Microwave-accelerated curing with low-pressure of Portland cement paste at very early stage

Natt Makul

Department of Construction Technology, Faculty of Industrial Technology, Phranakhon Rajabhat University,
Changwattana Road, Bangkhen Bangkok 10220, Thailand.
Tel., Fax: (+662) 544-8000; E-mail: shinomomo7@hotmail.com

Abstract

The microstructure characteristic of microwave-accelerated curing of the paste which had a 0.38 water-to-cement mass ratio (w/c) under low pressure level of cavity was investigated experimentally. The microwave power levels of 390, 811, and 1231 watt for 45 minutes were taken into account. The results indicated that the increased temperature consistently related to an increasing microwave power level. Microwave-cured pastes consisted of hydrated phases and pores, $Ca(OH)_2$ dendrite crystals, C–S–H, and granular structure. The range of the Si/Ca ratios was 0.147 to 0.263, while the that of the Al/Ca ratios was 0.029 to 0.061. At elevated temperatures, the sample subjected to a high microwave power level of 1231 watt was suddenly burnt and exposed.

Keywords*:* Microwave-accelerated curing; Portland cement paste; Low pressure; Cavity

1. Introduction

Microwave sintering is the most popular energy source to heat dielectric materials in various industrial processes [1-3]. In this work, microwave energy to accelerated curing of ordinary Portland cement paste was applied. The advantage of rapid heating, short processing time and energy savings are main reasons for using microwave energy. Hereunder, we reported the effect of microwave sintering on the morphology, atom ratio of Si/Ca versus Al/Ca and phase identification.

2. Experimental programme

2.1. Specimen preparation

The chemical composition as weight percent of the Portland cement Type 1 was 20.30 SiO_2, 5.67 Al_2O_3, 60.43 CaO, 6.23 Fe_2O_3, 3.14 MgO, 0.90 K_2O, 0.36 Na_2O, 2.80 SO_3. The Portland cement Type I had L.O.I. of 2.80%, specific gravity of 3.12, and surface area (BET method) of 0.85 m^2/g. Deionized water was used to mix with Portland cement to make pastes. The paste used was proportioned at a w/c ratio of 0.38 by mass. After mixing and molding, they were cured at room temperature by wrapping with polyethylene plastic until the delay time (time

after mixing until introducing microwave energy with a multi-mode cavity) for 30 minutes.

2.2. Microwave sintering setup

The microwave sintering setup used in this study was shown in Fig. 1 [4]. The temperatures and power histories of the paste during the application of microwave energy at power levels of 390, 811, and 1231 watt for 45 minutes on samples subjected to low-pressure environments (initial pressure at 15 ± 5 mm Hg). For the three monitored points, top surface, inside, and bottom surface, the temperature rise and pressure inside the cavity behave in a similar way by an infrared thermometer which was used to monitor suddenly the temperature of the sample at the end of heating.

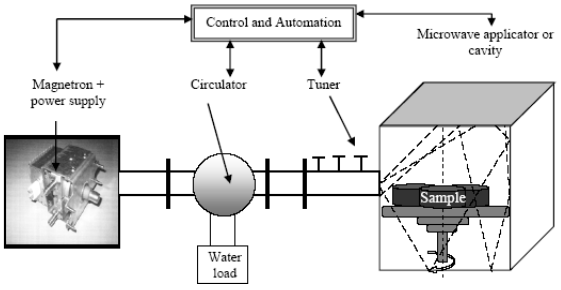


Fig.1 Configuration of the microwave curing package.

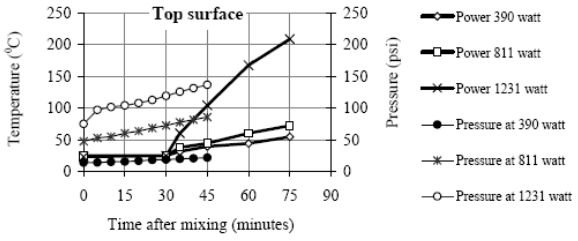
2.3 Testing procedures

A scanning electron microscope associated with energy dispersive X-ray spectroscopy, specifically an International Scientific Instruments ISI-130 electron microscope, was used to observe the morphology of the samples. The crystalline phase identification of the various samples was performed on a Scintag X-ray Diffractometer.

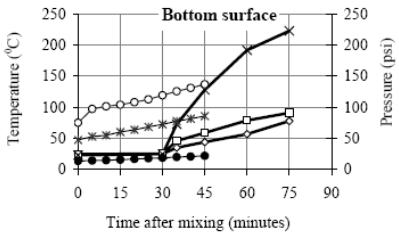
3. Results and discussion

3.1 Temperatures and power histories

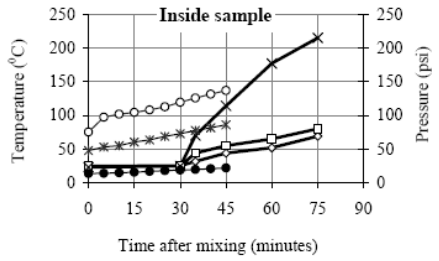
Fig. 2 showed the temperatures and power histories of the paste during the application of microwave energy, it was showed that the temperature increases was related to the increase in microwave power level; in particular, at a power of 1231 watt, the temperature increased rapidly until reaching a final temperature of 209 ^{0}C (at the top surface), 223 ^{0}C (at the bottom surface), and 215 ^{0}C (inside the sample). For the lower powers (390 and 811 watts), the rate of the temperature increase is very low. The pressure inside the cavity is raised continuously as an increment of the temperature. This is because when microwave energy is applied, some of the sample's water content evaporates, and as a consequent the inside pressure increases.



(a) At top surface



(b) At bottom surface



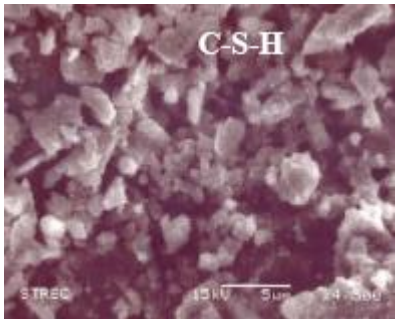
(c) Inside the sample

Fig. 2 Temperature and power history during applying microwave energy of paste

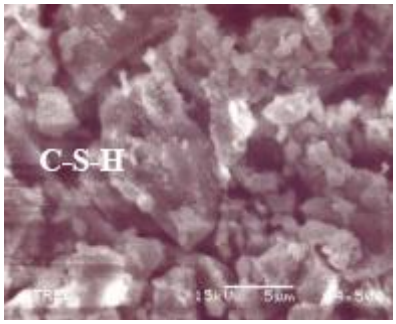
3.2 Morphology

Fig. 3 showed typical micrographs for the paste subjected to low pressure. Fig. 3(a) and 3(c) showed that the microwave-cured samples consist of hydrated phases and pores, as well as cores of $Ca(OH)_2$ dendrite crystals or other crystals (marked CH), C–S–H, and granular structure [5]. Furthermore, the samples showed no differences. However, if microwave power increases to 1231 watt, some part of the sample appears to be burnt. Fig. 3(d) shows the sintered part of the paste sample. It was found that when cured at elevated temperatures, pastes subject to a low-pressure cavity can burnt and exposed quite rapidly when applying a microwave power level of 1231 watt.

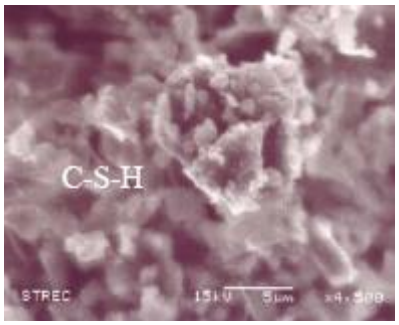
The SEM–EDS results as shown in Fig. 4 in regard to the atom ratio of Si/Ca versus that of Al/Ca for the 1CW/S_P0.38 paste subjected to low pressure show that the measured Ca/Si and Al/Ca ratios of the pastes were similar in magnitude and that they are unpredictable distributed when the microwave decreased from 390 to 1231 watt. The range of the Si/Ca ratios is 0.147 to 0.263, while the that of the Al/Ca ratios is 0.029 to 0.061.



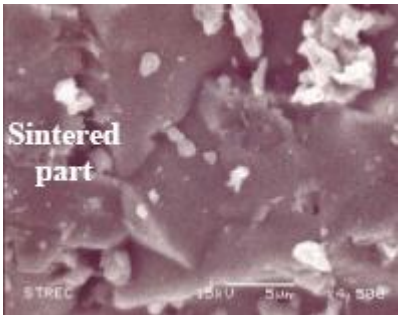
(a) At power 390 watt for 45 minutes



(b) At power 811 watt for 45 minutes



(c) At power 1231 watt for 45 minutes (Unburnt sample)



(d) At power 1231 watt for 45 minutes (Burnt sample)

Fig. 3 Micrographs of paste under subjected to low pressure.

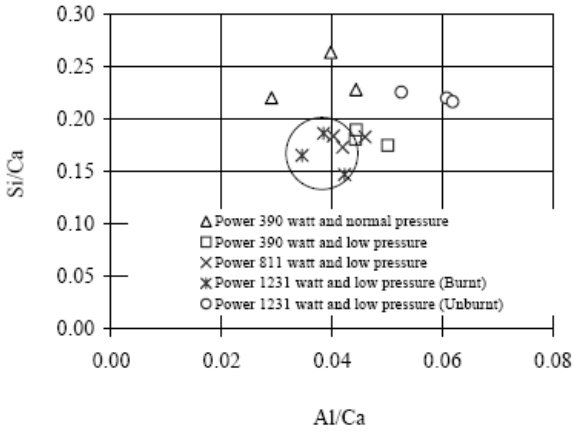


Fig. 4 Atom ratio of Si/Ca versus Al/Ca of pastes.

3.3 Phase identification

Fig. 5 presented the effects of a low-pressure environment on the phase characteristics of the paste after microwave power of 390, 811, and 1231 watt had been applied for 45 minutes: the Ca_3SiO_5 and $Ca(OH)_2$ phases are shown to be similar.

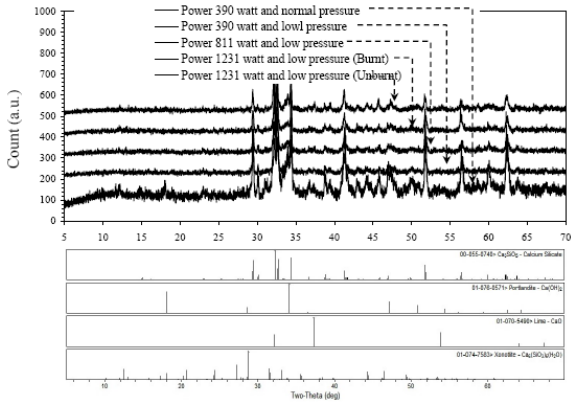


Fig. 5 X-ray diffraction of paste under subjected normal and low pressure environments.

4. Conclusion

Under microwave-accelerated heating associated with low-pressure of cavity at 15 ± 5 mm Hg with various microwave power levels, the Portland cement paste occurred sintered part. Such a power of 1231 watt, the temperature increased rapidly until reaching a final temperature more than 200 ^{0}C. Its microstructure consisted of hydrated phases and pores, $Ca(OH)_2$ dendrite crystals and the Si/Ca ratios was between 0.147 to 0.263, while the that of the Al/Ca ratios was 0.029 to 0.061.

5. References

[1] Metaxas, A.C., 1991, Microwave Heating, Journal of Microwave Power and Electromagnetic Energy, pp. 237-247.

[2] Leung, K.Y.C. and Pheeraphan, T., 1995, Microwave curing of Portland cement concrete: experimental results and feasibility for practical applications, Construction and Building Materials, 9 (2), pp. 67-73.

[3] Hutchinson, R.G., et al., 1991, Thermal acceleration of Portland cement mortars with microwave energy, Cement and Concrete Resrach, 21, pp. 795-799.

[4] Natt Makul , Dinesh K. Agrawal, 2010, Microwave (2.45 GHz)-assisted rapid sintering of SiO_2-rich rice husk ash, Materials Letters 64, 367-370.

[5] Hewlett, P.C., 1998, Lea's Chemistry of Cement and Cementitious Material, 4th Edition, New York: John Wiley & Sons Inc.