached 14.5 %. The increase in water absorption with increasing the CS content may be due to the higher absorption of CS relative to the sand.

The above mentioned results showed that the optimum content of ceramic sludge in sand-CS bricks was 70 % of the dry weight. Brick specimens made with 70 % CS and 30 % sand had the highest compressive strength of 19.53 MPa combined with moderate unit weight of 1.37 ton/m^3 and acceptable water absorption of 12.4 %.

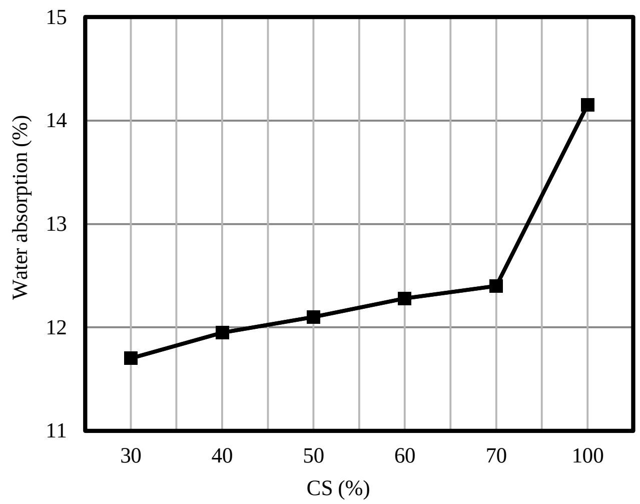


Fig. 5. Water absorption of sand-CS bricks.

The effect of burning temperature and time on the compressive strength of sand-CS bricks with 70 and 100 % CS is shown in Figs. 6, 7. In both cases, the compressive strength was increased with increasing the burning temperature and time. The compressive strength of 70 % CS brick specimens burned at 800 ^{0}C was 8.8 Mpa at 4 hours and increased to 11.3 and 13.3 MPa at 6 and 8 hours, respectively. The

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 5 Issue 10, October-2016

corresponding results for specimens made with 100 % CS were 5.7 MPa at 4 hours and 9.4 and 11 MPa at 6 and 8 hours, respectively. Similarly, the increase of burning temperature from 800 to 900 and 950 ^{0}C increased the compressive strength at 6 hours burning time from 11.3 MPa to 16.8 and 19.5 MPa for brick specimens made with 70 % CS and from 9.4 MPa to 12.6 and 15.2 MPa for brick specimens made with 100 % CS, respectively. These results can be discussed by the increase in the content of melting phases with the increase in the burning temperature and/or time. The melting phases closed the pores and led to more stiff structure with less content of pores. Also, they worked as bonding materials.

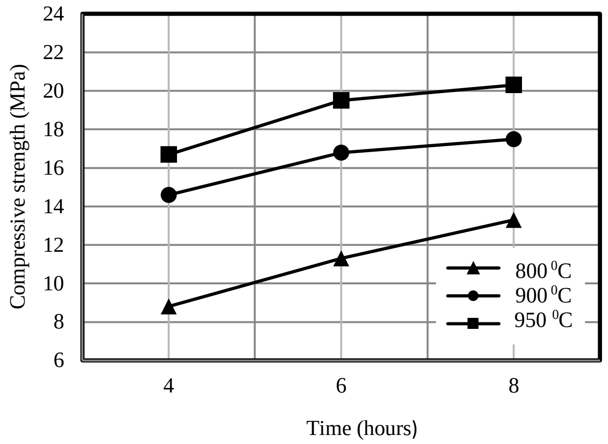


Fig. 6. Effect of burning temperature and time on the compressive strength of bricks with 70 % CS.

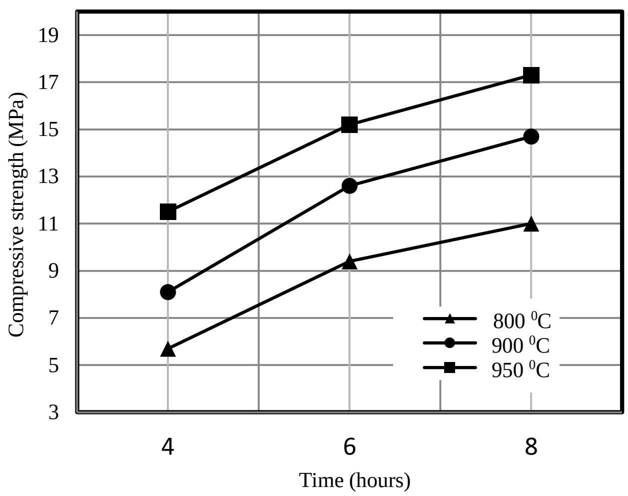


Fig. 7. Effect of burning temperature and time on the compressive strength of bricks with 100 % CS.

Figures 8 and 9 present the effect of burning temperature and time on the unit weight of sand-CS bricks with 70 and 100% CS, respectively. Different trend of results was observed at different burning temperatures; however, little variation in the value of unit weight was occurred with increasing the burning time. Generally, the unit weight of the brick specimens made with 100 % CS were lower than those contained 70 % CS due to the great difference in the unit weight of CS relative to that of sand as mentioned earlier. In the two cases of bricks the highest values of the unit weight were observed in the specimens burned at 800 ^{0}C for 4 hours then slightly decreased with increasing the burning time. This means that burning of organic materials and dissolution of $CaCO_3$ had taken place near 800 ^{0}C and more pores were opened with increasing the burning time, however, the melting temperature had not been reached yet.

With increasing the burning temperature to 900 ^{0}C more burning of organic materials and more dissolution of $CaCO_3$ had been occurred, therefore, the unit weight of both mixes (70 and 100 % CS) at 4 hours burning time were lower than those subjected to 800 ^{0}C and slightly decreased with increasing the burning time to 6 hours, see Figs. 8 and 9. However, beginning of the increase in the unit weight for specimens subjected to 900 ^{0}C for 8 hours indicated that the milting phase with amorphous structure began to form and began to close the small open pores. The milting phase was increased with increasing the burning temperature to 950 ^{0}C, so the results of unit weight were increased in comparison with those at 900 ^{0}C. At 950 ^{0}C, the unit weight of both mixes was increased with increasing the burning time as a result of the increase of the liquid phase content and formation of the crystalline structure in the small pores.

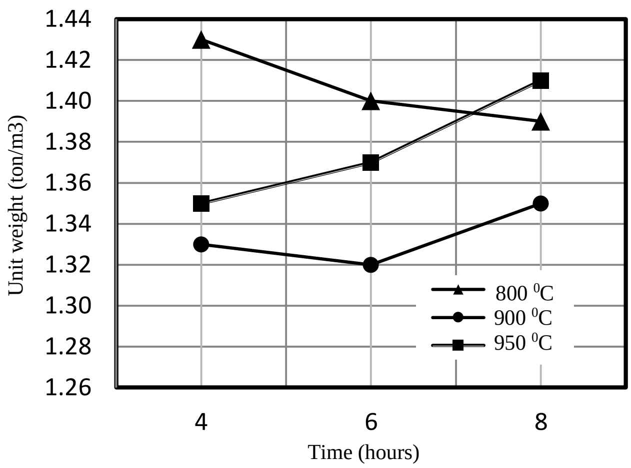


Fig. 8. Effect of burning temperature and time on the unit weight of bricks with 70 % CS.

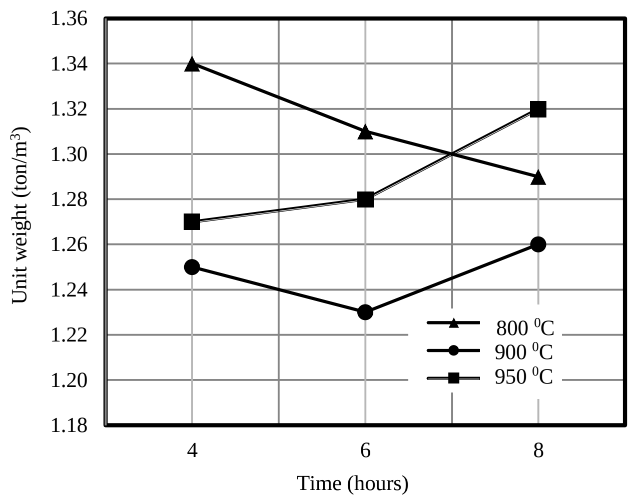


Fig. 9. Effect of burning temperature and time on the unit weight of bricks with 100 % CS.

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 5 Issue 10, October-2016

The effect of burning temperature and time on the water absorption of mixes with 70 and 100 % CS is shown in Figs. 10 and 11. The lower values of absorption were observed in specimens subjected to 800 ^{0}C burning temperature. With increasing the burning time the water absorption was increased as a result of increasing the pore content due burning of organic materials and dissolution of $CaCO_3$ as described earlier. More pore content was developed at 900 ^{0}C with more increase in the water absorption. However, the results of 950 ^{0}C began to decrease as a result of milting and closing of small pores. Generally, the results of water absorption matches the results obtained for the unit weight.

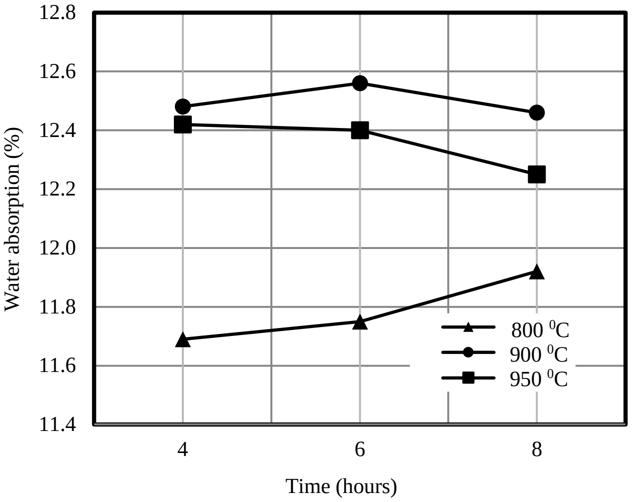


Fig. 10. Effect of burning temperature and time on the water absorption of bricks with 70 % CS.

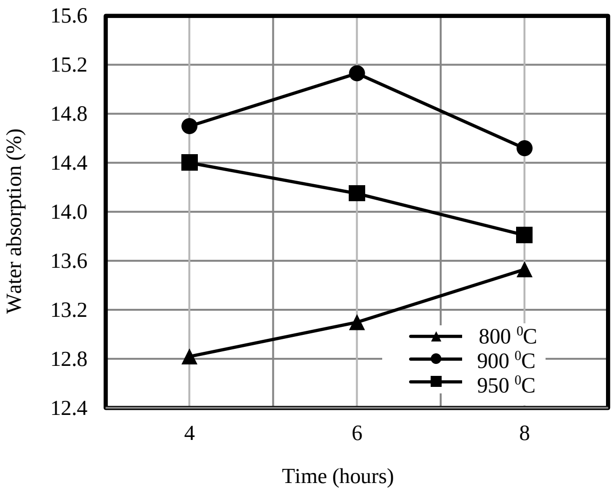


Fig. 11. Effect of burning temperature and time on the water absorption of bricks with 100 % CS.

IV. CONCLUSIONS

The experimental results showed that the ceramic sludge can be successfully recycled in brick industry to produce green building units with reasonable cost. It can be added to dune sand to produce sand-CS bricks; the optimum content was found at 70 % CS, or it can be used alone to produce building brick with 100 % CS. In both cases, there was a gradual improvement in the compressive strength of bricks with increasing the burning temperature and/or time. However, there was a variable effect on the results of the unit weight and water absorption as a result of heat on the internal pore content due to burning of organic materials, dissolution of $CaCO_3$ and milting phase. The optimum burning was found at 950 ^{0}C temperature for 6 hours; at which the compressive strength, unit weight and water absorption of sand-CS bricks with 70 % CS were 19.53 MPa, 1.37 ton/m^3 and 12.40 %, respectively. The corresponding values for bricks with 100 % CS were 15.20 MPa, 1.28 ton/m3 and 14.15 %, respectively.

REFERENCES

[1] Abdul Kadir A. and Abdul Rahim A., "An Overview of Sludge Utilization into Fired Clay Brick", World Academy of Science, Engineering and Technology International Journal of Environmental, Chemical, Ecological, Geological and Geophysical Engineering, Vol. 8, Issue 8, 2014, pp. 567-571.

[2] Hegazy B. Fouad H. and Hassanain A.," Incorporation of Water Sludge, Silica Fume and Rice Husk Ash in Brick Making", Materials and Structures/ Advances in Environmental Research, Vol. 1, Issue 1, 2012, pp. 83–96.

[3] Bilgina N., Yeprem H., Arsla S., Bilgin A., Gunay E. and Mars M., "Use of Waste Marble Powder in Brick Industry", Construction and Building Materials, Vol. 29, 2012, pp. 449–457.

[4] Khater H., "Utilization of Demolished Concrete, Grog, Hydrated Lime and Cement Kiln Dust in Building Materials", Journal of Mechanical Engineering Research, Vol. 3, Issue 8, August 2011, pp. 279-285.

[5] Giuseppe C. and Eduardo S., "Fly Ash Addition in Clayey Materials to Improve the Quality of Solid Bricks", Construction and Building Materials, Vol. 23, 2009, pp. 1178–1184.

[6] Hiroshi H., Manote S., Mutsumi M. and Osamu T. "Efficiency of Ground Granulated Blast-Furnace Slag Replacement in Ceramic Waste Aggregate Mortar", Cement and Concrete Composites, Vol. 49, May 2014, pp. 43–49.

[7] Patel J., Shah B. and Patel P., "The Potential Pozzolanic Activity of Different Ceramic Waste Powder as Cement Mortar Component (Strength Activity Index)", International Journal of Engineering Trends and Technology (IJETT), Vol. 9, Issue 6, Mar 2014, pp. 267-271.

[8] Juan A., Medina C., Guerra M.., Morán M., Aguado P.,De Rojas M., Frías M. and Rodríguez O., "Re-Use of Ceramic Wastes in Construction", Ceramic Materials, September 2010, pp. 197-214.

[9] Kusiorowski R., Zaremba T. and Piotrowski J., "The Potential Use of Cement–Asbestos Waste in the Ceramic Masses Destined for Sintered Wall Clay Brick Manufacture", Ceramics International, Vol. 40, Issue 8, Part A, Sept. 2014, pp. 11995–12002.

[10] Da Silva V., Góis L., Duarte J., Da Silva J. and Acchar W.,"Incorporation of Ceramic Waste into Binary and Ternary Soil-Cement Formulations for the Production of Solid Bricks", Materials Research, Vol. 17, Issue 2, 2014, pp. 326-331.

[11] El Fadaly E., Bakr I. and Abo Breka M., "Recycling of Ceramic Industry Wastes in Floor Tiles Recipes", Journal of American Science, Vol. 6, Issue10, 2010, pp. 224–247.

[12] Andreola F., Barbieri L.and Lancellotti I., "Recovery of Glazing Ceramic Sludge in Construction Materials" 2nd International Conference on Sustainable Construction Materials and Technologies, Università Politecnica delle Marche, Ancona, Italy, June 28 – 30, ISBN 978-1-4507-1490-7, 2010.

[13] Abd El-Ghafour N., " Making Green Building Units by Using Some Wastes of Ceramic Industry", Proceedings of the 10th International Conference for Enhanced Building Operations, Kuwait, October 26-28, 2010.

[14] Nandi V., Raupp-Pereira. F, Montedo O. and Oliveira A., "The Use of Ceramic Sludge and Recycled Glass to Obtain Engobes for Manufacturing Ceramic Tiles", Journal of Cleaner Production, Vol. 86, Issue 1, January 2015, pp. 461-470.

[15] Ahmed S., Metwally M. and Zakey S.," Utilizing Industrial Waste-Water as Alkali Activator in Sand-Cement Kiln Dust Bricks" , Journal of Structure Engineerig and Mechanics, in Press.

[16] BS EN 772-1, "Methods of Test for Masonry Units, Part 1: Determination of Compressive Strength", BSI Standers Publication, 2011.

[17] BS EN 772-13, "Methods of Test for Masonry Units, Part 13: Determination of Net and Gross Dry Density of Masonry Units", BSI Standers Publication, 2000.

[18] BS EN 772-21, "Methods of Test for Masonry Units, Part 21: Determination of Water Absorption of Clay and Calcium Silicate Masonry Units by Cold Water Absorption", BSI Standers Publication, 2011.