Construction Wastes as Raw Materials for Geopolymer Binders

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Abstract: *It has been shown that geopolymerization can transform a wide range of waste aluminosilicate materials into building materials with excellent chemical and physical properties such as fire and acid resistance. In this research work, geopolymerization of construction waste materials with different alkali-activators based on combinations of* Na_2SiO_3 *and NaOH has been investigated. A number of systems were designed and prepared with water-to-dry binder ratio, silica modulus, and sodium oxide concentration were adjusted at different levels and setting time and 28-day compressive strength were studied. The results obtained reveal that construction wastes can be activated using a proportioned mixture of* Na_2SiO_3 *and NaOH resulting in the formation of a geopolymer cement system exhibiting suitable workability and acceptable setting time and compressive strength. Laboratory techniques of Fourier Transform Infrared Spectroscopy (FTIR) and Scanning Electron Microscopy (SEM) were utilized for studying molecular and microstructure of the materials.*

Keywords: *Geopolymer, Construction Waste, Alkali-activator, Compressive Strength*

1. Introduction

Construction waste is a growing problem in many countries. Stokoe et al. [1] reported that construction and demolition (C&D) waste took up about 65% of Hong Kong's landfill space at its peak in 1994/1995. According to Formoso et al. [2], over 50% of the waste in a typical UK landfill could be construction waste. Craven et al. [3] reported that construction activity generates 20–30% of all waste deposited in Australian landfills. In the US, C&D waste represents about one-third of the volume of materials in landfills [4]. Serpell and Labra [5] report that of the 3.5 million tons of C&D waste generated in Chile, only 10% is placed in authorized and controlled landfill sites. In the European Union, it is estimated that 0.5–1 ton per capita of C&D waste is generated annually [3,6].

The environmental aspects of waste from the building sector have been of great interest in recent years. For the building sector, this means, among other things, increased recycling. Recycling of building waste can reduce the need for energy and natural resources and can also reduce both the need for land area for extracting resources and the need for land area for landfill. The benefits of recycling depend on the materials and the form of recycling [7].

On the other hand, development and production of new industrial products from recycling materials has been attracted growing importance in recent years. Geopolymer cements belonging to the group of alkali-activated materials are such new industrial products. Compared to Portland cement, they exhibit some superior engineering properties. Synthesis of geopolymers is based on the activation of aluminosilicate materials by an alkali metal hydroxide and an alkali metal salt [8].

In recent years, many research works have been carried out to investigate the possibility of utilizing industrial waste materials as raw material in the production of geopolymer cements. The use of granulated blast-furnace slag and fly ash has been reported in many research works [9-14]. This work is a preliminary investigation on the possibility of utilizing construction wastes consisting of brick and concrete as raw materials in the production of geopolymer cements.

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2. Experiments

2.1. Raw materials

Waste brick and concrete were used as raw materials. Waste brick was prepared from Abyek brick production plant located in north of Iran. The waste concrete prepared from a concrete technology laboratory was a sample of an 8-month old concrete. The samples were crushed and ground using laboratory crusher and ball mill. The prepared materials were then characterized by determining their chemical composition and particle size distribution. The results of wet analysis are presented in table 1. Particle size distribution curves of the waste brick and concrete powders are shown in figure 1. The mean particle size of the waste brick and concrete were 26.74 µm and 24.17 µm, respectively.

The FTIR spectra of the used brick and concrete are shown in figure 2. As seen, the FTIR spectra of the waste brick and concrete show two strong peaks. One at wavenumber about 460 cm-1 and the other a broad peak at wavenumbers in about 1000 cm-1 which are both attributed to asymmetric stretching of Al-O and Si-O bonds of aluminosilicate structure. Industrial sodium silicate with SiO_2/Na_2O weight ratio of 0.86 and silica content of 34.32 wt% and industrial-grade sodium hydroxide of 99% purity were used in all experiments.

2.2. Specimens Preparation

Mixtures of waste brick and concrete with given proportions in table 2 were homogenized using a domestic grinder (type SANA SCG-3001). The proportion of the waste concrete was limited to the maximum amount of 60% (by weight), because higher proportions resulted in severe efflorescence formation in a number of preliminary tests. Enough sodium hydroxide was added to sodium silicate for preparing an alkali-activator having silica modulus of 0.60. The sodium oxide contents of the designed geopolymer cement mixes were adjusted at three different levels of 6, 7, and 8% (by weight of dry binder). The water-to-dry binder ratios (W/DB-ratios) were adjusted at four different values of 0.26, 0.27, 0.28 and 0.30, for an approximately the same consistency. Mix proportions, sodium oxide content, and W/DB-ratios are presented in table 2. After adding activators to the dry binders and enough mixing, the pastes were cast into moulds of 2×2×2 cm^3 in size. The moulds were held at an atmosphere of more than 95% relative

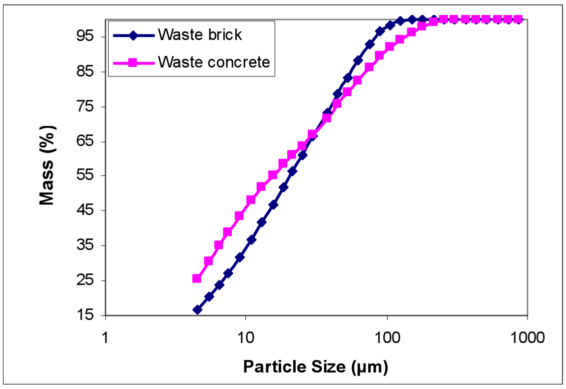

Fig. 1. Particle size distribution of ground waste brick and concrete

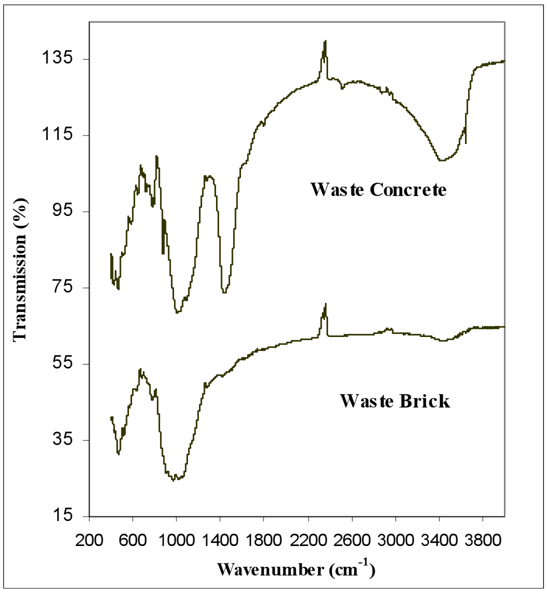

Fig. 2. FTIR spectra of waste brick and concrete

Table 1 Chemical composition of the waste brick and concrete (wt %)

Oxide	**SiO_2**	**Al_2O_3**	**Fe_2O_3**	**CaO**	**MgO**	**K_2O**	**Na_2O**	**LOI**
Waste Brick	53.40	10.48	5.80	24.92	1.40	2.18	1.46	0.52
Waste Concrete	41.15	7.80	12.57	20.64	1.50	2.07	1.98	13.07

Table 2 Mix proportions, sodium oxide content, and W/DB-ratios (Ms=0.60)

Mix. Name	Mixture proportion (wt%)		Na_2O (wt %)	W/DB-ratio
	Waste brick	Waste concrete		
1-1	40	60	6	0.26
1-2			7	0.26
1-3			8	0.26
2-1	50	50	6	0.26
2-2			7	0.26
2-3			8	0.26
3-1	60	40	6	0.27
3-2			7	0.27
3-3			8	0.27
4-1	80	20	6	0.28
4-2			7	0.28
4-3			8	0.28
5-1	100	0	6	0.30
5-2			7	0.30
5-3			8	0.30

humidity and ambient temperature, i.e. 25°C. The moulds were opened after 24 hours and the specimens were stored in the humid bath until the testing time.

2.3. Test Procedure

The mixes were characterized by measuring their initial and final setting times and 28-day compressive strength. Setting times of all the mixes was measured using Vicat needle in accordance with ASTM standard C191-82. From each mix, three specimens were used for determining compressive strength. Samples of waste brick and concrete and hardened paste of mixes exhibiting the highest 28-day compressive strengths were characterized by laboratory techniques of Fourier Transform Infrared spectroscopy (FTIR, Nicolet 740) and Scanning Electron Microscopy (SEM, Philips XL30) for studying molecular and microstructure of the materials. For SEM studies, a number of 28-day hardened specimens were cut into halves to expose internal regions. Suitable halves were then impregnated with epoxy resin, polished and coated with carbon.

3. Results and discussion

3.1. Setting times

All the measured initial setting times were too short, less than 5 minutes, implying a false set probably due to high thixotropic properties of the fresh pastes. Detailed experimental work is necessary for studying the rheological behavior of the material and determining the reason for such a short initial setting time.

Figure 3 shows the effects of Na_2O concentration on final setting time of mixes. As seen, final setting time of mixes varies in the range between 100 – 250 minutes. Such final setting times are practically acceptable compared to normal values reported for ordinary Portland cement. It is seen that at constant silica modulus, the final setting time reduces when Na_2O concentration is increased. Any increasing in the Na_2O concentration could accelerate activation reactions which in turn results in a significant decrease in final setting time. A comparison of the results clearly shows the presence of

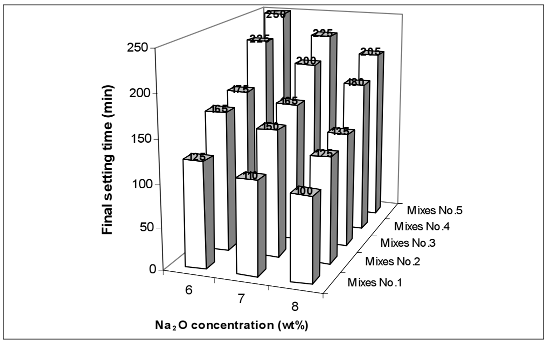

Fig. 3. Effect of Na2O concentration on final setting time

harmonic variations between final setting time and the other variables including W/DB-ratio and mix proportion. It is reasonable to expect that any increase in W/DB-ratio results in an increase in the final setting time. However, more experimental works are necessary to realize the effect of mix content on the setting times of such systems.

3.2 Compressive strength

Before measuring 28-day compressive strength, the specimens were observed visually for any possible crack. They were quite sound and no crack was observed visually. Figure 4 shows the effects of Na_2O concentration on compressive strength of different studied mixes. As seen, the strength increases by increasing Na_2O concentration. However mixes with relatively higher proportions of waste brick, e.g. No. 3 to 5, show a quite higher strength development with any increase in the Na_2O concentration. Mixes with lower content of waste brick, e.g. No. 1 and 2, show quite smaller variations in compressive strength with Na_2O concentration. This proves that the calcinated aluminosilicate content of waste brick is more suitable for geopolymerization reactions.

As seen, the maximum achievable 28-day compressive strength is 40 MPa for mix No. 5-3 comprising of only waste brick and containing 8% Na_2O by weight of dry binder.

3.3. FTIR analysis

From each group of mixes with the same content of waste brick and concrete, those with higher content of Na_2O, i.e. 8 wt%, showing maximum 28-day compressive strength (systems No. 1-3, 2-3, 3-3, 4-3, and 5-3) were selected and samples of 28-day hardened pastes were analyzed by FTIR. Figure 5 displays the corresponding infrared spectra. As seen, the infrared spectra of the samples are rather similar, presenting analogous absorption bands. All show bands at 3440 and 1650 cm^{-1}, respectively, related to O-H stretching and bending modes of molecular water and also near 1000 cm^{-1} and 450 cm^{-1} due to asymmetric Si-O-Al stretching vibrations and to in-plane Si-O bending vibrations in SiO_4 tetrahedral, respectively [15,16].

The Si-O stretching modes for the SiQ^n units show infrared absorption bands localized around 1100, 1000, 950, 900, and 850 cm^{-1} for n = 4, 3, 2, 1, and 0, respectively [15]. These values shift to lower wavenumbers when the degree of silicon substitution by aluminum in the second coordination sphere increases, as a consequence of the weaker Al-O bonds. A comparison of the wavenumbers shows that Si-O stretching band shifts progressively towards greater wavenumbers from mix No. 1-3 to mix No. 5-3. For sample 5-3, the Si-O stretching band appears at the wavenumber of 1027 cm^{-1}. This

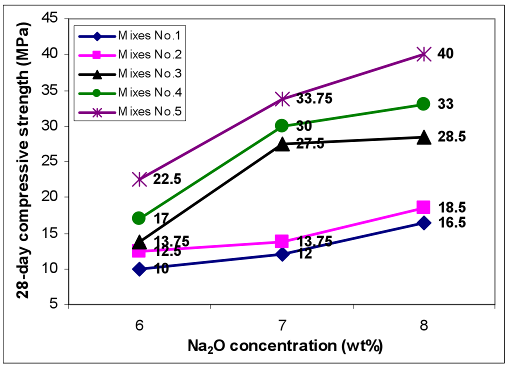

Fig. 4. Effect of Na_2O concentration on 28-day compressive strength

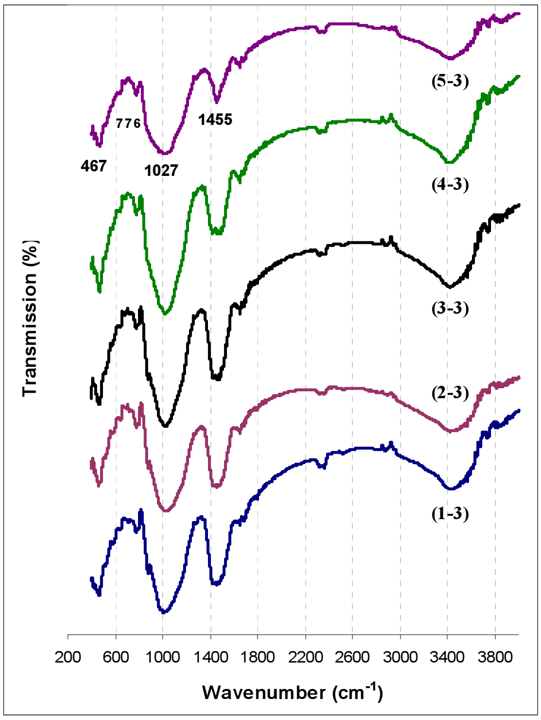

Fig. 5. FTIR spectra of 28-day hardened paste of mixes showing maximum compressive strength

indicates a distribution of the polymerized Q^n units centered on Q^3 and Q^4 units. All the tested samples contain carbonate species pointed out by the presence of the large absorption band near 1450 cm^{-1}, related to asymmetric stretching and out of plane bending modes of CO_3^{-2} ions [17,18].

3.4. SEM analysis

Investigations were done by Scanning Electron Microscopy (SEM) on 28-day hardened pastes comprising of only waste brick and containing 8% Na_2O by weight of dry binder (No. 5-3). Figure 6 shows the microstructure of the hardened paste at four different magnifications. The observed particles are those of waste brick which were bond together by dissolution of their surface in alkali-activator and formation of geopolymer compounds. As seen in figure 6, the microstructures are relatively coarse along with a number of microcracks. It is hypothesized that hydrothermal curing is probably useful to dissolve a higher proportion of waste brick and to increase the extent of geopolymerization reactions. Also according to author's previous work [19], hydrothermal curing could effectively improve the microstructure of the specimens by preventing microcracks formation and hence resulted in the formation of a quite sound and more uniform microstructure.

4. Conclusions

1. Results obtained from activation of mixtures of waste brick and concrete with a proportioned alkali-activator prove the possibility of producing geopolymer cement from construction wastes.
2. Final setting time of systems prepared with different proportions of waste brick and concrete and

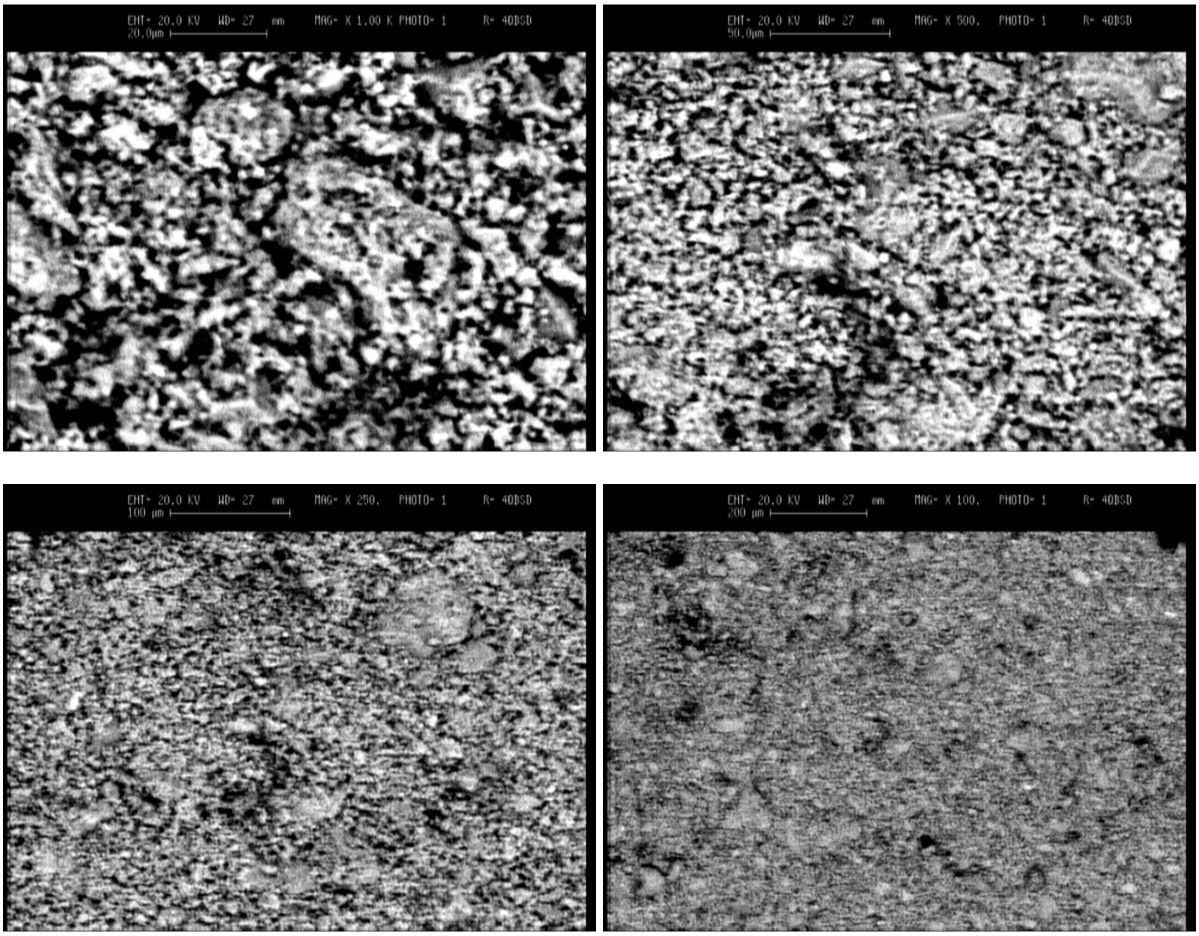

Fig. 6. SEM image from microstructure of 28-day hardened paste of mix No. 5-3

activated at a constant silica modulus of 0.6 and Na_2O concentrations of 6, 7, and 8 wt% varies in the range between 100-250 minutes.

3. Results obtained for 28-day compressive strength confirm that waste brick is more suitable than waste concrete for geopolymerization reactions. The maximum achievable 28-day compressive strength is 40 MPa for system comprising of only waste brick and containing 8% Na_2O by weight of dry binder.

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