MODELLING AND SIMULATION OF TEMPERATURE DISTRIBUTION IN CAST IRON FOR MICROWAVE HEATING APPLICATIONS

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Abstract. Microwave heating represents a fast technology for processing materials, but it can be applied with success to some restricted class of materials. Ceramic materials contain dipolar particles that can generate frictions when are exposed to electric field lines, but metals, generally, reflect microwaves and create conditions for microwave plasma initiation. However, by creating specific conditions, the metal powders can be heated in microwave. This paper aims to simulate the temperature distribution in Fe samples by considering three different cases of simulation in terms of ceramic susceptor as primary heating source. The results of simulation revealed that using a combination of plate support and a second plate with a central hole, the temperature distribution outside the Fe sample affects the ceramic.

Key words: temperature distribution, thermal field simulation, microwave heating.

1. INTRODUCTION

Microwave heating is a multi-physics phenomenon that involves electromagnetic waves and heat transfer; any material that is exposed to electromagnetic radiation will be heated up. Metaxas [1] defined the principle and mechanism of microwave heating as electro-heat technique governed by the loss mechanism at microwaves frequencies when the dipoles are re-oriented due to polarization. Hu et al [2] presented the microwave technology as a process which transfers the energy uniform, with low energy consumption and rapid heating. They reported different applications of microwave technology from food drying to medicine, materials and chemistry. Sun *et al*. [3] reported studies regarding aspects of the reflection, heating and discharge effects. They presented several distinct strategies to improve microwave power in terms of efficiency of heating process.

Regarding the dissipation of the power and conversion of microwaves into heat, there are many studies that focuses to particular approaches. The temperature

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distribution is modelled by Zhang *et al*. [4]. They studied the influence of the geometrical shape of the products on temperature field during microwave heating. They concluded that, samples with equal volume but different shapes, placed in the microwave heating cavity form hot spots at different positions in the center or near the surface of samples. Housova and Hoke [5] studied the temperature profiles in dough products during microwave heating with susceptors. They reported that, the presence of susceptors, affects positively the food samples tested in the microwave heating. In addition, they concluded that at the contact between susceptors and samples, the total heat developed into samples is not influenced only by the susceptors, but also by the product itself. The non-uniformity of temperature distribution inside the materials represents one of the most important issues in sintering process but not only. Vadivambal and Jayas [6] reported that several studies have proven that there is a wide variation in the temperature distribution during microwave heating. The non-uniformity distribution of temperature represents the main issue and imposes major limitations for using microwave heating in industrial applications. This issue leads to the necessity of computational analysis of temperature distribution, in order to increase the stability of the microwave heating. Singh *et al*. [7] focused on simulation of temperature distribution in microwave heated convenience food such as potato. They reported that, in case of food, the simulation, using MATLAB software, presents a uniform distribution of the temperature throughout the whole product in the form of three-dimensional structure.

This paper aims to study a model of temperature distribution in metal materials using ceramic susceptors. The research is focused on determining the optimal geometrical shape of the susceptors in order to reach the sintering temperature of the samples without major influences of heat under ceramic susceptors.

2. MATERIALS AND METHODS

The simulation of temperature distribution using ceramics susceptor in microwave heating uses the Fourier' Law related to heat transfer in solids. The initial condition for simulation was that, for a certain temperature obtained through microwave heating of susceptors, the susceptors transfer heat to the samples. The Eq. 1 presents the heat transfer through conduction.

$$\frac{Q}{t} = k \cdot A \cdot \frac{\left(T_2 - T_1\right)}{d}, \qquad (1)$$

where:

- Q/t – represents the rate of heat transfer [W],
- k – represents thermal conductivity of the material [W/mk],

- A – represents the surface area of the objects in contact [m^2],
- T_2 – represents the temperature of the hot material [ºC],
- T_1 – represents the temperature of the cold material [ºC],
- d – represents the thickness of the material tested [m].

The material used in simulation was pure Fe having the diameter 15 mm and height 3 mm. For susceptors were considered three shapes with different geometry which are presented in Table 1.

Table 1

Shapes and geometry of ceramic susceptors

Susceptor	Shape	Dimensions [mm]
Code S1	Parallelepiped	L = 50 l = 40 h = 40
Code S2	Parallelepiped 2 parts: – parallelepiped – parallelepiped with hole in center	2 parts: – parallelepiped: L = 50 l = 20 h = 40 – parallelepiped with hole in center: L = 50 l = 20 h = 40 Φ = 20
Code S3	Cylinder	Φ = 20 h = 80

The simulation started from a known hot temperature obtained in microwave field for all three susceptors. In order to have similar approach for all cases, each susceptor has been heated in microwave field. Table 2 presents the microwave heating parameters, time of heating and temperatures reached during heating process.

Table 2

Microwave heating parameters and experimental results

Susceptor	MW power, P [W]	Heating Time, t [s]	Temperature, T [ºC]
Code S1	1000 W	240	1199
Code S2	900 W	300	1088
Code S3	1200 W	280	1198

The temperatures from Table 2 are those used as hot material in process of simulation. For susceptors S1 and S3, the heating process was similar in terms of heating time and reached temperature. Only the microwave injected power was higher for S3 taking into consideration that the total volume of the S3 was higher than the total volume of S2. On the other hand, for S2, the microwave injected power was 900 W, but the heating time was the highest. In addition, the maximum of temperature, reached in stable conditions, was 1 088 ^{o}C. Beyond this value of temperature, the process became unstable and the thermal runaway phenomenon occurred. Starting with these input parameters, the simulation was peformed using thermal module from SolidWorks 2016 software. For the simulation was considered the temperature of cold material equal with ambient temperature 25 ^{o}C.

3. RESULTS AND DISCUSSIONS

All three cases studied in this research were simulated in order to determine which shape presents optimal results for further experimental applications. The main objective of the simulation was to determine the lowest area on susceptor ‘surfaces influenced by temperature distribution. Figure 1 presents the results of simulation for all three geometrical shapes of susceptors.

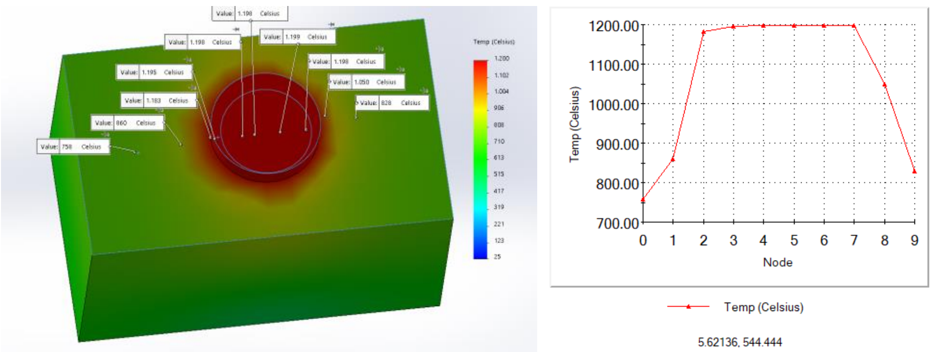

Fig. 1 – Simulation of temperature distribution for shape S1.

Figure 1 presents the temperature distribution when the susceptor has a parallelepiped shape. The highest temperatures, 1 199 ^{o}C was recorded in the center of the sample, but the temperature distribution was similar on the entire surface. The lowest value, according to simulation, was at the edge of the sample. However, the heat affected area around the sample was quite large with a maximum value of temperature at 860 ^{o}C. Ten nodes in plane coordinates (x, y) were considered in order to evaluate the axial distribution of the temperature.

Figure 2 refers to the second case of simulation, where the sample was placed in a central hole of the second part of the shape. The bottom part was considered as main thermal source and the second piece was designed in order to maintain temperature to a high level. The simulation has shown not so good condition of microwave heating, therefore the maximum-recorded temperature, 1 088 ^{o}C was in the center of the sample. According to the simulation results, the presence of the second pieces led to high values of temperature 930 °C at 2.6 mm away from the edge of the sample. However, the temperature decreases very fast towards to the edge of central hole.

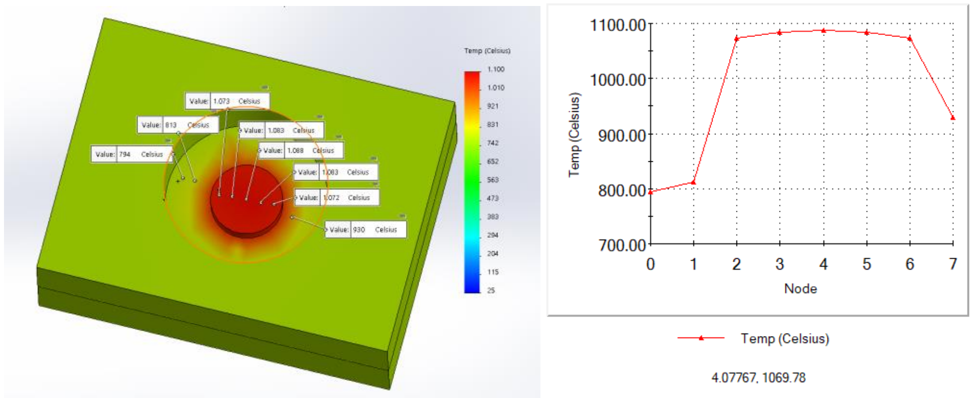

Fig. 2 – Simulation of temperature distribution for shape S2.

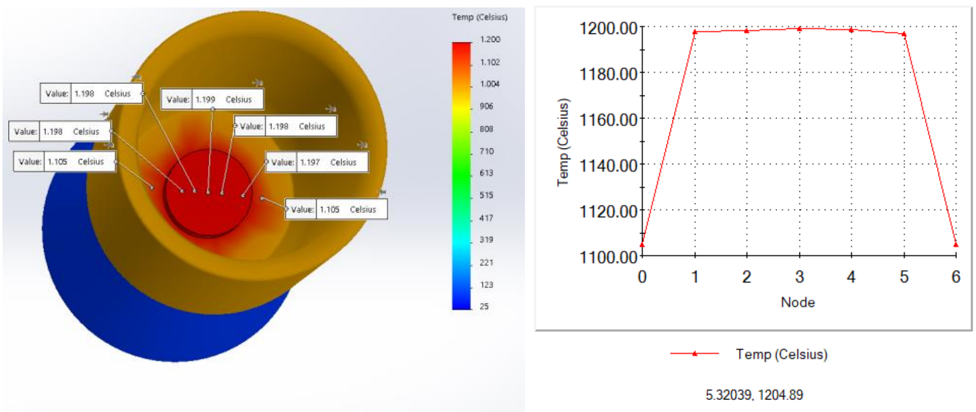

Fig. 3 – Simulation of temperature distribution for shape S3.

The third case, presented in Fig. 3, can be considered the worst scenario from heat affected zone point of view. With a temperature around 1 200 °C recorded on entire surface of the sample and high values of temperature in proximity, the simulation shows a large area affected by heat transfer. The lowest values recorded were around 1 105 °C that can be explained by the height of the crucible. Therefore, the heat exchange between sample, crucible and ambient was low.

4. CONCLUSIONS

Simulation of the temperature distribution in cast iron samples can provide valuable information for sintering process using microwave heating. Because microwave heating cannot be applied directly to metallic samples, the process is an indirect one requiring ceramic susceptors for conversion of the microwave into heat that is transferred according to Fourier ‘Law to the samples.

The best results have obtained when the simulation of temperature distribution was applied to geometrical shape S2, where the surface affected by heat transfer was lower in the proximity of the sample. These results can be used for further sintering processes of different shapes and sizes of iron cast samples, using the same susceptor for many times. In microwave heating, the susceptors suffers from the mechanical frictions of dipoles and, due to the heat developed, lead to thermal runaway phenomenon and microwave plasma arc initiation.

The worst results of research were obtained for shape S3. From sintering point of view, this thermal transfer is optimal because the samples are maintained with all their volume at sintering temperature. However, the susceptors will be affected and after one heating process should change with new ones.

For the second case of simulation, the results are not concluded because the variation of the temperature is different in different nodes. With 8 nodes considered for monitoring the axial distribution of the temperature, the results have shown high differences for similar coordinates on the surface of the samples such 794 ^{o}C on the right side and 930 ^{o}C on the left side. These differences will definitively influence the performance of the sintering process of iron cast samples.

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