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RESEARCH ARTICLE - CHEMICAL ENGINEERING

Effect of Sodium Silicate to Sodium Hydroxide Ratios on Strength and Microstructure of Fly Ash Geopolymer Binder

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Abstract Geopolymerization can transform a wide range of waste aluminosilicate materials into building and mining materials with excellent chemical and physical properties. The present experimental study investigates the effect of sodium silicate/sodium hydroxide ratios on the feasibility of geopolymer synthesis at 80 °C using fly ash. The sodium silicate/sodium hydroxide (S/N) ratios 0.5, 1.0, 1.5, 2.0 and 2.5 were studied. The result showed that the compressive and flexural strength increases as the curing age increases. Also, the compressive strength increases as the sodium silicate/sodium hydroxide ratio increases from 0.5 to 1.0 and then decreases. Morphology studies, conducted by SEM analysis of the geopolymer samples, indicated that geopolymers gel had the fly ash particles and pores embedded in a continuous matrix. At S/N = 1 a homogeneous and less porous microstructure was observed.

Keywords Geopolymer · Microstructure · Compressive strength · Flexural strength

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الخلاصـة

يمكن تحويل مجموعة كبيرة من النفايات المحتوية على الألومينا والسيليكات الى مواد بناء ذات مواصفات كيميائية وفيزيائية جيدة وذلك بإستخدام عملية الجيوبلمرة. وقد أجريت الدراسة التجريبية الحالية على تاثير نسبة سيليكات الصوديوم و هيدروكسيد الصوديوم على تصنيع الجيوبلمر عند حرارة 80 درجة وذلك بإستخدام الرماد المتطاير . وقد إستخدمت في هذه الدراسة النسب التالية من سيليكات الصوديوم و هيدروكسيد الصوديوم : 0.5 ، 1.0 ، 1.5 ، 2.0 ، و 2.5. وقد أظهرت النتائج أن قوة الإنضغاط والانحناء تزداد بزيادة عمر المعالجة. وتزداد أيضا قوة الإنضغاط بزيادة نسبة سيليكات الصوديوم/هيدروكسيد الصوديوم من 0.5 الي 10. ثم تتناقص. وقد تمت هذه الدراسات بإستخدام الميكرسكوب الالكتروني الماسح لعينات الجيوبلمر والتي أشارت إلى وجود جزيئات هلامية من الجيوبلمر تحتوي علي جزيئات الرماد المتطاير والمسام في منظومة منتظمة . وكذلك لوحظ وجود نسيج متجانس واقل مسامية عند نسبة سليكات الصوديوم/هيدروكسيد الصوديوم = 1 .

1 Introduction

Ordinary Portland cement (OPC) is the most commonly used binder in the production of concrete. The production of OPC goes through energy-intensive processes, which release a large amount of greenhouse gases to the atmosphere [1]. Geopolymer concrete is emerging as a potential alternative to OPC-based cement concrete. The relative merits of geopolymer concrete are: (i) low heating temperature and thus low energy consumption; (ii) low CO_2 emission making it a green material; (iii) rapid gain of strength; (iv) low permeability making it more durable; and (v) superior resistance to fire and acid attacks [2–9]. Geopolymers are thus considered as new generation materials for coatings and adhesives, a new binder for fiber composites and new cement for concrete. Moreover their superior properties, make the geopolymer a potential candidate for several industrial applications [6,9].

Geopolymers provide the possibilities to prepare inorganic bonds using waste materials such as slag, silica fume, fly ash, kaolinite substances, etc. Geopolymers are inorganic polymeric materials with a chemical composition similar to zeolites but containing an amorphous structure and possessing ceramic-like structure and properties. The amorphous to semi-crystalline three-dimensional structure of silicate network consists of SiO_4 and AlO_4 tetrahedral, which is linked alternately by sharing all the oxygen to create polymeric Si–O–Al bonds [7].

The geopolymers contain negatively charged tetrahedral aluminum sites in the network which are charge-balanced by alkali metal cations such as sodium and/or potassium [6]. However, sodalite and hydroxysodalite, which are included in zeolite group, have been detected as reaction products in some of the metakaolinite'-fly ash geopolymer systems [10,11].

In the pioneering work on geopolymers, Davidovits [2,3,12] used metakaolinite which was activated by alkali hydroxide and/or alkali silicate. Further studies [6,13–15] investigated the use of other aluminosilicate materials such as fly ash, furnace slag, kaoline, silica fume, and some natural minerals in the production of geopolymers with great success. Xu et al. [6] investigated geopolymerization of sixteen natural aluminosilicate minerals with the addition of kaolinite. The study demonstrated that a wide range of natural aluminosilicate minerals provide potential sources for synthesis of geopolymers. In the area of nanopores the geopolymer porosity is very similar without any regard to preparing conditions [16].

The scope of this work is to provide experimental data on the effect of sodium silicate/sodium hydroxide ratios on mechanical properties, microstructure and phase composition of low-calcium fly ash geopolymer.

2 Experimental

2.1 Materials

Class F fly ash (FA) of Blaine surface area ≈ 3,800 cm^2/g and average diameter ≤ 10 μm was used in this investigation [6]. Figure 1 shows an SEM micrograph of raw fly ash particles. The mineral and chemical compositions of fly ash used in the investigation are shown in Fig. 2 and Table 1 respectively.

It is mainly glassy with some crystalline inclusions of mullite, hematite and quartz. The oxide composition of fly ash is summarized in Table 1. The chemical analysis of the fly ash used as the starting material in this work showed it to be a high-silica ash with the mole ratio of $SiO_2 : Al_2O_3$ = 2.796. Commercial local red sand was used as fine aggregate in the mortar.

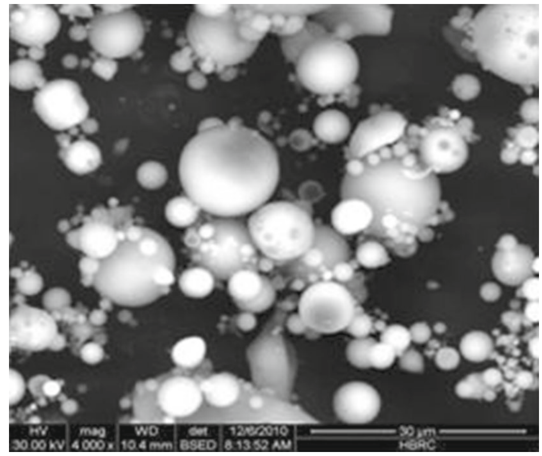

Fig. 1 SEM micrograph of fly ash

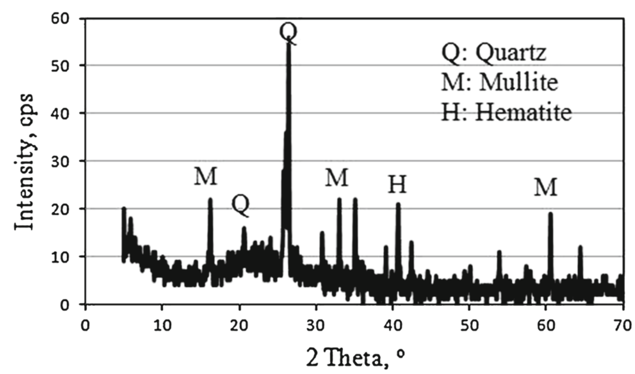

Fig. 2 XRD of fly ash

Table 1 Chemical composition of fly ash by XRF, mass %

Oxide	FA	Mob/100g of fly ash
Composition		
CaO	4.29	0.0051
SiO_2	52.87	0.8799
Al_2O_3	33.08	0.3146
Fe_2O_3	3.58	0.0224
MgO	0.9	0.0223
SO_3	0.38	0.0447
Na_2O	0.3	0.0048
K_2O	0.79	0.0083
TiO_2	1.89	0.0111
P_2O_5	0.55	0.0038
MnO	0.05	0.0007
Total	98.68	–
Ignition loss	1.32	–

Sodium silicate (Na_2SiO_3) mixed with sodium hydroxide (NaOH) as an alkaline activator has been used in this study. NaOH in pellet form with 97 % purity, and Na_2SiO_3 which consists of Na_2O; 7.9 %, SiO_2; 26.0 % and H_2O; 66.1 %,