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Research Paper

3D ELECTROMAGNETIC FIELD SIMULATION OF SILICON CARBIDE AND GRAPHITE PLATE IN MICROWAVE OVEN

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Now a days, microwave processing of materials is gaining popularity due to its specific characteristic such as rapid heating, volumetric and internal heating, selective heating, reduced processing time and power consumption in contrast to conventional processing of materials. The microwave interaction of materials depends upon the dielectric properties of the materials being processed. Thus for optimum utilization of this technology, the understanding of the phenomenon of propagation of electromagnetic field in the material and how it interacts with material with different dielectric properties is the key aspects. This paper represents the simulation of the materials having different dielectric properties, such as silicon carbide and graphite plate using COMSOL Multiphysics (version 4.3) FEA based simulation software. Simulation result shows that the temperature in the silicon carbide reaches up to 868 °C in 300 s with resistive losses of 1 x 10^8 W/m^3 and temperature in graphite plate reaches up to 486 °C in 300 s with resistive losses of 4 x 10^7 W/m^3 by exposure of microwave radiation at 900 W.

Keywords: MIcrowave, COMSOL, FEA, Electromagnetic field, Simulation

INTRODUCTION

Now a day, microwave heating of materials has attracted attention due to its significant advantages as compared to conventional heating. Microwave heats the material volumetrically at molecular level due to dipole rotation and ionic conduction. Microwave energy transforms into heat inside the material and it results in energy saving and reduction in process time (Thostenson and Chou, 1999; and Das *et al.*, 2008). In contrast with conventional heating of material, which depends upon the conduction, convection and radiation phenomenon, the material processed through microwave radiation is heated through the interaction of electromagnetic field at molecular level. Thus volumetric heating takes place and process is faster, because high heating rates are possible without excessive temperature gradients (Siores and Rego, 1995; and Clark *et al.*, 2000). Materials such as ceramics and

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ceramics composite which are difficult to process using conventional method can be easily processed with help of the microwave energy. In powder metallurgy, it can be used in removing binders and gases. In spite of all these advantages, microwave processing of materials are environmental friendly with greater productivity in less space and decrease of heat losses and consequently reducing the manufacturing costs (Clemens and Saltiel, 1996; Ku *et al.*, 1999; and OghbaeiMorteza and MirzaeeOmid, 2010). However, the amount of heat generated by interaction with microwave radiation depends upon the dielectric properties of the materials and electromagnetic field distribution inside the materials. The penetration depth or skin depth of microwave radiation inside the material depends upon the dielectric properties of the material being processed and gives rise to heat source. The absorption of electromagnetic field in the material is responsible for micro and macro structural changes in the material. Thus, for heating the materials using microwave radiation, knowledge of how electromagnetic field propagates and how it is absorbed by the material is essential (Kraszewski *et al.*, 1997; Trabelsi *et al.*, 1998; and Costa *et al.*, 2005a and 2005b). This paper represents the simulation of microwave interaction of materials. Simulation of microwave heating of materials such as Silicon Carbide (SiC) and graphite plate in a microwave oven was carried out at 900 W. The effect of rise in temperature due to conversion of electromagnetic energy in to heat energy of materials having different properties and physics of microwave interaction with materials was defined using COMSOL Multiphysics software.

MICROWAVE FUNDAMENTALS

Microwaves are electromagnetic waves with wavelength (λ) in the range from 1 mm to 1 m and having frequencies in the range between 300 MHz to 300 GHz. The microwave processing of materials depends upon the dielectric properties of the materials being processed. The dielectric properties of the materials, which required greatest considerations are complex relative permittivity (ε^*) and loss tangent (tan δ); which can be expressed by Equations (1) and (2) respectively

$$\varepsilon^* = \varepsilon' - i\varepsilon'' \quad ...(1)$$

$$\tan\delta = \varepsilon'' / \varepsilon' \quad ...(2)$$

where,the real part of Equation (1), is known as the dielectric constant which indicates penetration of microwave into the material, ε'' is the loss factor which indicates materials ability to store energy and tan δ is the loss tangent that determines the ability of a material to be polarized and to convert the absorbed energy in to heat energy. In short, when a material is polarized in an alternating field, some energy is lost as heat; the fraction of energy lost during each reversal is the dielectric loss (Siores and Rego, 1995). In microwave processing of materials, electromagnetic energy is transferred to materials through interaction of the electromagnetic fields at the molecular level, and the dielectric properties of materials ultimately determine the effect of the electromagnetic field on the material. Thus in microwave heating, there is energy conversion rather than energy transfer in contrast to conventional processing of materials. The mechanisms that aid in energy distribution process include ionic conduction and dipole rotation. The mechanism of ionic conduction takes place when an ion and a vacancy form a pair, in case a dipole moment is present. The vacancy moves around the ion and makes an attempt to align the dipole moment with the electric field (Clark *et al.*, 2000). The mechanism of dipole rotation occurs due to redistribution of charges or polarization under the influence of an external electric field, and energy is dissipated as heat from internal resistance against the rotation of dipoles at molecular level. For this, the greatest loss occurs at frequencies when the dipoles can almost be reoriented. The processing of materials with microwave energy can be classified according to the dielectric properties of materials. Materials with moderate dielectric loss can be easily coupled with microwave (Ku *et al.*, 1999). Materials with high loss factor normally reflects microwave and they do not allow microwave to pass through it. Material with minimum lossfactor are microwave transparent materials, these materials are difficult to heat at room temperatures; consequently they are heated with microwave hybrid heating technique (OghbaeiMorteza and MirzaeeOmid, 2010). On the basis of above described properties, microwave associated materials are classified as follows:

Transparent: These are insulating materials, which allow microwaves to pass through it with little losses such as teflon, glass, alumina, etc.

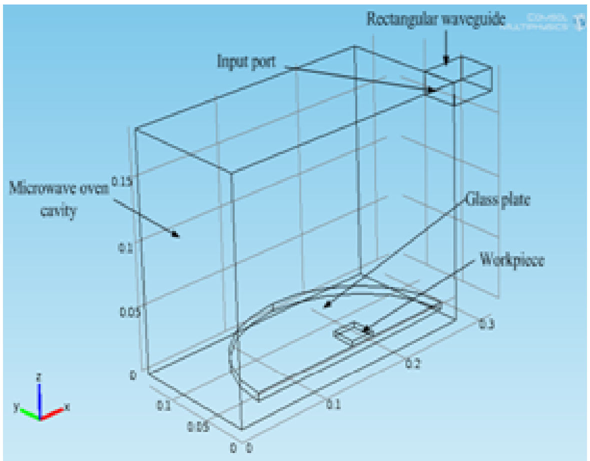
Opaque (Conductors): These are conducting materials having free electrons, which reflect microwaves and do not allow microwave to penetrate through it, e.g., metals.

Absorbing: These materials are high loss materials and their properties ranges from conductors to insulators. These materials absorb microwave energy and subsequently absorbed energy is converted in to heat energy, e.g., silicon carbide, water, charcoal, etc.

MICROWAVE HEATING SIMULATION

Simulation of the Silicon Carbide (SiC) bricks, which are good absorber of the microwave and graphite, which is also a microwave friendly materials were carried out in the present work. The mechanism of microwave interaction with these materials was simulated using COMSOL Multiphysics FEA based software and results are presented in this paper. For carrying the simulation of these materials, the various assumptions and boundary conditions were also incorporated. The walls of microwave oven cavity were considered as perfect conductors, represented by boundary condition, it indicate that the tangential electric field component is zero. For carrying out the simulation of the temperature variation in the silicon carbide and graphite, we used a symmetry cut as mirror symmetry for the electric field, which is represented by the boundary condition. Heat transfer in the microwave woven body was not considered in simulation of the materials. Thermal insulation boundary condition was provided for the specimen material. The excitation part of wave guide was powered by 900 kW at a fixed frequency of 2.45 GHz in the fundamental mode TE10. The cavity and wave guide are filled with air whose ìrand equal to 1. The configuration used for carrying out the simulation is shown in Figure 1, where a rectangular sample was placed at the bottom

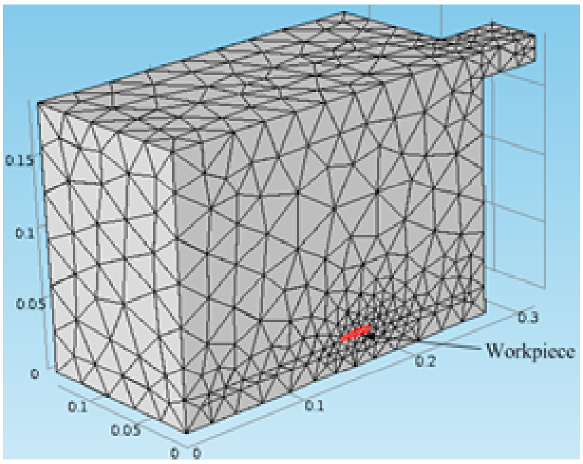
Figure 1: Microwave Oven Model Developed in COMSOL Multiphysics Software



of the cavity. A part of the plate was cut away for mechanical stability, which also facilitates the creation of a finite element mesh in the region where it is in contact with the plate. Symmetry is utilized by simulating only half of the problem. The symmetry cut is applied vertically through the oven, waveguide, sample and glass plate.

3D domain has been meshed using tetrahedral mesh elements. The maximum and minimum element sizes taken for sample meshing were 6 mm and 1.27 mm, respectively as shown in Figure 2.

Figure 2: Meshing of 3D Domain in the Microwave Cavity



RESULTS AND DISCUSSION

Microwave interaction of materials depends on the dielectric properties of the materials being processed. The materials properties used in carrying out the simulation of the silicon carbide and graphite plate were illustrated in Table 1. The relative permittivity of the air was considered as 1, thus it act as a transparent to microwave radiation. Silicon carbide is a good absorbers of microwave radiation at room temperature, hence it easily absorb microwave at room temperature. The simulation results of silicon carbide shows the increase in temperature of 868 °C in a time duration of the 300 s at a power output of 900 W with resistive losses of the order of 1 x 10^8 W/m^3. The temperature profile obtained in the silicon carbide is shown in Figure 3 and resistive losses profile in 2D is shown in Figure 4. The simulation results of graphite plate shows the increase in temperature up to

Table 1: The Various Input Parameters Used for Simulation of Microwave Heating by Comsol Software

Parameters	Silicon Carbide	Graphite
Relative permittivity	10	1
Relative permeability	1	1
Electric conductivity, S/m	1e3	3e3
Input power, W	900	900
Thermal conductivity, W/(m °K)	450[W/(mK)] $(300[K]/T)^{0.75}$	150[W/(mK)] (300[K]/T)
Heat capacity, J/(kg °K)	1200	710
Initial temperature, °C	30	30
Density (Kg/m^3)	3200	1950

Figure 3: Temperature Profile in Silicon Carbide Plate in COMSOL Multiphysics Software

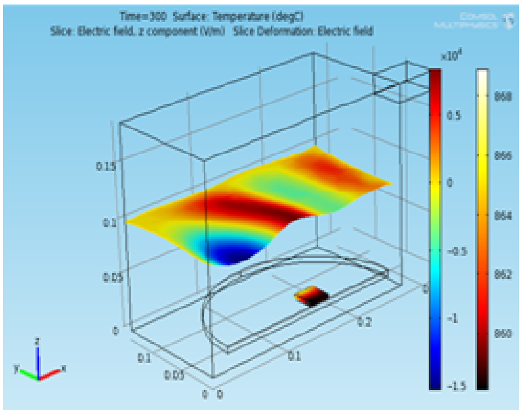


Figure 4: Resistive Losses in Silicon Carbide Plate in COMSOL Multiphysics Software

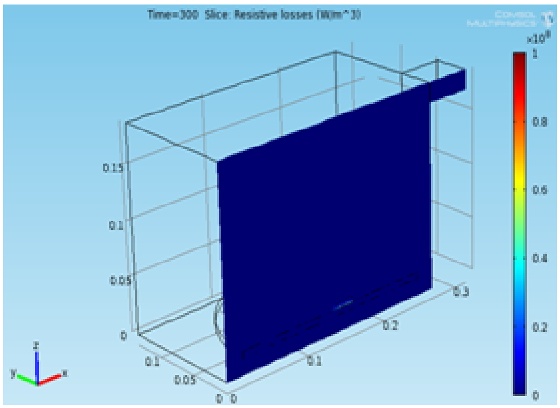


Figure 5: Temperature Profile in Graphite Plate in COMSOL Multiphysics Software

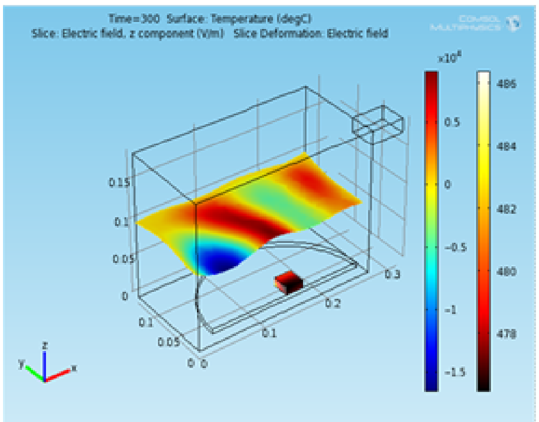
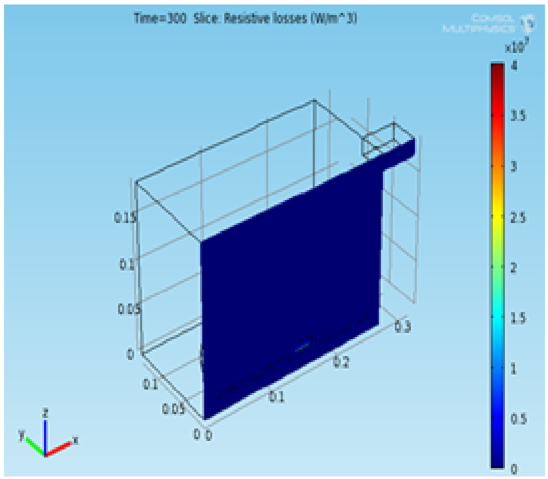


Figure 6: Resistive Losses in Graphite Plate in COMSOL Multiphysics Software



486 °C in a time duration of the 300 s at a power output of 900 W with resistive losses of the order of 4 x 10^7 W/m^3. The temperature profile obtained in the graphite plate is shown in Figure 5 and resistive losses profile in 2D is shown in Figure 6.

The present paper reports on the simulation results of silicon carbide and graphite using Comsolsoftware. The silicon carbide is one of the most commonly used susceptor for processing of the materials using microwave hybrid heating. The graphite plate and crucible was also commonly materials in microwave oven. The inferences drawn from the simulation results are summarized as below.

- The simulation result shows the temperature of silicon carbide reaches to 868 °C for a time duration of 300 s with resistive losses of the order of 1 x 10^8 W/m^3.
- The simulation result shows the temperature of graphite plate reaches to 468 °C for a time duration of 300 s with resistive losses of the order of 4 x 10^7 W/m^3.

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REFERENCES

1. Clark D E, Folz D C and West J K (2000), "Processing Materials with Microwave Energy", *Materials Science and Engineering A*, Vol. 287, pp. 153-158.
2. Clemens J and Saltiel C (1996), "Numerical Modelling of Materials Processing in Microwave Furnaces", *International Journal of Heat and Mass Transfer*, Vol. 39, pp. 1665-1675.
3. Costa L C, Devesa S, André P and Henry F (2005a), "Microwave Dielectric Properties of Polybutyleneterephtalate (PBT) with Carbon Black Particles, Microwave and Optical", *Technology Letters*, Vol. 46, pp. 61-63.
4. Costa L C, Devesa S and André P (2005b), "Microwave Dielectric Properties of Glass Reinforced Polymers", *e-Polymer*, Vol. 4.
5. Das S, Mukhopadhyay A K, Datta S and Basu D (2008), "Prospects of Microwave Processing: An Overview", *Bulletien of Material Science*, Vol. 31, No. 7, pp. 943-956.
6. Kraszewski A W, Trabelsi S and Nelson S O (1997), "Moisture Content Determination in Grain by Measuring Microwave Parameters", *Measurement Science and Technolgy*, Vol. 8, pp. 857-863.
7. Ku H S, Ball J A R, Siores E and Horsfield B (1999), "Microwave Processing and Permittivity Measurements of Thermoplastic Composites at Elevated Temperature", *Journal of Material Processing Technology*, Vol. 90, pp. 419-424.
8. OghbaeiMorteza and MirzaeeOmid (2010), "Microwave versus Conventional Sintering: A Review of Fundamentals, Advantages and Applications", *Journal of Alloys and Compounds*, Vol. 494, Nos. 1-2, pp. 175-189.
9. Siores E and Rego D (1995), "Microwave Applications in Materials Joining", *Journal of Material Processing Technology*, Vol. 48, pp. 619-625.
10. Thostenson E T and Chou T W (1999), "Microwave Processing: Fundamentals and Applications", *Composites: Part A*, Vol. 30, pp. 1055-1071.
11. Trabelsi S, Kraszewski A W and Nelson S O (1998), "Nondestructive Microwave Characterization for Determining the Bulk Density and Moisture Content of Shelled Corn", *Measurement Science and Technolgy*, Vol. 9, pp. 1548-1556.