CHAPTER 1

INTRODUCTION

1.1 Research problem and its significance

Curing by microwave irradiation (or microwave curing) is a high-performance curing method for dielectric materials used in a variety of industrial processes. On average, it is 1.50-2.0 times more effective than conventional curing methods. The primary differences between conventional curing methods and microwave curing are the heat generation mechanism and whether the direction of heat transfer is inward or outward. In the former method, the component being cured is heated by an external source and heat transfer is from the outside inward (Figure 1.1(a)). Microwave curing (Figure 1.1(b)) is based on the rapid polarization and depolarization of charged groups when the material to be heated is subjected to a high-frequency electromagnetic field, resulting in internal heat generation.

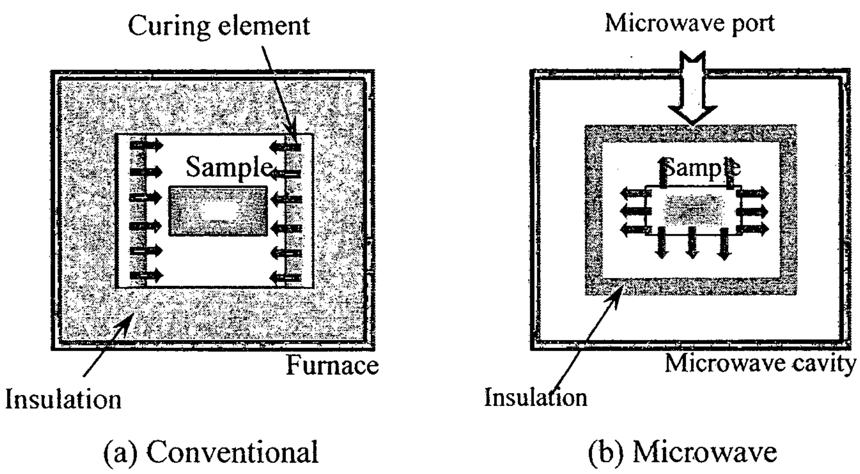

Figure 1.1 Comparison of heat generation and transfer mechanism in (a) conventional, and (b) microwave curing.

Microwave curing has been used in research and industrial applications such as thawing frozen meat, vulcanizing rubber, curing adhesive agents in lumber manufacture, curing of food, drying, decontamination of surfaces, and disinfection and sterilization. In order to be suitable for microwave curing the material in question must be a dielectric, and most current applications involve porous media composed of a solid phase containing a second fluid phase within the internal voids. Concrete may be classed as one of these materials.

Concrete is the predominant modern construction material with annually ½ cubic meters used per capita worldwide. One disadvantage to concrete is the slow development of strength under normal temperatures and pressures. Various accelerated-curing methods have been invented to enhance the rate of strength development, including application of external heat and pressure in an autoclave. However, the low thermal conductivity (0.8 to 1.28 W/m.K) of concrete reduces heat transfer during curing. Microstructural development in concrete is dependent on the uniformity of heat liberation from hydration and from external heating, and a steep temperature gradient from the external heat source to the inner regions of the component results in crack formation within the internal structure. In particular, concrete structures containing reinforcing steel are susceptible to fracture, substantially reducing the service life of the component. Thermal gradient problems may be reduced by using an internal heating process such as microwave curing.

Microwave curing of plain and steel-reinforced concrete is a relatively new field that will expand in importance in the near future. In particular, research is necessary to understand curing mechanisms with adaptive dielectric properties and to characterize the heat and mass transfer properties of concrete materials.

1.2 Objectives

This research aims to:

- Investigate the mechanisms of changes in the dielectric properties of plain containing pozzolan materials and reinforced concrete.
- Characterize the microstructure of microwave-cured plain and reinforced concrete.
- Study the mechanism of microwave heat generation, heat dissipation, and mass transfer of plain containing pozzolan materials and reinforced concrete.
- Formulate mathematical models for the relationships between microwave curing and mass transfer for steel-reinforced concrete.

1.3 Scope of research

This research combines both experimental and theoretical analyses. The dielectric properties of plain and steel-reinforced concrete including the relative dielectric constant ε' and relative dielectric loss ε'' during the first 24 h of hydration were measured at a frequency of 2.45 ± 0.05 GHz, and the characteristics of concrete subjected to short-term microwave curing (without loss of moisture) were investigated experimentally and numerically.

To measure the dielectric properties of concrete, a network analyzer with an open-ended coaxial probe was used. The apparatus consisted of a coaxial cavity, a microwave reflectometer, a 3.5-mm coaxial cable, a 3.5-mm female calibration, and short-, open-, and matched-load software. The coaxial cavity was suitable for measurements from 1.5 - 2.6 GHz with a precision of better than 2% for the dielectric constant and 5% for the dielectric loss factor. In order to eliminate the effects of the metal thermocouple on the microwave distribution the temperature and dielectric properties were measured in three separate samples each.

The microwave system was a monochromatic magnetron source with a frequency of 2.45 GHz. The energy was transmitted directly along the propagation direction (+z) of a rectangular wave guide toward a water load situated at the end of the waveguide to ensure that a minimal amount of microwave energy would be reflected back to the sample. The heated water load was recirculated through a cooling tower.

The waveguide and auxiliary equipment limited direct access to the sample, and evaporation within the structure of the concrete could not be continuously measured. Instead, evaporation measurements were based on weight loss of the sample.

The samples were fabricated from Type I Portland cement and were 109.22 mm long, 54.61 mm wide, and 50 mm or 80 mm thick. Water-cement ratios by mass were 0.25, 0.38 and 0.45 After mixing, the concrete samples were moulded and covered with plastic to prevent moisture loss. The hardened concrete samples were demoulded after ½ hour for microwave curing and 23½ hours for water curing. In reinforced concrete samples, the reinforcing steel was arranged at ½ times of the thickness of the concrete sample.

The effects of controlled curing methods such as lime-saturation and air at 25 ± 2 °C were experimentally investigated by monitoring the quantity and quality of hydration reaction products such as calcium silicate hydrate (C-S-H), and measuring changes in porosity and free and fixed moisture content in the cured samples.

During microwave curing, each sample was subjected to microwave energy in a rectangular waveguide for a specific amount of time. The microwave-cured samples were tested to determine compressive strength, curing water and air content, quantity and quality of hydration products such as calcium silicate hydrate (C-S-H), porosity, and changes in free and fixed moisture content.

Solutions to Maxwell's equations and the heat and mass transfer equations were used to understand heat and mass transfer phenomena occurring during microwave curing. The concrete was assumed to be a porous material with variable internal fluid flow. To simplify the problem, a 2-dimensional theoretical model was constructed to analyze the microwave behaviour using a TE_{10} propagation mode. Rattanadecho previously described a 3D model of the electromagnetic field inside a rectangular waveguide in TE_{10} mode developed using the COMSOL Multiphysics modeling software.

1.4 Expected benefits

The benefits to be gained from this project are as follows:

- **Benefit to academic**

The results of this research will lead to an in-depth understanding of the adaptive dielectric properties of plain and steel-reinforced concrete, enabling prediction of changes occurring during application of microwave energy and during hydration. Suitable mathematical models of heat and mass transfer and microstructural development during hydration and microwave curing will be developed. Results obtained using the laboratory scale apparatus may be applied to industrial curing systems for concrete, related cementitious materials, and eventually to microwave curing of other reactively-cured materials.

- **Benefit to faculty and related institution**

This project will benefit higher education as well as providing technology transfer to cement and concrete production. The results will be published in high-impact peer-reviewed journals at an international level. Consequently, publication of this research may raise the standard of research at Thailand and Phranakorn Rajabhat university to an international level.