UTILIZATION OF SILICA WASTE TO REPLACE SILICA FUME FOR MIXED MORTAR

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Abstract

This research investigated the utilization of silica waste to replace the imported condensed silica fume for the production of ready mixed mortar. The silica waste was classified using sieve analysis procedures in order to achieve a high degree of fineness with a spherical shape and average particle size of 3.2 microns. Classified silica waste was used to replace 10% volume content weight of Type I Portland cement to produce ready mixed mortar. In addition, the samples of condensed silica fume obtained from a representative supplier were also used to produce ready mixed mortar by replacing 10% cement by weight. The water binder ratio was fixed at 0.4 for all samples. The compressive strength of the concrete samples containing classified silica waste and condensed silica fumes was determined and compared at curing times of 7, 14 and 28 days. The results revealed that mortar mixed with condensed silica fume produced the highest compressive strength. For the mortar mixed with silica waste samples, the mortar with 10% classified silica waste was found to produce the highest compressive strength. The use of classified silica waste replacement at 10% of cement was compatible with condensed silica fume as 10% of the cement yielding nearly the same compressive strength of mortar at the curing age of 28 days. In addition, the mortar containing 10% classified silica waste as a cement replacement tended to have higher compressive strengths than those of condensed silica fume mortars after 28 days. The results, therefore, suggested the high potential of classified silica waste as a replacement for condensed silica fume in producing ready mixed mortar.

Keywords: silica waste, ready mixed mortar, silica fume, recycle, pozzolan materials

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บทคัดย่อ
งานวิจัยนี้เป็นการพัฒนากากของเสียซิลิกาเพื่อใช้แทนซิลิกาฟูมในการผลิตมอร์ต้าร์ผสมเสร็จ โดยน้ำยาการลงออกแบบซิลิกาฟูมโดยค่อนข้างจะได้มาเป็นการลดตามมวล ขนาดอนุภาคเฉลี่ย 3.2 ไมครอน จากนั้นนำกำกับเรียกให้ได้ความละเอียดสูงขึ้นเป็นกลุ่มซิลิกาแยกละเอียด มีรูปร่างทรงกลม ขนาดอนุภาคเฉลี่ย 3.2 ไมครอน จากนั้นนำกำกับเรียกให้ได้ความละเอียดสูงขึ้นเป็นกลุ่มซิลิกาแยกละเอียด มีรูปร่างทรงกลม ขนาดอนุภาคเฉลี่ย 3.2 ไมครอน จากนั้นนำกำกับเรียกให้ได้ความละเอียดสูงขึ้นเป็นกลุ่มซิลิกาแยกละเอียด มีรูปร่างทรงกลม ขนาดอนุภาคเฉลี่ย 3.2 ไมครอน จากนั้นนำกำกับเรียกให้ได้ความละเอียดสูงขึ้นเป็นกลุ่มซิลิกาแยกละเอียด มีรูปร่างทรงกลม ขนาดอนุภาคเฉลี่ย 3.2 ไมครอน จากนั้นนำกำกับเรียกให้ได้ความละเอียดสูงขึ้นเป็นกลุ่มซิลิกาแยกละเอียด มีรูปร่างทรงกลม ขนาดอนุภาคเฉลี่ย 3.2 ไมครอน จากนั้นนำกำกับเรียกให้ได้ความละเอียดสูงขึ้นเป็นกลุ่มซิลิกาแยกละเอียด มีรูปร่างทรงกลม ขนาดอนุภาคเฉลี่ย 3.2 ไมครอน จากนั้นนำกำกับเรียกให้ได้ความละเอียดสูงขึ้นเป็นกลุ่มซิลิกาแยกละเอียด มีรูปร่างทรงกลม ขนาดอนุภาคเฉลี่ย 3.2 ไมครอน จากนั้นนำกำกับเรียกให้ได้ความละเอียดสูงขึ้นเป็นกลุ่มซิลิกาแยกละเอียด มีรูปร่างทรงกลม ขนาดอนุภาคเฉลี่ย 3.2

คำสำคัญ: ของเสียซิลิกา, ของเสียซิลิกาแยกละเอียด, ซิลิกาฟูม, วัสดุปอซโซลาน

Introduction
Silica wastes are obtained from the depolymerization process of silicone compound recycling, which accounts for approximately 300-400 tons per year. The treatment costs for waste disposal and management of such wastes are expensive. Therefore, studies are encouraged to utilize used materials and waste, such as silica waste, as part of a mixture of raw materials that can be used productively and consequentially to reduce waste pollution. Silica wastes have characteristics similar to pozzolanic materials (1) and the composition of silicon dioxide, i.e. silica fume saturated equivalents. This study aims to improve the silica waste compound to be used as the pozzolanic material for the production of ready mixed mortar (2) used in construction. The study aims to observe different ratio mixtures of raw materials that conform (3) as a mixture of cement in order to obtain the optimal chemical composition and quality for mortar production. Objectives of the study are as follows.

- To study the physical and chemical characteristics of silica waste compared with silica fume.
- To study the chemical composition and micro-structure of the product, appropriate proportion of silica waste and silica fume saturated to produce mortar and the optimal curing period from different time variations, are also included.

Experimental Concept
The silica waste from the recycling process is composed of silicone-silicon compounds from waste recycling plants which can be advantageous for ready-mixed mortar production. The
The experiment was intended to compare silica waste with the saturated silica fume purchased from abroad. The study of physical and chemical properties of materials and two kinds of material X-ray fluorescence (XRF) were analyzed for heavy metals by using an atomic absorption spectrophotometer (AAS). Varying proportions of silica and silica waste soaked in the mixture was used to prepare the mortar (size 5 × 5 × 5 cm) to 10 % by weight of cement, fixing water to binder ratio of 0.40 and 28 day curing period to determine the optimum conditions. Then, test the quality of the mortar.

**Materials and Methods**

**Preparation of Silica waste and saturated silica fume**

The silica waste and saturated silica fume samples were analyzed for the material properties, i.e. pH, density, size distribution, mixing and leaching tests. The materials used were prepared by thermal transfer to rack, which was then used to mix with cement.

**Mix Design**

The mix design of the mortar was prepared for two kinds of cementitious materials (silica waste and saturated silica fume), which was then compared to the controls. The mix design, was designed with a water/material ratio fixed at 0.40, using silica content accounting for 10 % of the mass of cement. The mortar product was tested at 7, 14 and 28 days for variation of curing time.

**Preparation of Composite Materials**

The sand used for the experiment was washed with water then dried at temperatures ranging from 103 to 105 °C. The sand was then mixed with Type 1 Portland cement with a fine aggregate ratio of 1 to 2.5.

**Leaching Tests of Heavy Metals**

The heavy metal leaching test was performed using the waste extraction test (WET) in accordance with the Ministry of Industry’s protocol established in 2005 for the disposal of waste or used materials. The leaching was analyzed using AAS.

**Analysis of Size Distribution of the Mixed Materials**

The analysis of the mixed size distribution for the silica waste and saturated silica fume was carried out by Sieve Analysis in accordance with ASTM C136 – 95. The test was performed in the Concrete Materials Testing Room in the Department of Civil Engineering, Chulalongkorn
University. The sieve boxes were sorted by size from larger sizes on the top to lower sizes at the bottom. The material was then shaken through the sieve boxes to obtain different material sizes, which were 3/8 inch, No. 4 (4.76 mm), and No. 8 (2.36 mm).

**Chemical Composition and Microstructure of Materials**

The specific gravity of the cement was tested in accordance with ASTM C150-07 standards. The specific gravity of the sand and water absorption was tested in accordance with ASTM C128-07a standards to analyze the chemical composition of materials (Silica Waste and Silica Fume) using XRF. Micro structure was analyzed using scanning electron microscopy (SEM).

**Optimum Conditions for Mortar in the Production of Concrete with Silica Waste Compared to Saturated Silica Fume**

By varying the proportion of materials to be mixed with cement and water/binder ratio and curing time, the cast piece sample size was 5 x 5 x 5 cm. (5 sample cubes for each experimental mixture). The samples were produced by using the silica waste to replace 10 % of the cement weight and a water/cement ratio of 0.40. The experimental samples were compared with saturated silica fume mixed with cement to 10 % by mass with a water to cement ratio of 0.40 in varying durations of the curing mass samples at 7, 14 and 28 days. The samples were measured for unit weight in accordance with ASTM C29 standards by weighing the samples, then dividing the volume of the cube specimens. Investigation of the compressive strength was used as the basis for the decision for the experimental samples with different ratios and varying water/binder mix designs.

**Comparison of Compressive Strengths and Heavy Metal Leaching Test**

The mortar prepared with the proper proportion was tested to determine the compressive strength. The samples were then tested using the leaching method (WET) in accordance with the Ministry of Water Industry Act of 2005. The leaching of heavy metals was analyzed using the atomic absorption spectrometer (AAS).

**Result and Discussion**

**Chemical Characterization**

The comparative results for the chemical composition of waste saturated with silica and silica fume using computer X-ray fluorescence: XRF are shown in Table 1. The materials used in the experiment are shown in Figure 1.
The study found the chemical characteristics of silica waste to contain an average of 84 % of silicon dioxide. Silica fume samples contained 92 % silicon dioxide. The silica waste yielded characteristics of pozzolanic compositions similar to silica fume \(^{(5)}\). Therefore, the silica waste can be used instead of saturated silica to lower the costs associated with importing silica fume from overseas.

**Table 1** Chemical Composition of Silica Waste Compared to Cement, Silica Waste and Different Pozzolanic Materials

<table>
<thead>
<tr>
<th>Oxide</th>
<th>Cement Type I *</th>
<th>Silica Fume **</th>
<th>Silica Waste **</th>
<th>Coal Ash Mah Mo*</th>
<th>Husk Ash*</th>
</tr>
</thead>
<tbody>
<tr>
<td>SiO₂</td>
<td>20</td>
<td>92</td>
<td>84</td>
<td>48</td>
<td>90</td>
</tr>
<tr>
<td>Al₂O₃</td>
<td>5</td>
<td>0.7</td>
<td>&lt;0.1</td>
<td>26</td>
<td>0.5</td>
</tr>
<tr>
<td>Fe₂O₃</td>
<td>3</td>
<td>1.2</td>
<td>&lt;0.1</td>
<td>10</td>
<td>2.0</td>
</tr>
<tr>
<td>CaO</td>
<td>60</td>
<td>0.2</td>
<td>&lt;0.1</td>
<td>5</td>
<td>0.5</td>
</tr>
<tr>
<td>MgO</td>
<td>1.1</td>
<td>0.2</td>
<td>&lt;0.1</td>
<td>2</td>
<td>0.2</td>
</tr>
<tr>
<td>SO₃</td>
<td>2.4</td>
<td>-</td>
<td>&lt;0.1</td>
<td>0.7</td>
<td>1.5</td>
</tr>
<tr>
<td>Other</td>
<td>1.5</td>
<td>2.6</td>
<td>&lt;0.1</td>
<td>1.3</td>
<td>-</td>
</tr>
<tr>
<td>Oxide</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LOI</td>
<td>2</td>
<td>-</td>
<td>-</td>
<td>3</td>
<td>4.7</td>
</tr>
</tbody>
</table>

Source: * Therarath and and Chai, 2002 ** The chemical composition analysis by XRF.

**Figure 1** Materials Used in the Experiment a) Waste Silica b) Silica Fume c) Cement

**Physical Characteristics**

The physical properties are critical to determining the pozzolanic material of silica waste needed to improve product quality. The materials were grounded and the amount of particles remaining on Sieve No. 325 (aperture of the 45-micron mesh) were no less than 5 % by weight \(^{(5)}\), which are considered very small non-crystalline silica particles \(^{(6)}\).
Heavy Metal Leaching of Silica Waste Compared to the Saturated Silica Fume

The study found the silica waste with copper, zinc, lead and chromium to be 0.015, 0.2031, < 0.0005, and 0.698 mg/L. The silica fume samples found copper, zinc, lead and chromium to be 0.122, 0.310, 0.149, and 0.093 mg/L. Yields from the test on leaching of heavy metals by the Waste Extraction Test (WET) show that all types of heavy metals were within the standard of the Ministry of Industry Act of 2005. Therefore, the results suggest the possibility of utilizing waste silica for the production of concrete for construction.

Compressive Strength to Determine Optimal Proportions for Mortar

Packed mortar was prepared by mixing raw materials passed through sizing classification and mixed with cement. The samples were produced with a water-to-binder ratio of 0.4, utilizing free silica and silica fume at 10% of cement weight. The samples were tested for compressive strength at curing times of 7, 14, and 28 days as shown in Figure 2. The results show the compressive strength of the cube mortar mixed with silica waste, silica fume and cement gave average compressive strengths of 148, 221 and 225 ksc, respectively (curing period of 28 days).

![Figure 2 Compressive Strength of Mortar Cubes at Curing Times of 7, 14 and 28 days.](image)

Pozzolanic Materials

The mortar that had been cured for 28 days was placed under a microscope for electron scanning which showed ongoing pozzolanic reactions in the illuminated area. This result indicates that the mortars of silica fume and waste silica can develop greater compressive strength with longer incubation periods.
Heavy Metal Leaching of Silica Waste Compared with Silica Fume Casting at 28 Days

The study found silica waste cast as mortar to contain heavy metals, i.e. copper, zinc, lead and chromium, in amounts of 0.088, 0.465, 0.026 and 0.192 mg/L, respectively. In the case of the silica fume, the heavy metals, i.e. copper, zinc, lead and chromium, were 0.084, 0.361, 0.027 and 0.160 mg/L, respectively. The leaching of heavy metals test was performed in accordance with the standards of the Waste Extraction Test (WET) prescribed by the Ministry of Industry Act of 2005. The results found all of the heavy metals to be within the limitations set forth in the Ministry of Industry Act of 2005. Therefore, the conclusions can recommend the possibility of using waste silica in the production of concrete for construction.

Conclusion

This study searched for ways to utilize silica waste as a replacement for silica fume in ready mixed mortar production with satisfactory results indicating the potential of silica waste as a replacement material in the production of silica fume mortar. The ratio of silica waste mixed with cement used as raw material can be adjusted to obtain the appropriate chemical composition and quality for mortar production for construction as follows:

- Grounded silica waste can be used as a pozzolanic material to be mixed with mortar at a rate of 10% by weight binder. The mixture material can obtain compressive strengths similar to standard mortar at a 28-day curing period.

- Free silica waste has characteristics similar to pozzolanic material with more than 70% of the weight. The composition of the silica dioxide meets the specifications for pozzolanic material from ASTM C 618-96; therefore the material can obtain increased compressive strengths when incubated for longer periods of time. The results also show that the material can be used as a silica fume replacement in concrete production.

Figure 3 SEM Photographs of Scanning Electrons Expanded 2500 Times:

(a) Silica Fume (b) Free Silica
- The results for the heavy metal leaching test of waste silica for casting mortar in comparison to silica fume cast as mortar indicated the solutions to contain heavy metals, including lead, copper, zinc and chromium, within acceptable limits of the Ministry of Industry, 2005.

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