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Fabrication and Characterization of Geopolymer Bricks using Construction and Demolition Waste

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Abstract- The current study presents the preparation of geopolymer bricks from costless raw materials, mainly industrial wastes, besides using construction and demolition solid waste (C&D) as a substituent with different proportions to homra (waste from clay brick industry), calcium hydroxide (waste resulting from acetylene industry) and NaOH to decrease the number of pollutants released to the environment, moreover reduction of CO_2 emission to the atmosphere that produced from the firing of normal bricks. The economic merit in the fabrication of geopolymer bricks is saving the energy required for firing the fired bricks. The raw materials were characterized by XRD, XRF & their particle size distribution. The mechanically blended mixes were moulded, air-dried at room temperature, and tested on compressive strength, water absorption, and bulk density for different curing times (3,7,14 & 28 days). The 5 wt.% C&D waste replacement was also investigated and yielded compressive strength of 6.6 MPa, 8.8MPa, 9.1MPa, and 8.7MPa at 3, 7, 14, and 28 days respectively. The results showed that it was possible to substitute up to 5% of the original mix with construction and demolition solid waste powder to obtain geopolymer bricks samples abiding by ES 4763 / 2006 and ASTM C 62 / 2013 standards.

Keywords- Geopolymer; Sustainability; Bricks; Wastes; Construction and Demolition Waste.

I. Introduction

Geopolymer is classified as an inorganic polymer, which is mostly made from silicon and aluminium materials and can be manufactured from fly ash. The energy consumption in the fabrication of fired clay bricks is very high (900 °C–1000 °C) in kiln firing, along with enormous greenhouse gas releases (e.g., NO_x and CO_2 emissions) [1-2]. The overall construction and demolition waste C&D generation of waste worldwide reaches over 3.0 billion tons in 40 countries per annum and these concerns in increasing endlessly. Egypt suffers from rising, increasing consumption, and rapid development it follows the generation of enormous amounts of slide waste. In Egypt, 10,000 tons a day was recorded as a waste of construction and demolition (C&D). That is about one-third of the overall generated daily solid wastes in Egypt. Construction and demolition wastes are recycled to save natural resources used to manufacture the traditional bricks, that have hazardous effects on the environment so geopolymer brick can be a better alternative to ensure sustainability [3]. Bricks manufacture ordinarily uses clay and shale as raw materials, which are not considered sustainable and cost-effective owing to the great energy needed and the depletion of natural resources [4, 5]. Researchers have used a wide-ranging variety of solid waste (e.g., fly ash, mine tailings, slags, cotton waste, rice husk ash, wood sawdust, and oyster shell) in brick manufacture as a substitute or an addition [1, 6-13]. Geopolymerization has been presented as another path for brick manufacture using numerous wastes from industrial secondary products consistency of rich aluminosilicate materials for the profitable and environmental benefits of reusing wastes [14, 15]. recycling of (C&D) wastes is now a priority because they are heavy and voluminous, as a result, unpleasant for landfill disposal they might be recycled to a large extent while most of them are important for the reuse process [16]. Geopolymer (GP) is being modern sustainable building material, improved to decrease the carbon dioxide footprint of cementing material. (GP) contain acid resistance, compact, structure, low density, and thermal stability. Mainly consisting of waste ashes and landfill material, (GP) displays various levels of sustainable development. Though utmost research is dedicated to the area of constructing manufacturing, there are supplementary uses for that material. [17]. Geopolymers have economic and environmental benefits, they involve now in a lot of industries and fields such as advanced construction materials in civil engineering, substituting (OPC) cement, thermal resistance, solidifying hazardous waste in the shape of products like bricks, tiles & pipes which have low leaching ability, including also the aeronautical industry in lining the internal for aeroplanes as inflammable smokeless composite panels [18]. Geopolymers lastly is a technology occupied various applications like decorative stone artefacts fire resistant, low technology constructions materials with the property of thermal insulation, biotechnologies materials, concretes,

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cement, composites, art, and decoration [19]. The environmentally friendly effect of Geopolymer- constituents is still an inquiry for scientists, other researchers have offered the CO_2 releases as a result of Geopolymer constituents manufacturing from the environmental viewpoint [20]. Nicolas et al., revealed that the manufacturing process of geopolymer bricks implies the same compressive strength for fired bricks, a reduction of CO_2 emissions by up to 55% for clay-based geopolymer bricks [21]. The aim of the present study is the manufacturing of Geopolymer bricks from cheap raw materials, mainly industrial wastes, using construction and demolition solid wastes as a substituent with different proportions to Homra (waste from clay brick industry), calcium hydroxide (waste resulting from acetylene industry) and NaOH to reduce the number of pollutants that exists in the environment without firing to save firing cost, besides reduction of CO_2 emission in the atmosphere that produced from the firing of normal bricks.

II. MATERIALS AND METHOD

A. Materials

1. Raw Materials

The geopolymer raw materials are homra (fired clay brick waste), construction and demolition solid waste (C&D) waste as a substituent with different proportions to fired clay bricks waste, alkaline activators used are NaOH (commercial sodium hydroxide provided by Morgan Company) and Ca $(OH)_2$ (a waste resultant from acetylene manufacturing).

2. Characterization of Raw Materials

The raw materials were subjected to X-ray Fluorescence (XRF) which was carried on AXIOS, Paralytic 2005 Sequential Spectrometer to investigate the chemical composition of raw materials. X-ray Diffractometer (XRD) has been used to supply historical information on the quantity of sample mineralogy. Measurement of the power density by measuring the bulk of material minus any open pores or closed pores volume [22]. Size distribution of grain size for both clay and waste was determined by using the main refining method defined in ASTM D 422/2007 [23].

B. Methods

Specimens were prepared by replacing fired clay bricks waste with C&D waste in different percentages of 0%, 5%, 10%, 15%, & 20% by weight. Fired clay bricks waste (0.075 mm) was hand mixed with (8%) Ca $(OH)_2$ and (0.5%) NaOH with (28%) H_2O, C&D waste replaced fired clay in different percentages of weight. These mixtures were mixed on a dry basis for 10 minutes for each sample and mixed with constant mass percent of $Ca(OH)_2$ (8 %), NaOH (0.5 %), and H_2O (28 %). Then the mixture was transferred to cubic moulds. with dimensions ($50\times50\times50$ mm^3). Specimens were left at room temperature for 24 h and then dried at 110 ℃ overnight in a drying oven to remove water and ensure enough drying. Finally, the specimens were kept at room temperature and tested for 3,7,14, and 28 days. The Specimens were tested for their compressive strength and water absorption as the most important properties of the construction bricks and the best replacement was chosen and underwent a mechanical mixing with the same ratios of alkaline activators and water for better homogeneity. The mechanically mixed specimens were then dried & tested for 3,7,14 & 28 days.

III. RESULTS AND DISCUSSION

A. Characterization of Raw Material

1. Chemical Analysis of Raw Material

The chemical analysis was performed for different raw materials using XRF (X-Ray fluorescence) as shown in Table (1). It shows that SiO_2, Al_2O_3, and Fe oxides are the main oxides present in homra, this is a logical assumption that all alumina formula $Al_2O_3.2SiO_2$. On the other hand, C&D waste is mainly constituted of silica with minor amounts of alumina. Organic material presents in the sample, this mud is about 7.6% of the sample from L.O.I (Loss of ignition), which affected the product by increasing the porosity and decreasing the compressive strength. Since the mud does not react with the mixture and particulate to increase its volume in the sample.

2. Mineralogical Analysis of Raw Material

Mineralogical analysis was performed using XRD (X-Ray Diffraction) to assess the phases present in both materials. The obtained diffraction patterns for homra and C&D wastes are shown in (Fig.1) and (Fig.2) respectively. The different phases present in the as-received homra are shown in (Fig.1), the main phases being quartz, albite, and tricalcium aluminate, since homra originated from clay bricks fired to a maximum temperature of 900^{o}C, it should consist of quartz and amorphous m-kaolinite. On the other hand, when C&D waste was subjected to XRD analysis,

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the results, illustrated in (Fig.2) reveal that its main crystalline phases are quartz and albite. It shows also the presence of Illite and this is an indication that the C&D originated from a rural area.

Table (1): Chemical Analysis of Raw Material HOMRA and C&D

Constituents, Wt. (%)	HOMRA Waste	C&D Waste
SiO_2	56.80	46.70
Al_2O_3	15.80	9.47
Fe_2O_3	10.60	4.19
CaO	6.48	24.30
MgO	1.49	0.72
K_2O	1.38	2.04
Na_2O	1.42	1.28
TiO_2	1.17	0.64
P_2O_5	0.20	0.22
SO_3	-	1.59
ZrO_2	-	0.20
ZnO	0.04	0.20
CeO_2	-	0.18
PbO	-	0.15
SrO	0.12	-
Cr_2O_3	0.06	-
BaO	0.05	-
MnO	0.05	-
Cl^-	0.25	0.14
L.O.I	1.40	7.66
Total	99.98	99.67

3. Particle Size Distribution of Raw Material

(Fig.3) shows the cumulative and differential curves for particle size analysis of the homra powder produced from fired brick industries.
The vertical axis represents the fraction passed from specific screen diameters. This figure demonstrates that homra is quite fine. The following results were obtained: Median particle size (D50) = 0.1mm.
Fig.4 shows the cumulative and differential curves for particle size analysis of the powder produced on C&D. The vertical axis represents the fraction passed from each particular screen diameter. This figure demonstrates that C&D is quite fine. The following results were obtained: Median particle size (D50) = 0.15 mm. The cumulative analysis fraction for dry milk of lime is shown in (Fig.5). It's median diameter = is 0.94 mm.

4. Powder Density of Raw Material

The true density of homra was found to be 3.237g/cm^3, and that of $Ca(OH)_2$=3.393g/cm^3 and of C&D waste =4.317g/cm^3. It appears that the density of C&D waste is significantly higher than that of homra and $Ca(OH)_2$ and this is related to the nature of the material.

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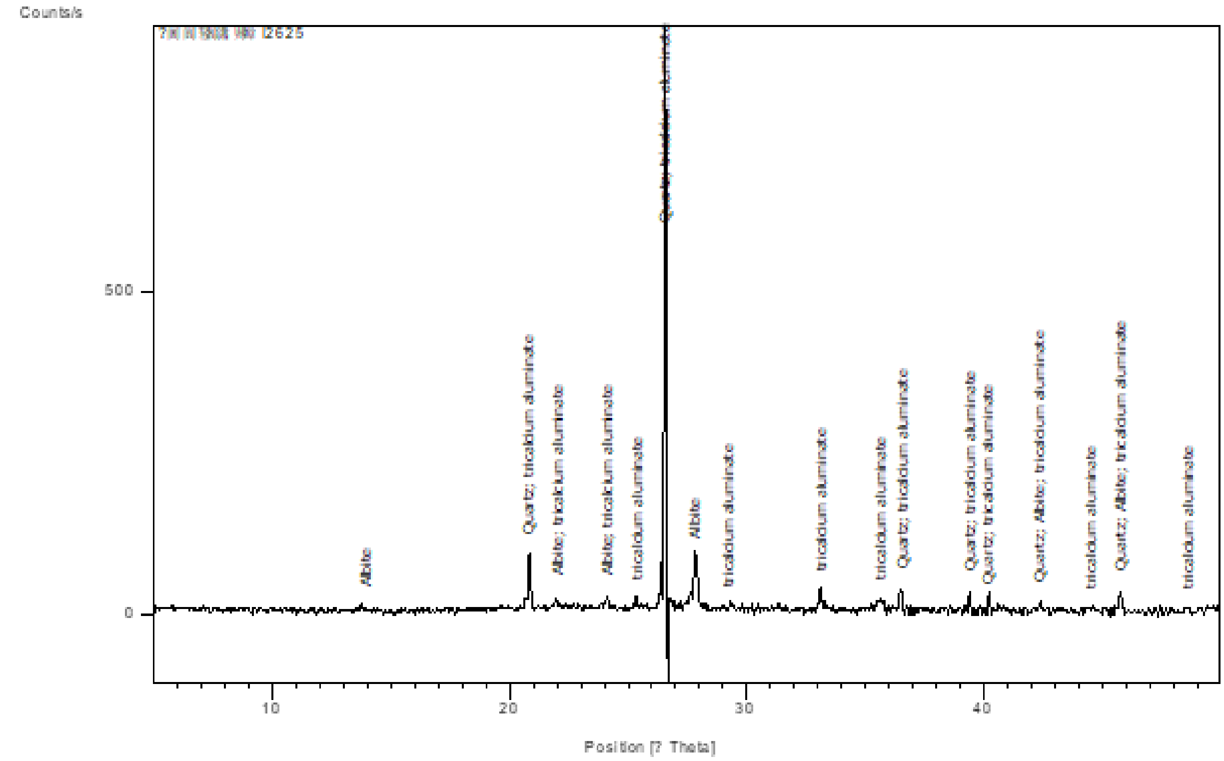

Fig.1. XRD Pattern of Homra

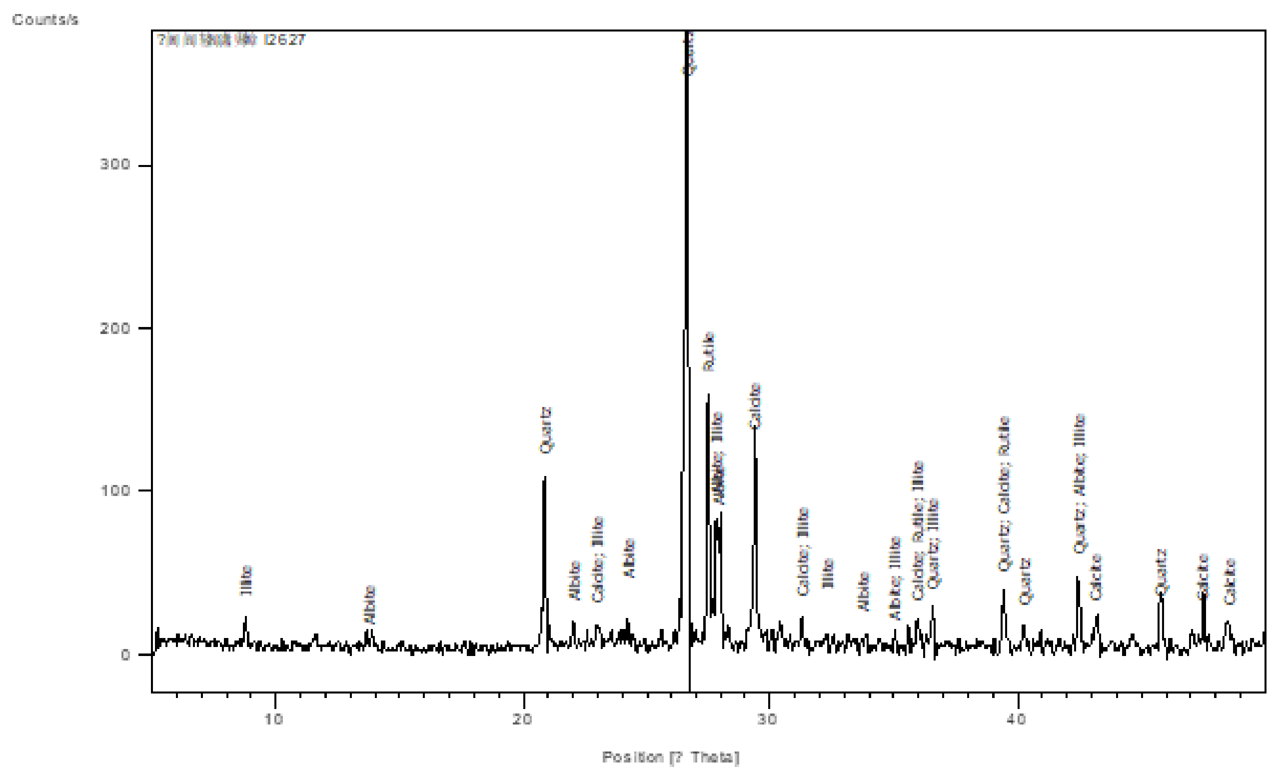

Fig.2. XRD Pattern of C&D Waste

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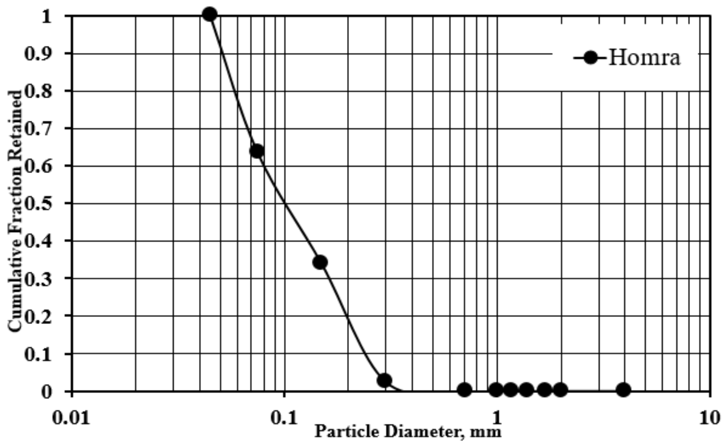

Fig.3. Particle Size Distribution of Homra

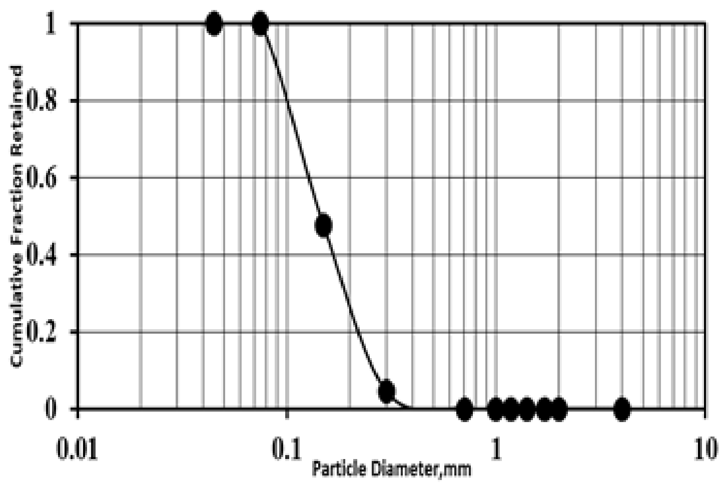

Fig.4. Particle Size Distribution of C&D

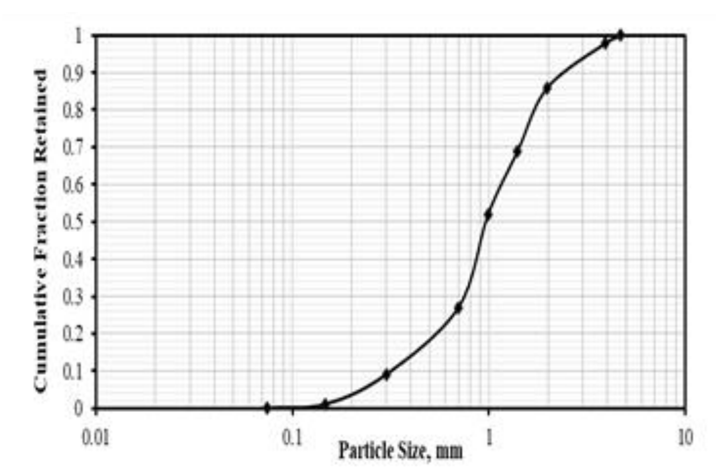

Fig.5. Cumulative Analysis of Dried Milk of Lime

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B. Effect of Hand Mixing on Compressive Strength at Different Waste Replacement

Compressive strength is considered the most important property of building brick. ES 4763 / 2006 and ASTM C 62 / 2013 standards require a minimum compressive strength of 8.6 MPa. Fig. 6 shows the effect of the replacement of different percentages of waste on the compressive strength of brick samples. The maximum value for compressive strength was for the 5% waste replacement and was of 6.6Mpa at 7 days then decreased to 5.4 MPa at 28, which is less than the minimum requirement. Mechanical mixing was performed to acquire more homogeneity and thus better mechanical properties.

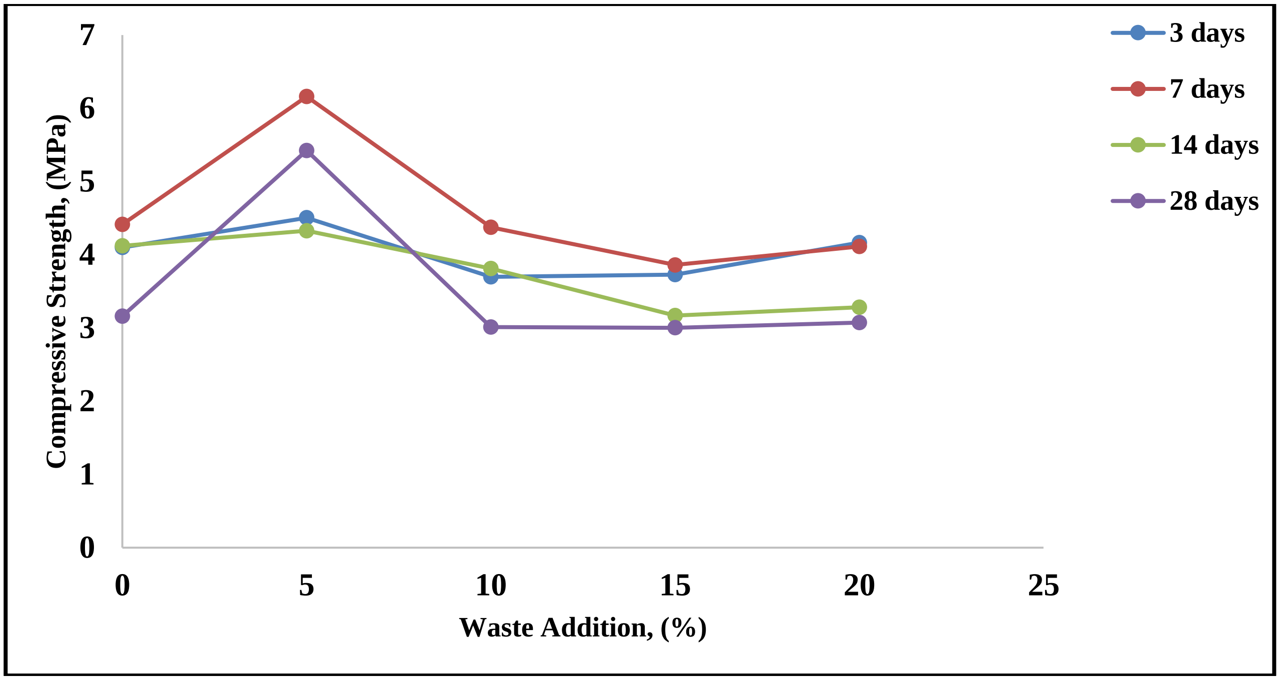

Fig.6. Effect of Waste Addition and Compressive Strength

Figure 7, XRD pattern of a specimen after 14 days' reveals that Ettringite was formed which is responsible for decreasing the compressive strength.

C. Physical and Mechanical Properties of Mechanically Mixed Geopolymer Bricks

1. Effect of Mechanical Mixing on Compressive Strength at 5% Waste Replacement

The effect of mechanical mixing on compressive strength shows in (Fig.8) as compressive strength is considered the utmost essential property for construction bricks, the 5 wt.% C&D waste replacement yield a compressive strength of 6.6 MPa, 8.8MPa, 9.1MPa & 8.7MPa at 3, 7, 14 & 28 days respectively, abiding by ES 4763 / 2006 and ASTM C 62 / 2013 standards of 8.6MPa minimum allowed compressive strength.

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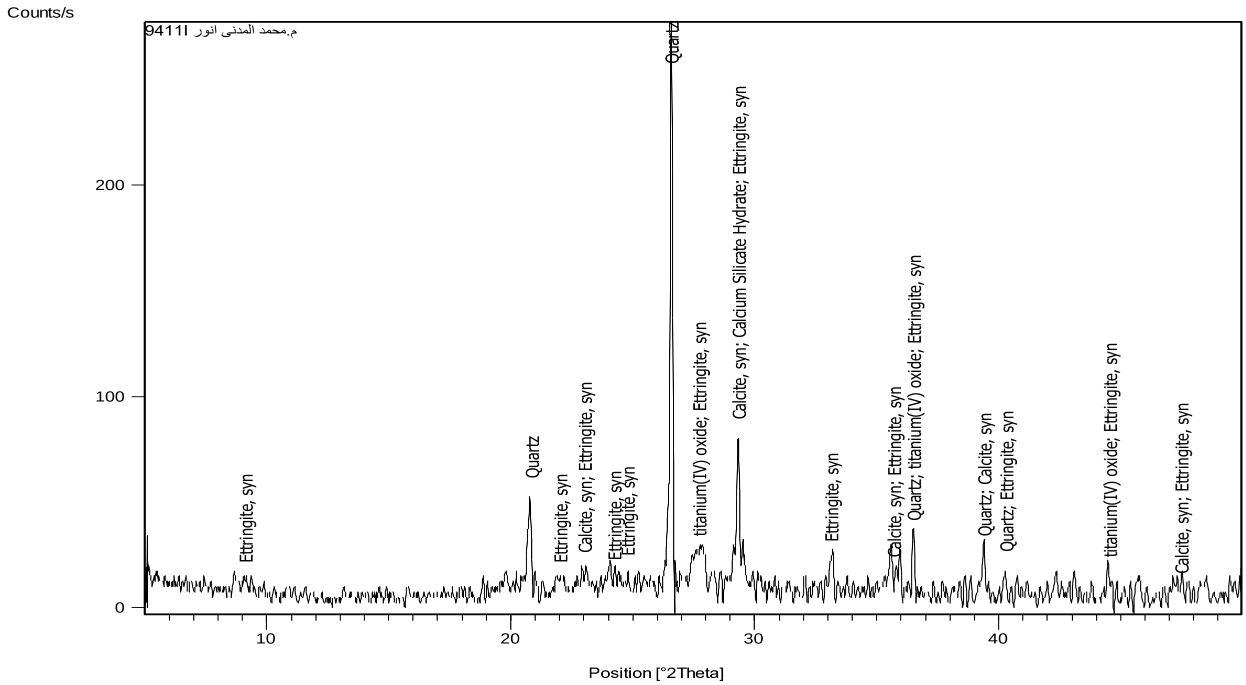

Fig.7. XRD Pattern of a Specimen after 14 Days

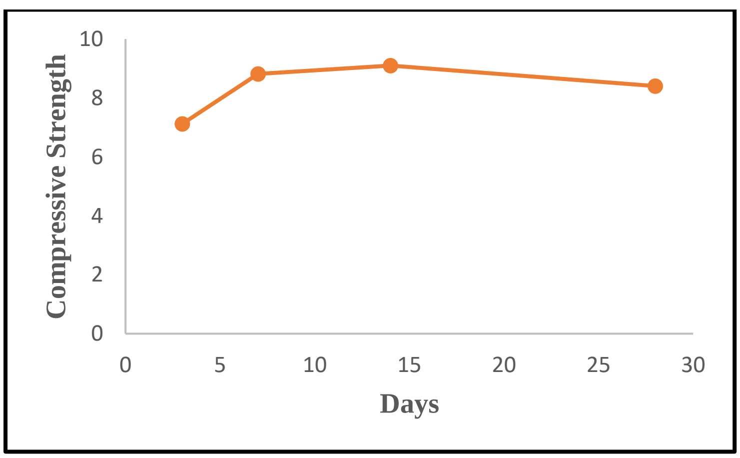

Fig.8. Effect of Mechanical Mixing on Compressive Strength at 5% Waste Addition

2. Effect of Mechanical Mixing on Bulk Density at 5% Waste Replacement

The effect of mechanical mixing on 5 wt.% C&D waste replacement on bulk density of brick samples show in (Fig.9). The bulk density displays a slight increase till 14 days then become of almost constant values with time.

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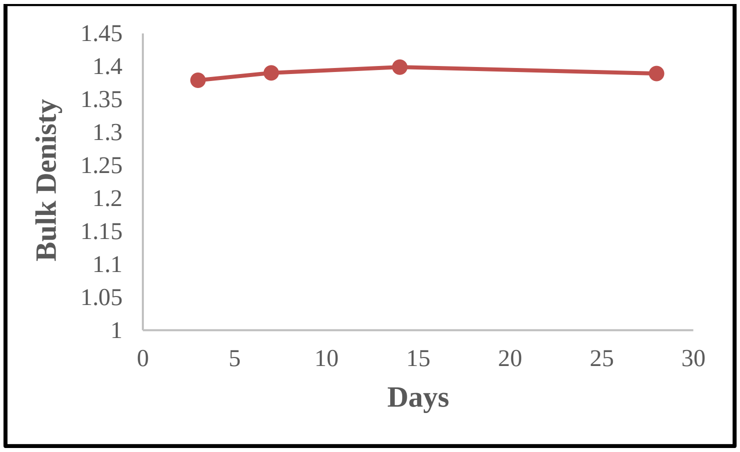

Fig.9. Effect of Mechanical Mixing on Bulk Density at 5% Waste Addition

3. Effect of Mechanical Mixing on Apparent Porosity (%AP) at 5% Waste Replacement

The variation of percent apparent porosity with mechanical mixing is illustrated in (Fig.10). The apparent porosity shows an almost uniform trend along the curing time.

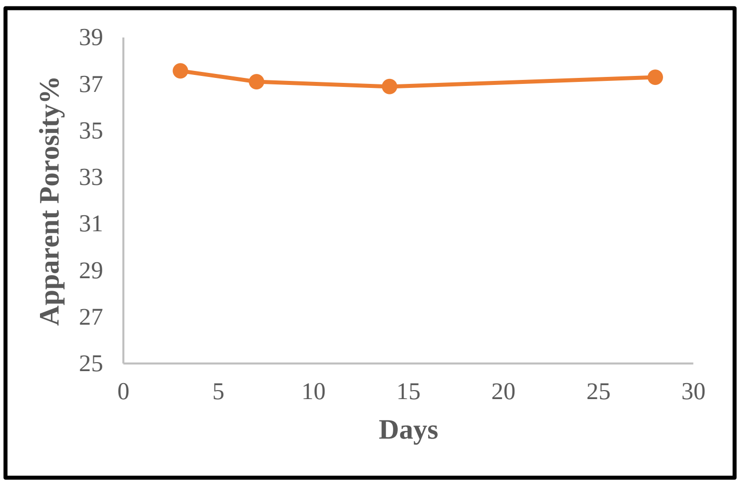

Fig.10. Effect of Mechanical Mixing on Apparent Porosity at 5% Waste Addition

4. Effect of Mechanical Mixing on Cold Water Absorption (%CWA) at 5% Waste Replacement

The effect of mechanical mixing on cold water absorption shown in (Fig.11) shows an almost uniform trend for the CWA during the different curing times and is directly proportional to the apparent porosity.

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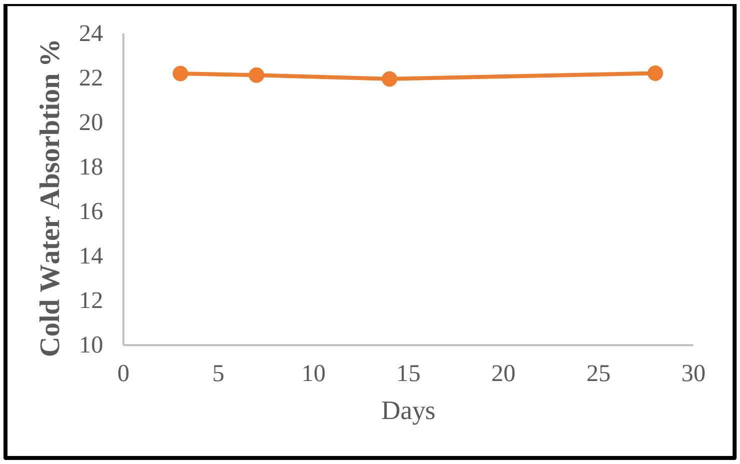

Fig.11. Effect of Mechanical Mixing on Cold Water Absorption at 5% Waste Addition

5. Effect of Mechanical Mixing on Boiling Water Absorption (%BWA) at 5% Waste Replacement

The effect of mechanical mixing on boiling water absorption shows in (Fig.12) as most points on the curve range between (24-26%) which complies with the Egyptian standard specification of boiling water absorption for both moderate weather and normal weather of 25% maximum allowed boiling water absorption.

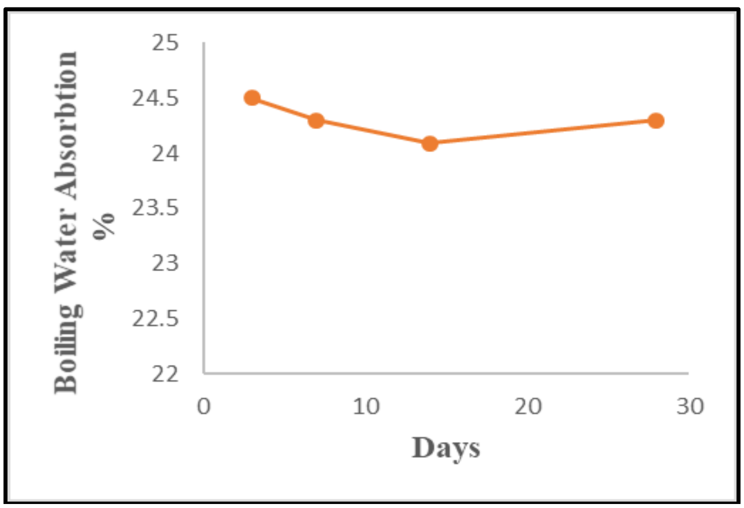

Fig.12. Effect of Mechanical Mixing on Boiling Water Absorption at 5% Waste Addition

6. Effect of Mechanical Mixing on Saturation Coefficient at 5% Waste Replacement

The effect of mechanical mixing on the saturation coefficient shows in (Fig.13) as most of the points on the curve range between (0.8-0.92) which also complies with the Egyptian standard specification for the saturation coefficient for both moderate weather and normal weather of 0.9 maximum allowed saturation coefficient abiding by ES 4763 / 2006 standard.

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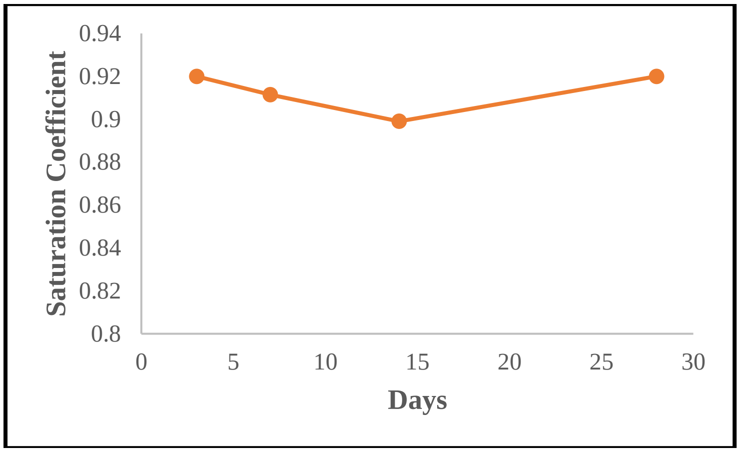

Fig.13. Effect of Mechanical Mixing on Saturation Coefficient at 5% Waste Addition

D. Comparison between Energy Consumption for Fired Clay Bricks and the Fabricated Geopolymer Bricks

The percentage of saved energy per ton of geopolymer brick for firing in this technique is about 100% as there is no need for firing in the manufacturing of geopolymer bricks. The energy requirement for firing one ton of solid clay bricks is about 2.61GJ [24], in computing the saving in firing cost per ton of the produced geopolymer bricks, it was found to be about 5.83 dollars

IV. Conclusion

The study of the effect of using construction and demolition waste, originated from a rural area to replace part of homra as the basic mixture in geopolymer brick manufacturing showed a slight increase in water absorption after 7 days. The effect of waste addition on a saturation coefficient showed an almost constant value of 0.9. 5% waste replacement at 28 days showed the lowest value of 0.9 for saturation coefficient. The bulk density displayed almost constant values of small variation with the curing time. The apparent porosity was directly proportional to the water absorption. It has been found that 5 wt.% C&D waste replacement yielded a compressive strength of 6.6 MPa, 8.81 MPa, 9.1 MPa, and 8.7 MPa at 3, 7, 14, and 28 days respectively, thus the replacement of 5 % by wt. of homra as a raw material in the mechanical mixing geopolymer brick industry by construction and demolition waste is recommended, as it showed a slight improvement of brick mechanical properties

References

[1] Ahmari S, Zhang L. Production of eco-friendly bricks from copper mine tailings through geopolymerization. Construction and building materials. 2012 Apr 1;29:323-31.

[2] Sieminski A. International energy outlook. Energy information administration (EIA). 2014 Nov 18;18:2.

[3] Elgizawy S, Nassar K, El-Haggar S. Quantification of construction waste: Egypt case study. In4th International Conference on Sustainable Solid Waste Management 2016 Jun 23 (pp. 23-25).

[4] China Economic Trade Committee. Tenth five-year program of building materials industry. China Building Materials. 2001;7:7-10.

[5] Chen Y, Zhang Y, Chen T, Zhao Y, Bao S. Preparation of eco-friendly construction bricks from hematite tailings. Construction and Building Materials. 2011 Apr 1;25(4):2107-11.

[6] Zhang Z, Qian J, You C, Hu C. Use of circulating fluidized bed combustion fly ash and slag in autoclaved brick. Construction and Building Materials. 2012 Oct 1;35:109-16.

[7] Kumar A, Kumar S. Development of paving blocks from synergistic use of red mud and fly ash using geopolymerization. Construction and building materials. 2013 Jan 1;38:865-71.

[8] Wang L, Sun H, Sun Z, Ma E. New technology and application of brick making with coal fly ash. Journal of Material Cycles and Waste Management. 2016 Sep;18(4):763-70.

[9] Lin KL. Feasibility study of using brick made from municipal solid waste incinerator fly ash slag. Journal of hazardous materials. 2006 Oct 11;137(3):1810-6.

Print ISSN 2682-3993
Online ISSN 2682-4000

[10] Malhotra SK, Tehri SP. Development of bricks from granulated blast furnace slag. Construction and Building Materials. 1996 Apr 1;10(3):191-3.

[11] Sukmak P, Horpibulsuk S, Shen SL. Strength development in clay–fly ash geopolymer. Construction and building Materials. 2013 Mar 1;40:566-74.

[12] Abdullah MM, Ibrahim WM, Tahir MF. The properties and durability of fly ash-based geopolymeric masonry bricks. InEco-Efficient Masonry Bricks and Blocks 2015 Jan 1 (pp. 273-287). Woodhead Publishing.

[13] Madani H, Ramezanianpour AA, Shahbazinia M, Ahmadi E. Geopolymer bricks made from less active waste materials. Construction and Building Materials. 2020 Jun 30;247:118441.

[14] Apithanyasai S, Supakata N, Papong S. The potential of industrial waste: using foundry sand with fly ash and electric arc furnace slag for geopolymer brick production. Heliyon. 2020 Mar 1;6(3):e03697.

[15] Kuranchie FA, Shukla SK, Habibi D. Utilisation of iron ore mine tailings for the production of geopolymer bricks. International Journal of Mining, Reclamation, and Environment. 2016 Mar 3;30(2):92-114.

[16] Siddique R, Cachim P. Waste and supplementary cementitious materials in concrete: characterization, properties, and applications. Woodhead Publishing; 2018 Jun 5.

[17] Khan MI, Azizli K, Sufian S, Man Z. Sodium silicate-free geopolymers as coating materials: Effects of Na/Al and water/solid ratios on adhesion strength. Ceramics International. 2015 Mar 1;41(2):2794-805.

[18] Mackenzie KJ, Welter M. Geopolymer (aluminosilicate) composites: synthesis, properties, and applications. advances in ceramic matrix composite 2014 Jan 1 (pp. 545-568). Woodhead Publishing.

[19] Davidovits J. Chemistry of geopolymeric systems, terminology. InGeopolymer 1999 Jun 30 (Vol. 99, No. 292, pp. 9-39). sn.

[20] Petrillo A, Cioffi R, Ferone C, Colangelo F, Borrelli C. Eco-sustainable geopolymer concrete blocks production process. Agriculture and agricultural science procedia. 2016 Jan 1;8:408-18.

[21] Youssef N, Rabenantoandro AZ, Dakhli Z, Chehade FH, Lafhaj Z. Environmental evaluation of geopolymer bricks. In MATEC Web of Conferences 2019 (Vol. 281, p. 03005). EDP Sciences.

[22] Adegbidi A, Mensah R, Vidogbena F, Agossou D. Determinants of ICT use by rice farmers in Benin: from the perception of ICT characteristics to the adoption of the technology. Journal of Research in International Business and Management. 2012 Nov;2(11):273-84.

[23] Rodriguez M, Cardenas A, Galain I, Castiglioni E, Castiglioni J, Fornaro L. Doped and undoped lead borate glass-ceramics as thermoluminescent detectors. In2011 IEEE Nuclear Science Symposium Conference Record 2011 Oct 23 (pp. 237-241). IEEE.

[24] Energy for Building, “Energy consumption in brick and tile manufacture,” 2022. http://www.nzdl.org/cgi-bin/library?e=d-00000-00---off-0cdl--00-0----0-10-0---0---0direct-10---4-------0-0l--11-en-50---20-about---00-0-1-00-0--4----0-0-11-10-0utfZz-8-00&cl=CL2.5&d=HASH6160c2d42fccbfed2297af.4.5&gt=1 (accessed July. 18, 2022).