International Journal of Heat and Mass Transfer 127 (2018) 179–192

Contents lists available at ScienceDirect

International Journal of Heat and Mass Transfer

journal homepage: www.elsevier.com/locate/ijhmt

An experimental study of microwave drying under low pressure to accelerate the curing of Portland cement pastes using a combined unsymmetrical double-fed microwave and vacuum system

Natt Makul [a], Somsak Vongpradubchai [b], Phadungsak Rattanadecho [b,]*

[a] Department of Building Technology, Faculty of Industrial Technology, Phranakhon Rajabhat University, Changwattana Road, Bangkhen, Bangkok 10220, Thailand
[b] Center of Excellence in Electromagnetic Energy Utilization in Engineering (CEEE), Thammasat University (Rangsit Campus), Khlong Luang, Prathum Thani 12121, Thailand

ARTICLE INFO

Article history:
Received 8 April 2018
Received in revised form 24 June 2018
Accepted 24 June 2018

Keywords:
Microwave-assisted drying (MD)
Portland cement pastes (CM)
Low pressure
Temperature
Moisture content
Compressive strength

ABSTRACT

An experimental study was conducted on the use of microwave-assisted drying (MD) to accelerate the curing of Portland cement pastes (CM) under a low pressure by using a combined unsymmetrical double-fed microwave and vacuum system. The effects of microwave power (800 and 1600 W) and pressure level (30 and 50 kPa) on the temperature, moisture content, and gained compressive strength of CM were examined. The CM specimens were prepared with standard CM at water-cement ratios (w/c) by mass (0.38 (38% moisture content), 0.45 (45% moisture content), and 0.75 (75% moisture content)) before applying MD. In the experiments, when the CM specimens were dried using MD, the increases in was faster because of the high level of humidity. As it became less humid, the specimens could absorb less microwave energy and eventually remained at a stable temperature. A low pressure level affected the moisture content in CM, as a lower pressure resulted in a lower boiling point. The moisture in CM evaporated quickly, and the moisture content decreased faster than the high pressure did. Further, the w/c affected the temperature because a low w/c caused the CM temperature to be higher than that observed for a high w/c. Finally, the CM specimen that was dried using a microwave at 50 kPa and a 0.45-w/c attained the highest compressive strength.

1. Introduction

Currently, concrete production is highly competitive for economic and sustainability reasons, and research aiming to increase knowledge about the rapid curing process and obtain a higher quality of concrete is one of the main goals of both entrepreneurs and producers. In particular, the development of concrete that is high strength and more durable and has minimal quality loss in both the early-age and the long term is desired. When using the shortest production time, typically, if the concrete has high compressive strength development, curing will take more than several days, and the concrete must be cured continuously, for which there are various methods and technologies [1]. However, currently, these methods have many disadvantages, such as the loss in strength observed when the concrete drying is accelerated by an autoclave; a non-uniform heat distribution in the concrete; and the low thermal conductivity of the materials used in concrete, which causes the concrete's properties to vary. Moreover, it takes more than a day to get the concrete to develop as required. Further, if a curing substance is used, it will have a negative impact on the concrete's properties in the long term. Therefore, most concrete producers and industries need to have alternative technologies to overcome these problems, such as the innovative use of microwave-assisted curing technology for accelerated curing during the early-age state. This is a new technology because microwave energy is an effective energy source. Very clean heat is also constant, and there is uniform heat dissipation. The basic mechanism of heat generation under microwave conditions and the dielectric properties of dielectric materials are the main properties of concrete, as observed when changing microwave energy into heat energy. This is beneficial for the properties of concrete, but in various studies, the application of microwave energy in concrete curing was done by using a household microwave oven and conducting the curing process under a normal pressure condition (101.325 kPa) [2]. However, microwave curing under low-pressure conditions has not been researched extensively, especially microwave drying (MD) for the accelerated curing of cement concrete materials under low-pressure conditions.

* Corresponding author.
E-mail address: ratphadu@engr.tu.ac.th (P. Rattanadecho).

https://doi.org/10.1016/j.ijheatmasstransfer.2018.06.119
0017-9310/

MD is an effective technique for thermal processes for improving the shortest drying time and the best overall quality of dried materials. It has more than twice the performance of conventional heating methods and is suitable for dielectric materials [3], such as food [4–12], biological tissue [12,13], wood [14,15], ceramic [16,17], and oil-water emulsions [18]. Principally, the mechanism and direction of heat generation and transfer differ from those of conventional heating methods [19]. In conventional heating methods, the material is heated by an external source, and the heat is transferred inward from the outside material. By contrast, microwave heating relies on the rapid polarization and depolarization of positively and negatively charged groups in the dielectric material, resulting in simultaneous internal heat generation and outward transfer. For this reason, microwave heating offers many advantages over conventional methods as follows [4,19–21]:

(a) Rapid heating rates and short processing times, which save energy,
(b) Deep penetration of the microwave energy, and
(c) Clean heating processes that do not generate secondary waste, among others.

This research aimed to experimentally investigate the use of microwave-assisted drying for the accelerated curing of CM under low-pressure conditions using a combined unsymmetrical double-fed microwave and vacuum system to study in depth the characteristics and kinetics of heating CM and the distribution of temperature, moisture and mechanical properties of CM when subjected to microwave irradiation and low pressure levels. Additionally, the mathematics based on the finite-element method for predicting the heat transfer within the CM while applying MD was proposed.

2. Materials and methods

2.1. Scope of research

As shown in Fig. 1, this research was carried out by drying CM using two asymmetric microwave feedings with a vacuum system to study the temperature distribution, moisture content, and compressive strength of the CM specimens that were tested after MD drying. The parameters used in the study were the magnetron position (1 (vertical magnetron) and 2 (horizontal magnetron), low pressure levels (30 and 50 kPa), and amount of specimen per drying process (12 and 24). The CM samples had water-cement ratios (w/c) of 0.38, 0.45, and 0.75 before drying.

2.2. Equipment

The commercialized combined unsymmetrical double-feed microwave and vacuum system is shown in Fig. 2 [22]. The microwave power was generated by unsymmetrical double-feed magnetrons (air-cooled magnetrons): 800 W, each at an operating frequency of 2450 MHz. The microwave power could be adjusted separately within a range of ±800 W. The microwave power was conveyed through a waveguide series with a rectangular size of 11.0 cm × 5.5 cm to a 0.13 m^3 vacuum cavity (0.24 m in diameter × 0.72 m in length).

The two levels of microwave power (800 W for one magnetron and 1600 W for two magnetrons turned on) and two levels of low pressure (30 and 50 kPa) were used.

2.3. Specimen preparation and testing methods

The CM specimens were made with dimensions of 5 cm × 5 cm × 10 cm. By mixing Type 1 Portland cement, which had the chemical composition and physical properties shown in Table 1, with tap water (pH = 7.0), as per the ASTM C305 standard [23], the water-cement ratios (w/c) were kept constant for all three cases (0.38, 0.45, and 0.75). The mix proportions of CM are shown in Table 2. After mixing and placing the CM slurry into a mold, a plastic sheet was used to cover the slurry and avoid moisture loss. At the age of 23.5 ± 0.5 h after mixing, the specimens were demolded and cured using different methods, including MD, water soaking, and air curing. In the water soaking method, 15 specimens were soaked in water at a controlled temperature of 25.0 ± 2.0 °C until testing. In addition, 15 specimens were cured at a temperature and relative moisture of 25.0 ± 2.0 °C and 60.0 ± 5.0%,

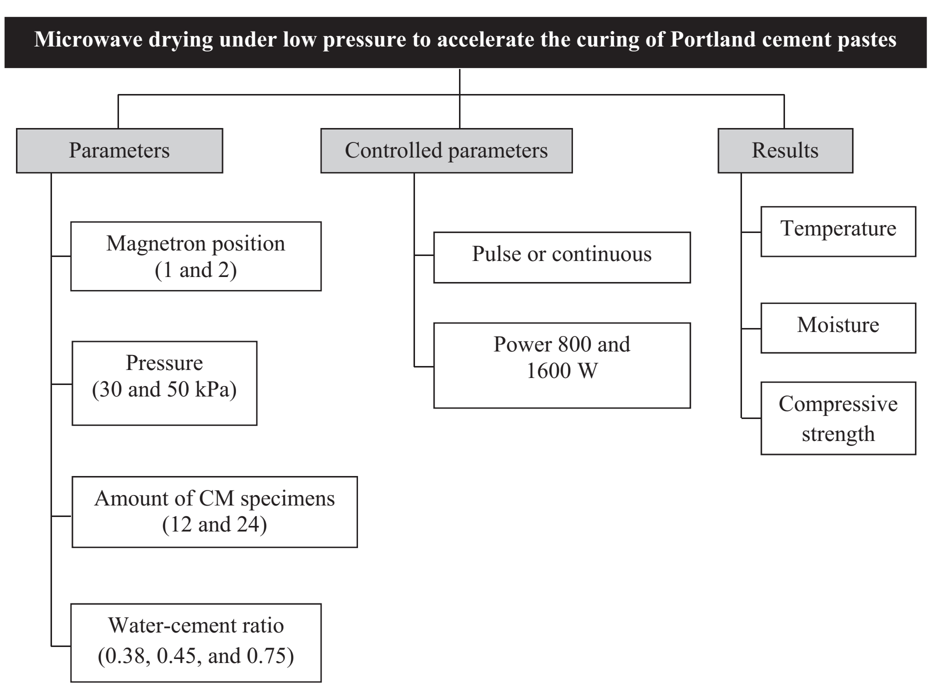

Fig. 1. Scope of the experiments.