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The effect of SiO_2 on the performance of inorganic sludge-based structural concretes

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As a relatively new material, geopolymer concrete offers benefits as a construction material for sustainable development. It utilizes waste materials such as recycled concrete sludge, fly ash, etc. It has a very low rate of green house gas emission when compared to ordinary Portland cement. In this study, the components of geopolymer are concrete sludge, metakaolin and water glass. NaOH was used as an alkaline activator. To improve the mechanical properties, silica fume was added as a bonding matrix from 0%-10% to replace part of the concrete sludge, and the specimens were cured in air, then their mechanical properties such as compressive strength and bending strength were measured and their microstructures were investigated.

Key words: Geopolymer, Concrete, Silica fume, Concrete sludge, Metakaolin.

Introduction

Concrete usage around the globe is second only to water. An important ingredient in conventional concrete is Portland cement. The production of one ton of cement emits approximately one ton of carbon dioxide to the atmosphere. Moreover, cement production is not only highly energy-intensive, next to steel and aluminum, but also consumes significant amounts of natural resources. Nowadays, more and more research is focused on environment-friendly construction materials. To reduce the CO_2 emission, geopolymer concrete is expected to replace the traditional Portland cement-based concrete. It is reported that geopolymer-based concrete releases only 1/6 of the CO_2 compared to that of ordinary Portland cement (OPC). But because of the relative high cost of metakaolin, which is the main component of the geopolymer, the application of geopolymer construction material is limited. On the other hand, huge volumes of concrete sludge are already generated around the world, most of which is not effectively used, and a large part of it is deposited in landfills, which also causes construction waste pollution. So the solution of this type of problem should be regarded as of importance.

Geopolymer-bonded mortar with metakaolin as the only raw material for construction applications can reach a 3-day compressive strength above 80 MPa from our previous research. From that point we realized a geopolymer can be developed as an excellent binder to replace cement if the cost could be reduced.

This research describes an attempt of using recycled concrete sludge as the raw material to fabricate a green geopolymer mortar. NaOH was used as an alkaline activator. To improve the mechanical properties, silica fume was added as a bonding matrix from 0-10% to replace part of the concrete sludge, and the specimens were cured in air, then their mechanical properties such as compressive strength and bending strength were measured and their microstructures were investigated.

Experimental Procedures

In this study, a geopolymer was prepared from metakaolin, recycled concrete sludge powder, silica fume and alkaline activators. Metakaolin was obtained commercially and concrete sludge was supplied freely by a company. The alkaline activators, sodium hydroxide and a soluble glass, were used to activate the alumino-silicate oxide.

Test 1 was to test the effect of metakaolin on the properties of a sludge-based geopolymer. Here the concrete sludge powder and silica sand were well mixed with different amounts of metakaolin additions from 10-40% (all the percentages here are wt% of powder matrix) with the aid of vibrating machine. The powder-to-sand ratio was 30 : 70 by weight. Sodium hydroxide was dissolved in water to get a solution with a concentration of about 10 M. Then the NaOH solution and water glass were mixed together and cooled down to about 20 °C. After that, the mixture was poured into the vibrating bowl to fabricate a castable geopolymer mortar. The mortar was filled into steel moulds with dimensions of $150 \times 15 \times 15$ mm and $50 \times 50 \times 50$ mm for bending and compressive strength tests respectively. After curing at room temperature for 24 h, demoulded specimens were given physical properties tests and microstructures were also observed by a scanning electron microscope (SEM).

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Test 2 was to investigate the use of silica fume on the sludge-based geopolymer. The concrete sludge powder and silica sand were well mixed with different amounts of silica fume additions from 2-10%. The other processes were the same as for test 1.

Results and Discussions

An XRD pattern of recycled concrete sludge is shown in Fig. 1. The main phases of concrete sludge are $CaCO_3$ and quartz, which partially provides SiO_2 for the geopolymerization reaction. The microstructure of sample that contained sludge only was shown in Fig. 2(a). Without a metakaolin addition, there is no active alumino-silicate existed, which is the main component for geopolymer formation. Also the SiO_2 contained in the sludge powder was not active enough to fabricate a strong bond. So an incompact structure with many pores and cracks was found, due to weak bonding between particles.

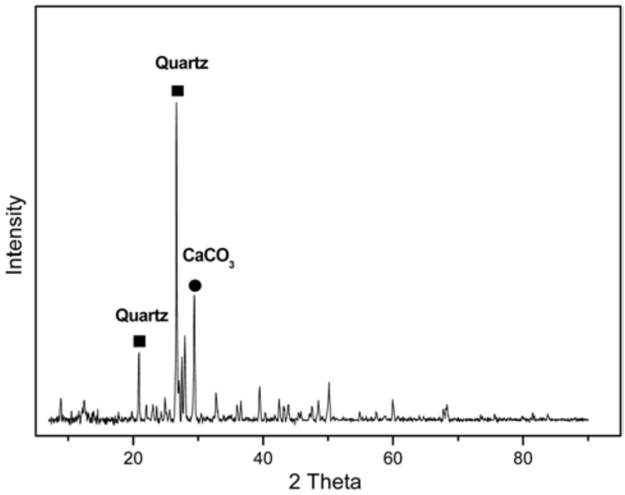

Fig. 1. XRD pattern of recycled concrete sludge.

The bodies of the specimens became more compact when metakaolin was added. The geopolymer synthesis was much enhanced with an increase of the metakaolin content. Sialate bridges (Si-O-Al-O-) were formed by the introduction of the alumino-silicate. The in-situ formed geopolymer bonded the sludge particles and silica sands very well, which lead to higher bending and compressive strengths which are shown in Fig. 3. The density also increased with the metakaolin content and the apparent porosity decreased. The microstructures of metakaolin containing samples showed smoother surface and well-bonded boundaries between sludge particles and sand particles with less cracks and pores as seen in Fig. 2(b). There only a few cracks existed and a homogeneous structure was observed compared to the coarse grains with no additives as shown in Fig. 2(a).

When the fine silica fume was added, it offered SiO_2

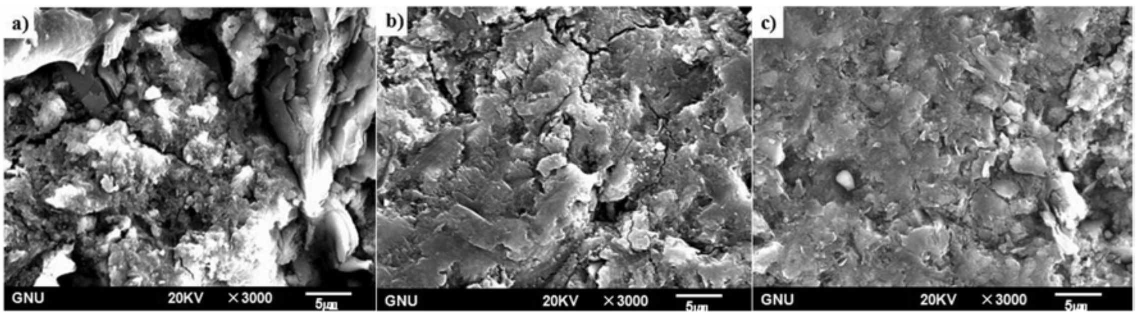

Fig. 2. Microstructures of geopolymers containing (a) concrete sludge only, (b) 20% metakaolin addition, and (c) 10% silica fume addition.

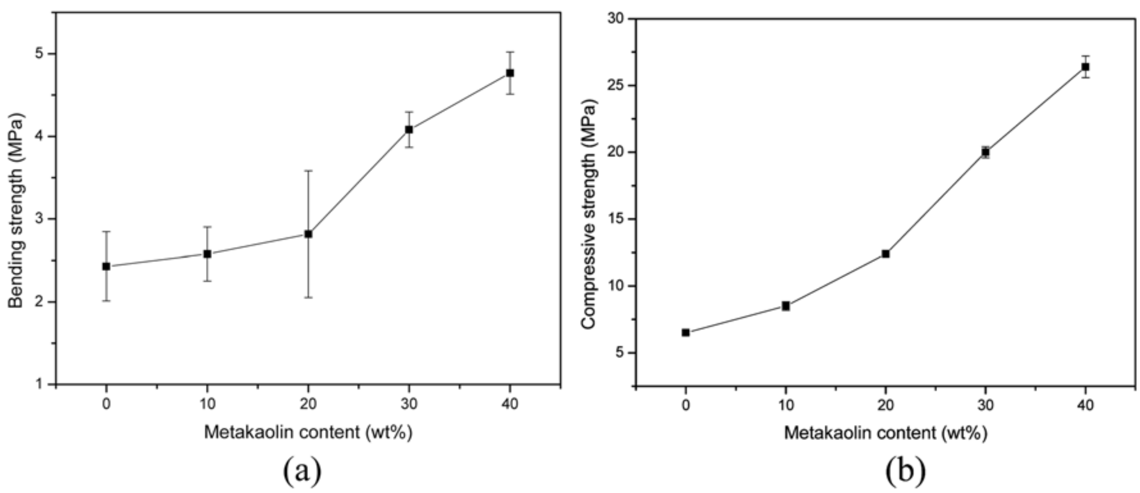

Fig. 3. Variation of (a) bending strength and (b) compressive strength of sludge-based geopolymers with metakaolin additions.

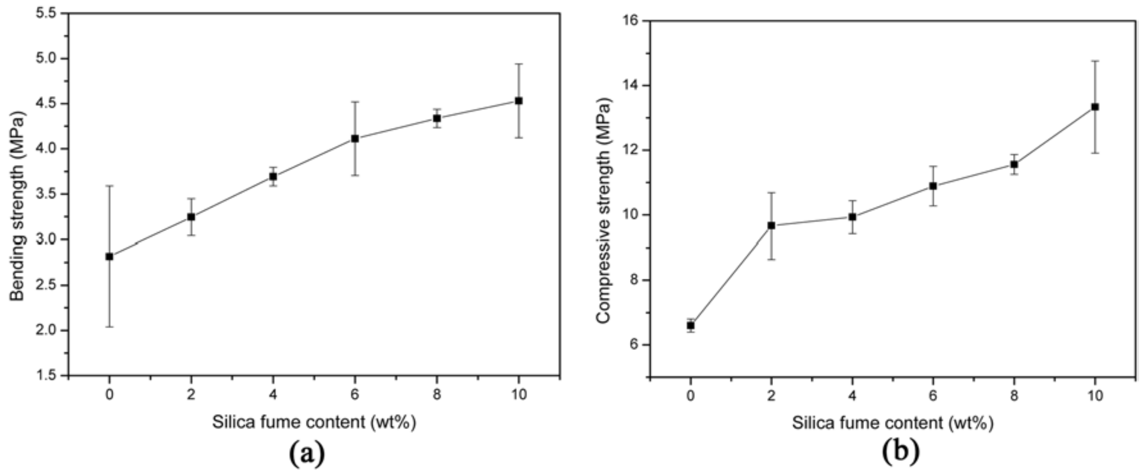

Fig. 4. Variation of (a) bending strength and (b) compressive strength of sludge-based geopolymers with silica fume additions.

with a high activity. This SiO_2 played a very important role in forming the siloxo bridges (-Si-O-Si-O-) in the geo-polymerization processing. These bridge chains bonded particles firmly; consequently, both bending strength and compressive strength were enhanced by the silica fume additions that may be seen in Fig. 4. A strength of more than 13 MPa, which is a satisfactory value for mortars, could be reached by a 10% addition. Also Fig. 2(c) showed a much denser and more compact matrix structure compared with those samples without silica fume additions.

Conclusions

To fabricate a construction applicable geopolymer in a cost-effective manner, recycled concrete sludge was used as a raw material, metakaolin powder and silica fume were used to optimize the properties.

1. A sample containing only concrete sludge showed poor mechanical properties because of the weak bonding. A microstructure with big cracks and large pores among the matrix and sand particles was found.

2. With the addition of metakaolin powder, by introducing an alumino-silicate, the in-situ formed geopolymer acted as a binder to the raw materials. Polymerization bonded particles together well, leadings to a better performance. Both bending strength and compressive strength of mortars could meet common construction requirements. The geopolymer stabilized the waste in a cost-effective and environment-friendly way.

3. The silica fume offered active SiO_2 which was advantageous for geopolymer production. So the addition of silica fume also improved the mechanical properties of mortars and made the structure much denser. But the amount of this should be considered because of its high cost.

4. Although the raw material was cheap recycled concreted sludge waste, the other components such as NaOH and water glass still have a relatively high cost. Substitutes of these materials should be found and the properties of this type of construction material may be further enhanced.

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