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BLENDED METAKAOLIN AND WASTE CLAY BRICK POWDER AS SOURCE MATERIAL IN SUSTAINABLE GEOPOLYMER CONCRETE

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Recently, sustainability and ecological related problems have attracted more attention around the world. The construction sector incorporates directly and indirectly in global warming, natural resources depletion, and environmental pollution. This study aims, firstly; to identify the optimum mix of metakaolin (MK) geopolymer concrete required to achieve high compressive strength with respect to the concentration of the alkaline solution and curing system. Secondly, to reduce the impact of brick waste on the environment, by producing geopolymer concrete based on blended MK and waste clay brick powder (WBP). The compressive strength, splitting tensile strength and flexural strength of MK-based geopolymer concrete specimens were studied. Different contents of waste clay brick powder (WBP) (0%, 10%, 15%, and 20%) as a replacement by weight of (MK) were investigated. The results appear that it is possible to produce MK-based geopolymer concrete with a compressive strength of 44.03 MPa, while it was 34.76 MPa at 28 days for specimens with 15% WBP replacement of main source binder. Finally, it could be concluded that green moderate strength geopolymer concrete can be produced and used in different civil engineering applications.

Keywords: Alkaline solution, CO_2 emission, Environmental pollution, Heat curing, Mix proportions, Molarity.

1 INTRODUCTION

The sustainability has become an important issue in recent years as the growth of waste production associated with the awareness of the environmental problems and the exhaustion of natural resources has increased at a rapid rate for producing materials such as concrete (Brito and Saikia 2013). In fact, the greatest challenge facing the sustainability of concrete as a building material comes from the production of cement, which is the key ingredient in concrete. Worldwide, high consumption of natural raw materials (1.6 tons) is required to produce one ton of Portland cement (Toniolo and Boccaccini 2017). Moreover, the cement industry has an extraordinary contribution to global CO_2 emission (Haberta and Plamondonb 2016, Ken *et al.* 2015, Karthika *et al.* 2017). Hence, considerable efforts have been made in order to get new innovations in the concrete industry by using more eco-friendly construction materials such as "geopolymers". Geopolymer concrete can be produced by a polymeric reaction of alkaline liquid; usually is Na_2SiO_3 and NaOH, with aluminosilicate-based powder materials such as Metakaolin (Verma and Dev 2018, Mehta and Siddique 2016). On the other hand, the generation of clay brick waste is increasing rapidly due to a spike in construction activities around the world. According to the United States Environmental Protection Agency, about 44 million tons of brick waste was produced during construction and demolition actions just between 2012 and 2014 (Wong *et al.* 2018). Most of the demolished bricks are disposed of in landfills, which causes economic losses and serious environmental problems. The main aims of this research are: [1] determine the optimum trial mix of geopolymer concrete using Iraqi metakaolin (MK) as a source material with respect to higher compressive strength and less curing energy consumption, and [2] investigate the effect of substitute the (MK) with different contents of waste clay brick powder (WBP) on mechanical properties of geopolymer concrete.

2 EXPERIMENTAL WORK

2.1 Materials

The source material Metakaolin was obtained from the calcination of Iraqi Kaolin clay at 700°C for 2 hours, while the waste clay brick powder was produced by crushing waste bricks to small pieces, then grinding it by cyclone machine. The physical properties and chemical composition of the (MK) and (WBP) according to X-Ray Fluorescence results are given in Table 1. The alkali activator was a mix solution of NaOH (pellets form with 98% purity dissolved in distilled water) and commercial grade Na_2SiO_3 which contents 54% H_2O, 32.5% SiO_2, and 13.5% Na_2O. For all mixes, the coarse and fine aggregate were within the requirements of the Iraqi Specification No.45/1984. The coarse aggregate was natural and crushed with size 5–14 mm, dry rod density of 1595 kg/m^3, specific gravity of 2.61 and absorption of 1.3%. The fine aggregate was natural sand within zone 1 with a fineness modulus of 3.3, dry rod density of 1787 kg/m^3, specific gravity of 2.58 and absorption of 1.6%. A superplasticizer (Conplast SP2000) and extra tap water were used to get the applicable workability and improving the mixing process.

Table 1. Chemical composition and physical properties of metakaolin and waste bricks powder

Oxide%	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	Na_2O	K_2O	LOI
MK	54.20	39.0	0.92	1.37	0.15	0.45	0.22	0.27	0.71
WBP	56.82	11.36	2.36	20.20	3.02	0.83	0.86	0.86	1.19

Physical Properties	**MK**	**WBP**
Specific gravity	2.64	2.84
Specific surface area (m^2/kg)	14300	462
7 days pozzolanic activity index, (%)	113.3	89.2

2.2 Preparation of Geopolymer Concrete

The alkali activator solution was prepared one day before casting to be coolede at room temperature. The coarse aggregate, sand, MK and WBP were mixed together in electrical pan mixer for four minutes. Next, the alkali activator solution, extra water, and superplasticizer were added to the dry mixture and the mixing process continues 6 to7 minutes. The fresh geopolymer concrete was cast in molds and compacted by tamping each layer 30 times then followed by 15-20 second on a vibration table. After demolded, the specimens curried according to the selected curing method. The compressive, splitting tensile and flexural strengths were determined according to BS 1881: Part 116 (1983) using 100 mm cubes, ASTM C496/C496M (2017), and ASTM C78/C78M (2018), respectively.

2.3 Mixture Proportioning

Geopolymer concrete attains most of its strength at early age, and the rate of strength development beyond 7th day is not significant Joseph and Mathew (2012). Thus, in this study, the trail mixes were prepared to select the optimum mix with higher compressive strength at 7 days. Table 2 shows the details of mix proportions and compressive strength results for trial mixes which have the same content of extra water (10% by weight of MK) and oven cured at 50°C for 5 hours. The results indicate that mix (M4) has the highest compressive strength at 7 days. To investigate the effect of alkaline liquid concentration, ratio of Na_2SiO_3 to NaOH and curing regime, other trials were carried out on mix (M4) to select the optimum MK-based geopolymer concrete which considered as reference mix. Four mixes that have 0, 10, 15, and 20% waste brick powder as a partial replacement by weight of metakaolin were prepared.

Table 2. Details of MK-based geopolymer concrete trial mixes

Mix	**MK, (kg/m^3)**	**Coarse Agg., (kg/m^3)**	**Fine Agg., (kg/m^3)**	**Alkaline solution, by wt. of MK**	**SP by wt. of MK (%)**	**Molarity**	**NaOH to Na_2SiO_3**	**Compressive Strength at 7days (MPa)**
M1	400	1100	720	0.45	3	12	1:3.5	6.4
M2	400	1100	720	0.45	3	12	1:2.5	5.83
M3	400	1100	720	0.52	3	12	1:2.5	18.0
M4	415	1240	475	0.65	2	12	1:2.5	26.56
M5	414	1136	660	0.52	3	12	1:2.5	23.78
M6	400	1185	630	0.55	3	12	1:2.5	20.16
M7	400	1300	500	0.5	3	12	1:2.5	13.03
M8	450	1217	608	0.55	2	12	1:3.5	9.8
M9	450	1267	558	0.55	2	12	1:3.5	12.7
M10	400	1185	630	0.65	2	14	1:2.5	12.36
M11	400	1185	630	0.65	2	14	1:2	17.5
M12	500	1150	575	0.65	2	12	1:2.5	22.5
M13	500	1481	787.5	0.65	2	12	1:2.5	24.5

3 RESULTS AND DISCUSSION

3.1 Effect of Curing Method

For geopolymer concrete, the heat curing is very important for geopolymerization of aluminosilicate gel, which enhances polycondensation process to obtain high early strength gain Ken *et al.* (2015). Table 3 illustrates the compressive strength at 7 days for mix (M4) after subjected to different curing methods. It is found that the optimum curing method was the oven treatment for 4-5 hours at 60°C then under sunlight in hot weather. The compressive strength of the specimens subjected to the optimum curing method was 32.6 MPa at 7 days, with an increase up to 49.38% compared with those subjected to sunlight curing alone. This curing method provides a continuous geopolymerization process to produce a more homogenous and dense structure of MK- geopolymer concrete. Al-Shathr *et al.* (2018) used curing in oven at 45 °C for 24 hrs. with molds followed by 48 hrs. without molds. They obtain MK-geopolymer concrete with a compressive strength of 22.7 MPa at 7 days. However the optimum combined curing method used in this research had an advantage in produce more sustainable geopolymer concrete with higher strength and less curing energy consumption, which can be applied in wide areas of civil engineering.

Table 3. Effect of curing method on compressive strength of mix M4

No.	Curing Regime	Compressive strength at 7 Days (MPa)
1	Inside Laboratory (12- 25 °C)	14.5
2	Outdoor subjected to sunlight at summer (35-49°C)	16.5
3	In oven at 50°C for 4-5 hours, then under sunlight at summer (35-49°C)	26.5
4	In oven at 60°C for (4-5) hours, then under sunlight at summer (35-49°C)	32.6
5	In oven at 70°C for (4-5) hours, then under sunlight at summer (35-49°C)	31.1
6	In oven at 80°C for (4-5) hours, then under sunlight at summer (35-49°C)	30.2
7	In oven at 100°C for (3) hours then, under sunlight at summer (35-49°C)	31.5

3.2 Effect of Alkaline Activator Concentration

The results in Figure 1 show that for the same (NaOH: Na_2SiO_3) ratio, the compressive strength of mix M4 increases with the increase of molarity from 12M up to14M. This behavior is attributed to the influence of the concentration of NaOH solution in geopolymerization as it is responsible for dissolving, hydrolyzing and leaching the (Si and Al) to form the precursor gel (Joseph and Mathew 2012, Livi and Repette 2017). Also, the (NaOH: Na_2SiO_3) ratio at (1:2) enhances the workability better than (1:2.5), therefore, the compressive strength was higher (Al-Shathr *et al.* 2018). The highest compressive strength obtained in this study was 41.4 MPa at 7 days for (1:2) ratio and 14 molarity, so it's selected as a reference mixture.

3.3 Mechanical Properties for Geopolymer Concrete with WBP

3.3.1 *Compressive strength*

The results of compressive strength for all mixes at 7 and 28 days are shown in Figure 2. Generally, the compressive strength at 28 days is higher than that at 7 days for all mixes. Geopolymer concrete containing WBP shows a reduction in compressive strength. The percentages reduction were 24.5, 21.1, and 29.8% for specimens with 10, 15, and 20% WBP respectively as compared with reference specimens (not containing WBP) at 28 days. This reduction may be attributed to the difference in fineness and strength activity index between MK and WBP.

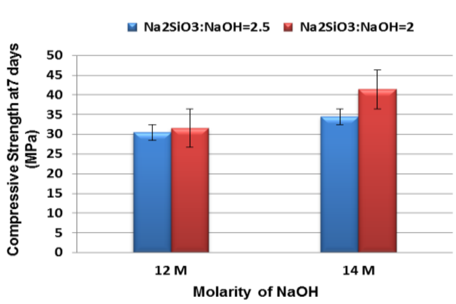

Figure 1. Effect of alkali solution concentration on the compressive strength of mix M4.

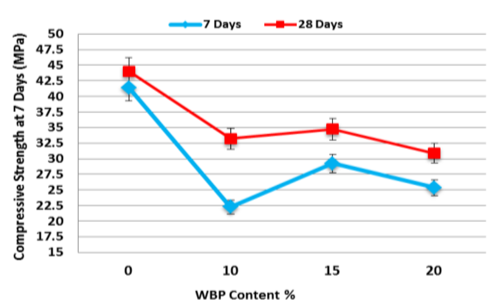

Figure 2. Compressive strength of geopolymer concrete with different waste bricks powder.

In addition, the incorporation of WBP altered the ideal balance of silicon/aluminum ratio and other elements, especially CaO during the geopolymerization (Wongsa *et al.* 2017). Also, the mismatching in optimal curing method (temperature and period) for MK based and WBP-based geopolymer causes reduction in compressive strength. According to Tuyan *et al.* (2018) the maximum compressive strength of waste clay brick powder-based was gained upon curing at 90 °C for 5 days. The reduction in compressive strength results is approved with the results presented by Rovnaník *et al.* (2016). This is related to the microstructure of alkali-activated brick powder, which is less compact and more porous. The optimum dosage of WBP was 15% by weight of MK, that gained 29.26 and 34.76 MPa strength at 7 and 28 days respectively.

3.3.2 *Splitting tensile strength*

Figure 3 presents the results of splitting tensile strength at 7 and 28 days. As in compressive strength, the splitting tensile strength increases with age, and the incorporation of WBP as partial replacement of MK decreases the results. The reduction in splitting strength reaches its maximum value of 37.9% at 28 days for mixture with 10% WBP. This declining in splitting results related to the same causes discussed in compressive strength previously. The minimum reduction in splitting strength was 6.66% for 20%WBP replacement of MK.

3.3.3 *Flexural tensile strength*

As shown in Figure 4, the blended binder geopolymer concrete mixtures exhibited better flexural strength than the mixture with 0%WBP at 28 days age. This enhancement is related to the feature of the microstructure of WBP-geopolymers, which consist of small particles of different sizes and shapes, and a few fiber-forms like crystals (Allahverdi and Kani 2013).

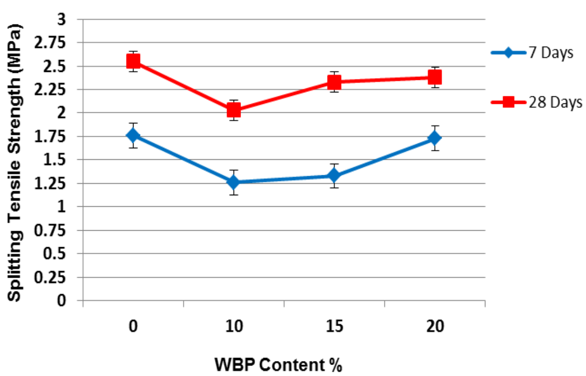

Figure 3. Splitting tensile strength of geopolymer concrete with different WBP contents.

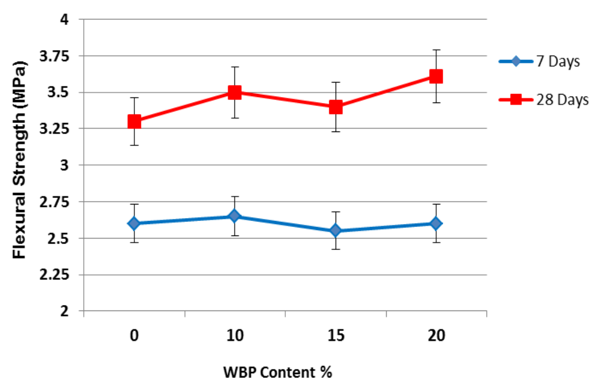

Figure 4. Flexural strength of geopolymer concrete with different WBP contents.

4 CONCLUSIONS

Based on the results obtained in this research, there is a direct relationship between the alkaline solution concentration, the curing method and characteristics of geopolymer concrete. Thus, it is possible to produce MK-based geopolymer concrete with higher than 40 MPa compressive strength at 7 days depending on accurate mix proportions, increased the alkaline activator concentration up to 14 molarity, and adopting efficient curing method. The combined curing method (in oven at 60°C for 4 - 5 hours, then exposure to the sunlight in hot weather) provides the best performance of MK-geopolymer with respect to the strength properties, sustainability and economically, because it reduces the energy consumption and the time of production especially in regions that have hot weather like Iraq. In addition, the incorporation of WBP in MK-based geopolymer concrete reduces both compressive and tensile strength, while the flexural strength showed a slightly increase. Related to compressive strength, the 15% WBP is the optimum dosage, while the 20% WBP gives the highest flexural strength.

The outcomes of this research confirm that the geopolymer concrete synthesized from blended MK and WBP had satisfactory mechanical properties for the concrete structures like multi stories buildings. It has the ability to be used in building industry such as precast elements, interlocking paving units, masonry units, sidewalk, and rigid pavement. Further studies on microstructure, long-term durability characteristics and time dependent deformations (creep and shrinkage) are suggested to be investigated.

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