Preparation of Geopolymer Bricks from Industrial Wastes

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Abstract

Geopolymer, categorized as an inorganic polymer, which is mostly made from silicon and aluminium materials or can be manufactured from fly ash. The main advantage of geopolymer technology comparing to that of fired clay bricks is to decrease harmful emissions. In seashore buildings where continuous erosion takes place in that situation, geopolymer plays an important role to minimize the erosion effect. The essential goal of the present study is to prepare geopolymer bricks from cheap raw materials, mainly industrial wastes to be used in the construction industry. The environmental benefits of recycling construction and demolition wastes in the geopolymer bricks industry decrease the negative impact of their dump filling on the environment, besides reducing CO_2 emission in the atmosphere that is produced from firing normal bricks. The raw materials used are construction and demolition solid wastes as a substituent with different proportions to homra (waste from fired clay brick industry), calcium hydroxide (waste resulting from acetylene industry), and NaOH. The raw materials were characterized by XRD, XRF. The water blended mixes were moulded, air-dried at room temperature, and tested on compressive strength, bulk density, and water absorption for different curing times (3,7,14 and 28 days). It has been found that 5 wt.% C&D waste replacement for homra yielded a compressive strength of 6.6 MPa at 14 days then there was a decrease in compressive strength values for curing time exceeding 7 days to reach an almost constant value of about 5.4Mpa, with a slight increase in water absorption after 7 days curing time. Mechanical mixing for the 5 wt.% C&D waste replacement was also investigated, yielded a compressive strength of 6.6 MPa, 8.8MPa, 9.1MPa, and 8.4MPa at 3, 7, 14, and 28 days respectively.

Keywords: Sustainability; Geopolymer; Construction and demolition wastes; Fired clay bricks wastes; Mechanical strength.

I. INTRODUCTION

Egypt produces enormous quantities of construction and demolition (C&D) waste daily. The waste problem has become a serious environmental and social issue in the world. The opportunity of waste recycling from the building industry is thus of increasing importance. Waste recycling provides several benefits, which could be determined in decreasing the demand on land for disposing of as an important environmental benefit. It also serves in protecting the natural resources and in reducing the cost of waste treatment before disposal. C&D wastes are normally composed of concrete, bricks and tiles, sand and dust, wood, plastics, cardboard, paper, and metals. C&D wastes generation is the main reason for CO_2 emission into the atmosphere. The overall C&D generation of waste worldwide reaches more than 3.0 billion tons in 40 countries annually and these concerns in increasing continuously. Particularly Egypt suffers from rising growth, 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 equivalent to one-third of the total solid wastes generated per day 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 [1]. 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 extend while most of them are important for the reuse process [2]. The usage of fossil fuels is in charge of economic, energy, environmental problems, and ecological issues. For example, the production of one ton of cement requires the consumption of 1.7 tons of raw materials and involves the emission of 0.8 tons of CO_2 into the atmosphere. However, in the production of building material is a large percentage of waste such as fly ash, waste bricks, and results in several environmental matters. The process of recycling and recovering a large number of waste bricks has become essential to guarantee protection to the environment [3]. 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, thermal stability. Mainly consisting of waste ashes and landfill material, (GP) shows multiple levels of sustainability. Although most research is focused on the area of the construction industry, there are other uses of this material. Catalysis, coating, encapsulation of hazardous waste, and separation are some of the other applications [4]. Geopolymers have economic and environmental benefits, it involves now in a lot of industries and fields such as advanced construction materials in civil engineering, substituting (OPC) cement, thermal resistance, solidify hazardous waste in shape of products like bricks, tiles and pipes which have low leaching ability, including also the aeronautical industry in lining the internal for airplanes as inflammable smokeless composite panels [5]. Geopolymers lastly is a technology occupied various applications like decorative stone artifacts fire resistant, low technology constructions materials with the property of thermal insulation, biotechnologies materials, concretes, cement, composites, art, and decoration [6]. The environmental impact of Geopolymer-based building materials remains an open research question for researchers, CO_2 emissions from the production of Geopolymer materials have been presented in other studies from the environmental perspective [7]. A study done by Duxson et al. in 2007, showed that CO_2 emissions from Geopolymer production are lower than those from ordinary cement [8]. This study was based on the alkaline activator as the main factor in CO_2 emissions and on the benefits of reduced water consumption and the absence of plasticizers in the preparation of Geopolymer. The results of this study show an 80% reduction in CO_2 emissions compared to Ordinary Portland Cement [9].

II. Experimental Methods

a. Raw Materials

The geopolymer raw materials are C&D waste as a substituent with different proportions to fired clay bricks and alkaline activators which are NaOH and Ca $(OH)_2$ that are used to bind the mixture components together.

b. Characterization of Raw Materials

The raw materials were subjected to X-ray Fluorescence (XRF) which was carried on AXIOS, Paralytical 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 [10]. Size distribution of grain size for both clay and waste was determined by using the main refining method defined in ASTM D 422/2007 [11].

c. Preparation of Geopolymer Bricks Specimens

Specimens were prepared by replacing fired clay bricks waste with C&D waste in different precents of 0%, 5%, 10%, 15%, 20%, by weight. Fired clay bricks waste (0.075 mm) was 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 then mixed with constant mass percent of Ca $(OH)_2$ (8 %), NaOH (0.5 %), and H_2O (28 %). Hand mixing was continued for specimens till complete homogeneity, then the mixture was transferred to cubic molds with dimensions ($50\times50\times50$ mm^3). Specimens were left at room temperature for 24 h and then dried at 110 °C overnight in drying oven to remove water and ensure enough drying. Finally, the specimens were kept at room temperature before testing for 28 days. It has been found that 5 wt.% C&D waste replacement for fired clay bricks yielded the highest compressive strength of 6.6 MPa at 14 days then there was a decrease in compressive strength values for curing time exceeding 7 days to reach an almost constant value of about 5.4Mpa, after performing mechanical mixing for the 5 wt.% C&D waste replacement was also investigated, yielded a compressive strength of 8.8MPa, 9.1MPa and 8.4MPa at 7, 14 and 28 days respectively.

III. Results and Discussion

a. 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 is not to react with the mixture and start to particulate to increase its volume in the sample.

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

b. 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°C, it should consist of quartz and amorphous m-kaolinite. On the other hand, when C&D waste was subjected to XRD analysis, 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 is originated from a rural area.

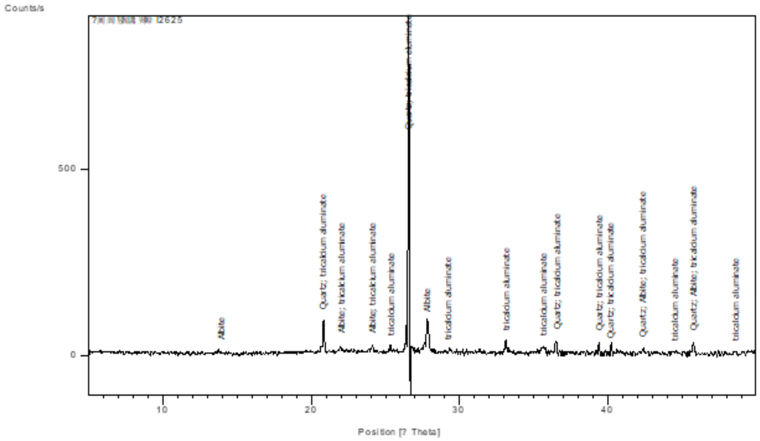


Fig.1. XRD Pattern of Homra

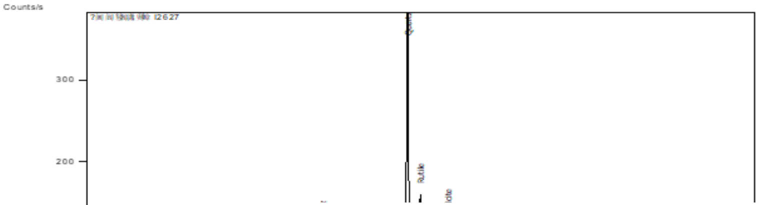
Fig.2. XRD Pattern of C&D Waste

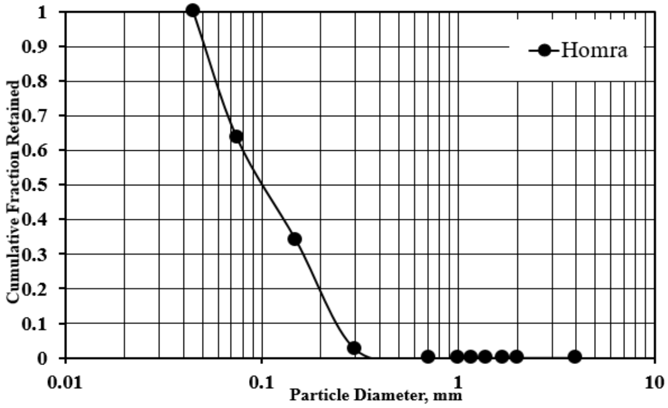
c. Particle Size Distribution of Raw Material

(Fig.3) shows the cumulative and differential curves for particle size analysis of the homra powder produced from fired brick industries.

Fig.3. Particle Size Distribution of Homra

The vertical axis represents the fraction passed from each particular screen diameter. This figure shows that HOMRA is very fine. The following results were obtained:





Median particle size (D_{50}) = 0.1mm.

The (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 shows that C&D is very fine. The following results were obtained:

Median particle size (D_{50}) = 0.15 mm.

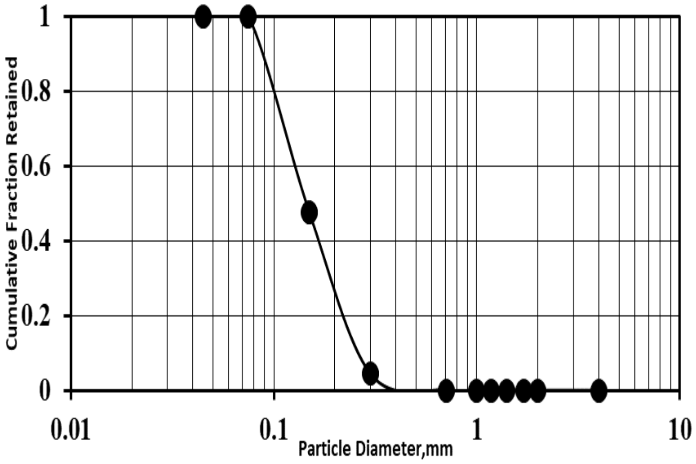


Fig.4. Particle Size Distribution of C&D

The cumulative analysis fraction for dry milk of lime is shown in (Fig.5). Its median diameter = 0.94 mm.

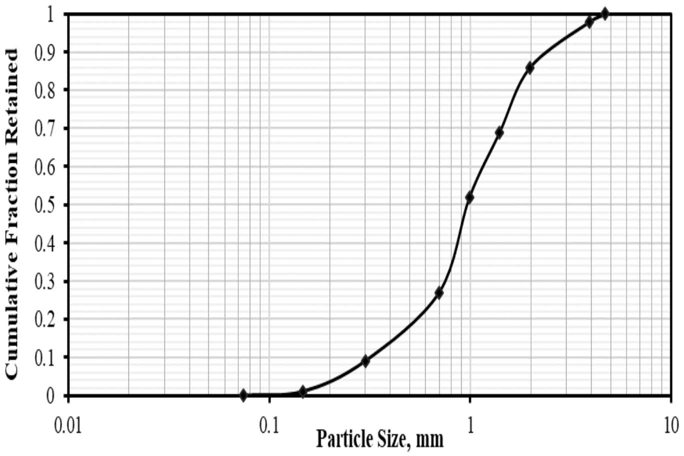


Fig.5. Cumulative Analysis of Dried Milk of Lime

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

The effect of mechanical mixing on compressive strength shows in (Fig.6) as compressive strength is considered the most important property for building bricks, the 5 wt.% C&D waste replacement yielded a compressive strength of 6.6 MPa, 8.8MPa, 9.1MPa and 8.4MPa at 3, 7, 14 and 28 days respectively.

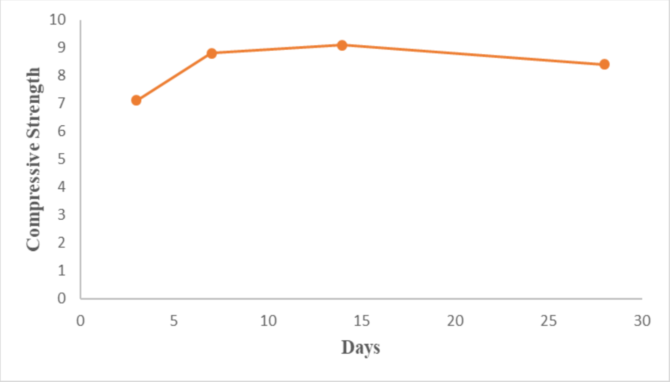


Fig.6. Effect of Mechanical Mixing on Compressive Strength at 5% Waste Addition

b. 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 showed in (Fig.7). The bulk density displayed a slight increase with increasing the curing time up to 14 days then slightly decreased till reached 1.39 g/cm^3 days at 28 days curing time. The determination of the true density of clay was about 2.38 g/cm3 while that of waste was 1.83 g/cm3. It is expected that increasing the waste percentage will generally decrease its true density and hence its bulk density. Moreover, the difference in particle size plays an important role in creating more porosity that is responsible for a further decrease in bulk density.

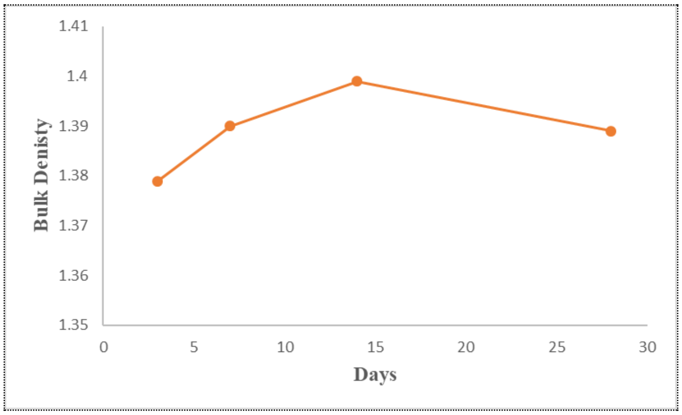


Fig.7. Effect of Mechanical Mixing on Bulk Density at 5% Waste Addition

c. 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.8). The apparent porosity showed no uniform trend along the curing time.

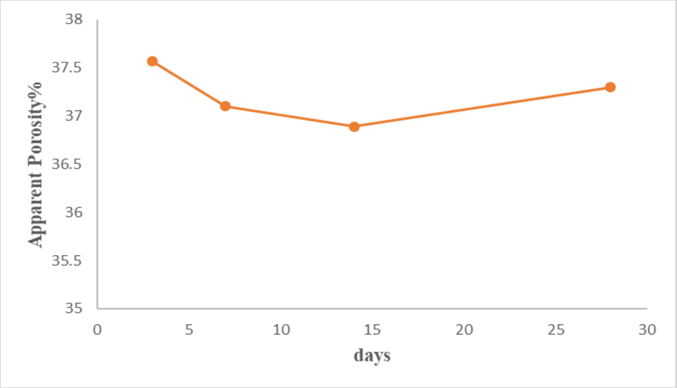


Fig.8. Effect of Mechanical Mixing on Apparent Porosity at 5% Waste Addition

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

The effect of mechanical mixing on cold water absorption shows in (Fig.9), there was no uniform trend for the CWA during the different curing times but it was directly proportional to the apparent porosity.

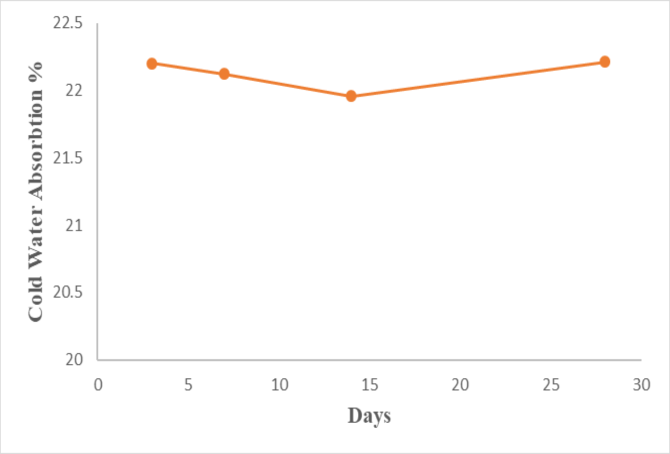


Fig.9. Effect of Mechanical Mixing on Cold Water Absorption at 5% Waste Addition

e. 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.10) as most points on the curve lied within the range between (24-26%) which complies with the Egyptian standard specification of boiling water absorption for both moderate weather and normal weather of 25%.

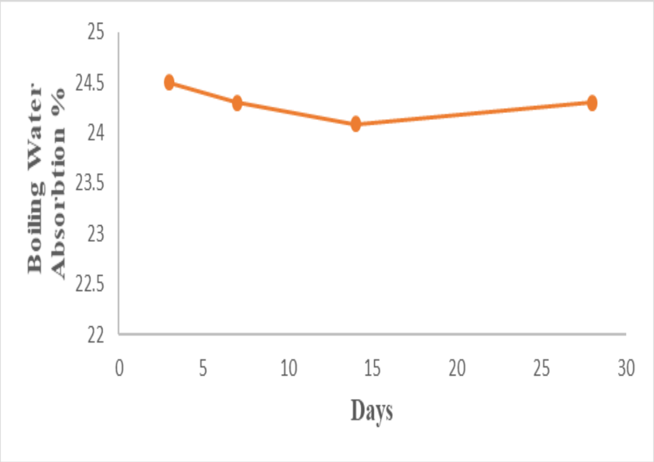


Fig.10. Effect of Mechanical Mixing on Boiling Water Absorption at 5% Waste Addition

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

The effect of mechanical mixing on saturation coefficient shows in (Fig.11) as most of the points on the curve lies in the 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.

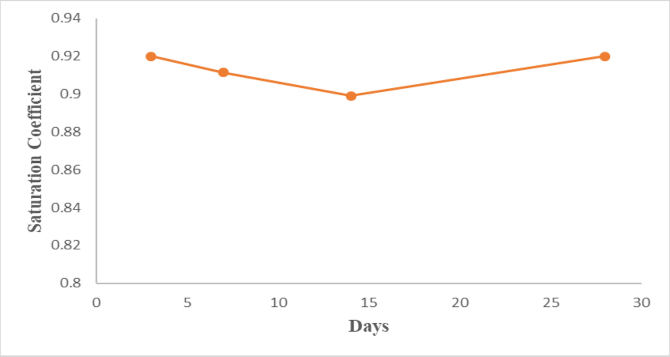


Fig.11. Effect of Mechanical Mixing on Saturation Coefficient at 5% Waste Addition

VI. 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 curing time. The effect of waste addition on saturation coefficient showed an almost constant value of 0.92, 5% waste replacement at 28 days showed the lowest value of 0.91 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 at 7 days then decreased to 5.4 MPa at 28. Mechanical mixing was used and displayed a compressive strength of 6.6 MPa, 8.81 MPa, 9.1 MPa, and 8.4 MPa at 3, 7, 14, and 28 days respectively, thus the replacement of 5 % by wt. of homra as a raw material in the geopolymer brick industry by construction and demolition waste, showed a slight improvement of brick mechanical properties.

VII. ACKNOWLEDGEMENTS

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VIII. REFERENCES

[1] S. M. Elgizawy and K. Nassar and S. El-Haggar, "Quantification of construction waste: Egypt case study", in fourth International Conference on Sustainable Solid Waste Management, P.P [23-25], (2016).
[2] R.Siddique and P.Cachim, "Waste and Supplementary Cementitious Materials in Concrete: Characterisation, Properties, and Applications", Woodhead Publishing, (2018), P.P [57-59].
[3] J.Bredenoord, W.Kokkamhaeng, P.Janbunjong, O.Nualplod, S.Thongnoy, W.Khongwong, P.Ngernchuklin, and A.Mahakhant, "Interlocking Block Masonry (ISSB) for sustainable housing purposes in Thailand, with additional examples from Cambodia and Nepal", Journal of Education and Learning, (2019), P.P [42-53].
[4] M.Khan, k.Azizi, S.Sufian, H.Ullah, Z.Man, "Geopolymer as Sustainable Binder of the 21st Century", Ceramic International, (2015), P.P [27-29].
[5] K.J.D.Mackenzie, M.Welter, "Geopolymer (aluminosilicates) composites: synthesis, properties, and applications", Advances in ceramic matrix composites, (2014) P.P [445-470].

[6] J.Davidovits, "Chemistry of Geopolymeric Systems, Terminology. Geopolymer" International Conference, France, (1999) P.P [69-73].

[7] A. Petrillo, R. Cioffi, C. Ferone, and F. Colangelo, "Eco-sustainable Geopolymer concrete blocks production process," Agric. Agric. Sci. Procedia, vol. 8, pp. 408–418, 2016.
[8] P. Duxson, J. L. Provis, G. C. Lukey, and J. S. J. van Deventer, "The role of inorganic polymer technology in the development of 'green concrete,'" Cem. Concr. Res., vol. 37, no. 12, pp. 1590–1597, 2007.
[9] C. Ouellet-Plamondon and G. Habert, "Life cycle assessment (LCA) of alkali-activated cement and concretes," Handb. Alkali-Activated Cem. Mortars Concr., no. December, pp. 663–686, 2014.
[10] A.Adegbidi, R.Mensah, F.Vidogbena, and D.Agossou, "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 2, (2012), P.P [273-284].
[11] M.Rodriguez, A. Cardenas, I. Galain, E. Castiglioni, J. Castiglioni, and L. Fornaro. "Doped and undoped lead borate glass-ceramics as thermoluminescent detectors", In 2011 IEEE Nuclear Science Symposium Conference Record, (2011), pp [237-241].