Three-dimensional simulation on the thermal response of a sample of heterogeneous material irradiated by single mode microwave.

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Highlights

- Model coupling the electromagnetic field and transport phenomena
- Experimental validation at 2.45 GHz
- Study of the effects of geometry and dielectric properties.

1. Introduction

Microwave is a particular heating technology that is of interest for process intensification. In this work we study the electromagnetic heating of heterogeneous solids for material reuse. With around 30 billion tons produced each year worldwide, concrete is the most used material in the world with a growing problem of recycling and availability. Concrete is a heterogeneous solid material, composed of a continuous phase (mortar) and a discontinuous phase (aggregates) [1]. Studies have shown that microwave heating improves concrete recycling. However, the interaction between electromagnetic waves and a heterogeneous solid remains a complex subject. The design of large-scale continuous processes requires energy optimization and homogeneity of treatment. To fully understand the microwave heating process, a model of microwave heating coupled with heat and mass transfer is necessary. The COMSOL® Multiphysics software is used for the simulation of the electric field and the evolution of the temperature. For this study, a single-mode experimental setup is used. Measurements of masses, powers, and temperatures as well as an analysis of dielectric properties are also carried out. The predictions from the simulation are then compared with the experimental measurements.

2. Experimental methods and equipment.

In this study, a complete three-dimensional model has been developed to study the interaction of microwaves with a concrete cylinder. The model includes the physics of electromagnetic heating using **Maxwell's equations and Poynting's** theorem [2], and **Fourier heat transfer** for solids**.** During the microwave heating process, the internal and external temperature of the concrete cylinder rises simultaneously, unlike conventional heating methods. For this study, we used concrete cylinders manufactured under the requirements of European standards and respecting the size of the aggregates in relation to the volume of the concrete cylinder. The simulation results of the numerical model are compared with the experimental results (**Figure 1**) to verify the reliability of the model. Through experimentation and simulation, we were able to compare the evolution of the temperature in the sample, at a heating time of 10 minutes, 2.45 GHz frequency and 100 W of power.

Our laboratory operates several WR340 single-mode microwave systems with a wide range of input powers. This work uses two such systems, with maximum input power 300W and 2000W respectively. They are equipped with sensors for measuring direct and reflected power as well as temperature. An integrated system using LabVIEW® is used to record the data and control the input power. This research also uses a vector network analyzer (Agilent Technology N5230A PNA-L) and coaxial probes to measure dielectric properties (permittivity) of the materials of interest.

Virtual replicates of the above-mentioned microwave heating systems are built using the COMSOL® Multiphysics software. The project uses concrete cylinders 20 mm in diameter and 30 mm in height, which are placed vertically inside the cavity. The simulation uses a finite element precision meshing and the equations of heat transfer in solids. Some of the material properties required for simulating a standard concrete sample were extracted from the simulation software database, while for others; the permittivities of the concrete constituents were measured in the laboratory.

3. Results and discussion

The 3D numerical simulation of a concrete specimen heated by single-mode microwave generally involves the estimation of the dissipation of microwave energy in the concrete. Electromagnetic modeling must consider the boundary conditions [3], to describe the intensity of the electric (E) and magnetic (H) fields. Simultaneously, solving the heat and mass transfer equations allows temperature increases within the sample to be predicted. The permittivity value was analyzed to perform the simulation calculation, compare the simulation results and the actual measurement results. We calculated the **RMSE** statistic variable, for quantifies the deviation between experimental and simulated short-time.

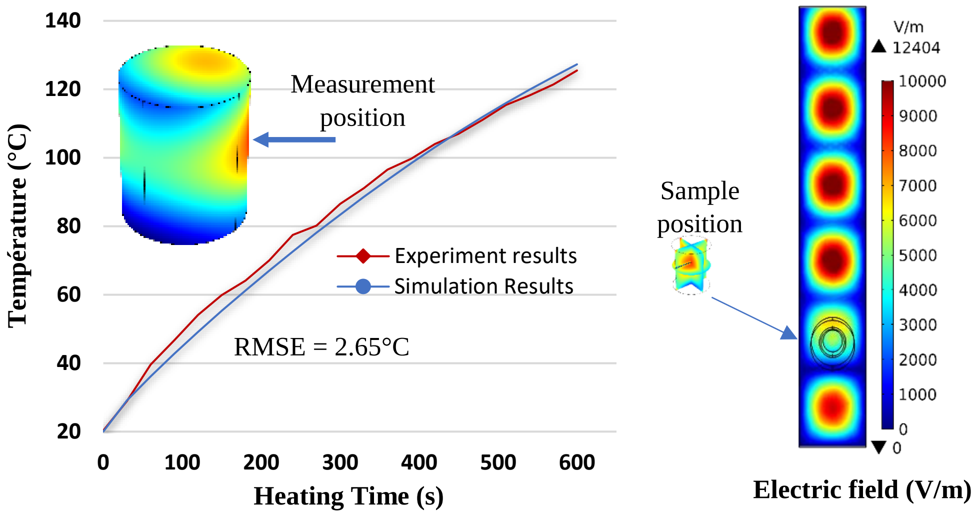

Figure 1: Experimental and simulation temperature profiles of the concrete sample.

4. Conclusions

In this study, electromagnetic radiation was set up for solving Maxwell's equations and heat transfer for temperature prediction and behavior coupled with COMSOL Multiphysics. Simulations were performed to investigate the effects of microwave power, applied frequency. The simulation was validated with the results of the experimental part**.**

It was concluded that the evolution of temperature, electric and magnetic field distribution are highly sensitive to microwave power and applied frequency. The heating increased with increasing microwave power. The influence of decreasing power on the heating rate inside the sample was investigated. The influence of sample dimensions on the microwave heating rate was also investigated and it was observed that the height of the sample was detrimental to the heating rate.

References

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Keywords

Microwave heating; Multiphysics simulation; waste recycling; heterogeneous material.