Evolution of the thermal field at microwave heating of metals and ceramics materials

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1. Introduction

The paper aims to present the evolution of the thermal field in metals and ceramics materials when they are heated using microwaves [1, 3]. The study has been performed in order to determine if the evolution of the thermal field is similar to conventional heating taking into account specific phenomena which occur on microwave heating such as thermal runaway [6].

Materials that can be microwave heated are materials that have material defects corresponding to a tangent of the loss angle. Materials containing polar particles are best to be subjected to the action of the high frequency electromagnetic field, ceramics being a good example. In the proposed experiments, it is desired to heat a dielectric material protected by barium type W for which in principle there will be no problems to ensure the thermal source, but the third material, in this case iron, is a good material conducting the electric current that electrical discharge will occur on the surface due to the potential differences created. To avoid this undesirable appearance, hybrid heating conditions (partial absorption from the electromagnetic field and heat transmission through conduction) will be created. The research was conducted to determine the temperature evolution around the thermal runaway triggering point.

The experimental program aimed to simultaneously determine the temperatures at different points of the material and to use them in two different directions:

Evolution of the thermal field in the material on microwave heating as it is a volumetric heating which means that the material will heat out from the center to the outside, the method being applied to the ceramic material

The evolution of the thermal field in the material at high frequency electromagnetic wave susceptibility heating, the thermal transfer through a cylindrical and spherical plane wall, and the comparative analysis of the experimental values with theoretical values by applying the Fourier thermal transfer law [2]

2. Materials and heating procedure

In the experiments, 12 mm diameter samples were heated, and controlled heating and heat field experiments were performed for 2 types of different materials: W barium ferrite and Fe. Forming the die parts by pressing in molds is the most used method because it results in the production of semi-finished products with high quality surfaces and with dimensional accuracy, porosity and compactness can be achieved within wide limits varying the specific pressing force. The research focused on the compaction of mixed powders prepared by homogenization and mechanical alloying. For this purpose, pressures of 600 MPa were pressed using a 12 mm cylindrical sample mold for the densities, porosity and microscopic analysis as well as for hardness and wear measurements [4].

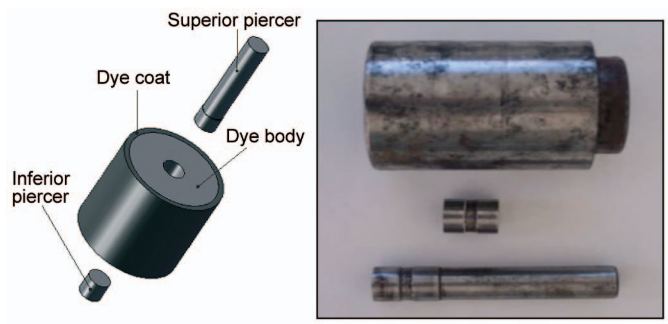

Figure 1. Cylindrical dye.

The advantages of using this process are the realization of complex shaped semi-finished products, with high quality surfaces and high dimensional accuracy and the porosity or compactness can be achieved within wide limits, varying the specific pressing force.

Figure 2. Samples used in experimental program.

The first experiment consists in heating samples at the maximum power prescribed until the temperature at the center of the piece reaches the prescribed value after which the process will resume by moving the piece so that the laser spot of the used pyrometers is moved 1 mm from the center of the piece.

Table 1 presents the results obtained during heating process of W barium ferrite sample. The total microwave heating time was 5 minutes and 13 seconds.

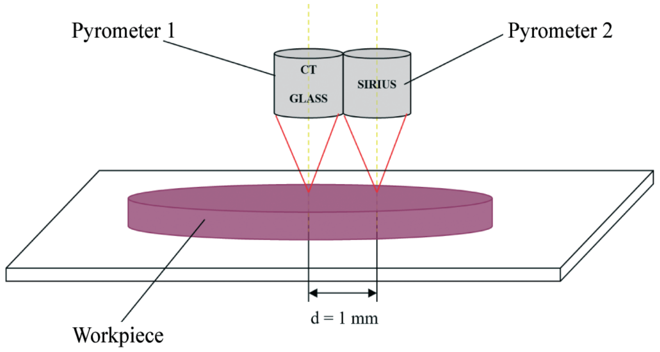

Figure 3. Temperature measurement of W barium ferrite.

The second experiment consists of measuring the temperature at the surface of the piece to determine the heat flow transferred from the ceramic crucible to the metal piece. Only one pyrometer is used for doing this and the heating is a conductive one. Figure 4 shows how to obtain temperatures at the surface of the workpiece. Table 2 presents the results obtained during heating process of Fe sample. The temperature of the ceramic crucible was maintained at a fix point temperature around 700 ^{0}C taking into account that the thermal runaway phenomena occurs between 550 ^{0}C and 650 ^{0}C for this category of materials.

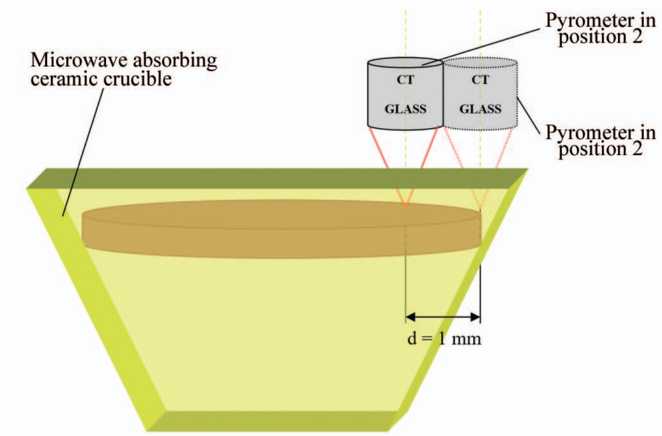

Figure 4. Temperature measurement of Fe sample.

Table 1. The results obtained during heating process of W barium ferrite sample.

Psition [mm]	$T_{pyrometer\ CT\ GLASS}$ [° C]	$T_{pyrometer\ SIRIUS}$ [° C]
0	700	695
1	691	682
2	684	677
3	678	670
4	668	661
5	658	657
6	650	644
7	642	631
8	632	624
9	618	611

Table 2. The results obtained during heating process of Fe sample.

$d_{crucible}$ [mm]	$T_{pyrometer\ CT\ GLASS}$ [° C]	$T_{crucible}$ [° C]
1	651	700
2	638	700
3	621	700
4	620	700
5	617	700
6	616	700
7	616	700
8	602	700
9	587	700
10	580	700
11	577	700
12	565	700
13	565	700

3. Computational modeling of the thermal field

Due to the fast-paced advantage, the graphical module was used, with the help of which surfaces were called surface-response, which provides an overview of the variation of the thermal field. Surfaces are considered in the real three-dimensional space because, as shown in Table 1 and Table 2, there are three series of data (for a 5 min 13 sec in the first experiment and a 700 ^{0}C platform temperature respectively in the second experiment).

As will be seen in the graphical analysis, the phenomenon of variation of the thermal field is relatively linear. However, to evaluate and analyze the variation of the second and third variables from a statistically/probabilistically desired „wait". From a statistical point of view the „variable1" represents the temperature of the first pyrometer and „variable2" respectively the temperature of the second. The variables are thus constituted as data strings, each with several variants.

From surface analysis (Figure 5a and Figure 6a) can be deduced that the phenomenon is linear. In both figures, the constitutive equations of the surfaces are labeled in legend and they were solved as first degree equations. However, the difference between the two constitutive equations must be observed, although the maximum is reached in both cases at the same temperature value, 700. It is interesting to note that if is taken into account the variations of the variables not only the global response surfaces, it can be noticed a tendency of nonlinearity, as shown in Figure 6b. If Figure 5a shows that the two variables have a very similar behavior, it can be deduced a stronger nonlinearity trend from Figure 6b. For both experiments, the histograms corresponding to each variable were constructed. They provide a template image of the variance of each of the variables as compared to the expected variation (theoretically).

The red curve represents the expected variation, and the hatched blocks give the picture of the heat field variation phenomenon as measured. It should be noticed that the software automatically performs a „division" on subintervals of variation of 10 units. Actual variation departs from what would be theoretically desirable, and this fact is also proven by the rather large level that is automatically calculated and passed to the chart label, namely a higher confidence level of 20.

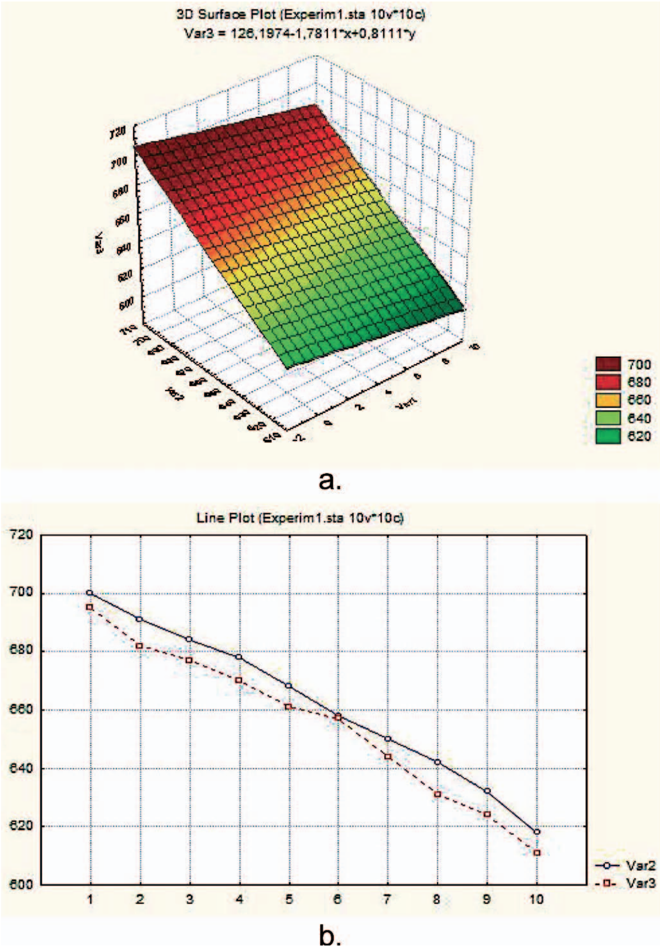

Figure 5. Surface-response and the variation of the variables.

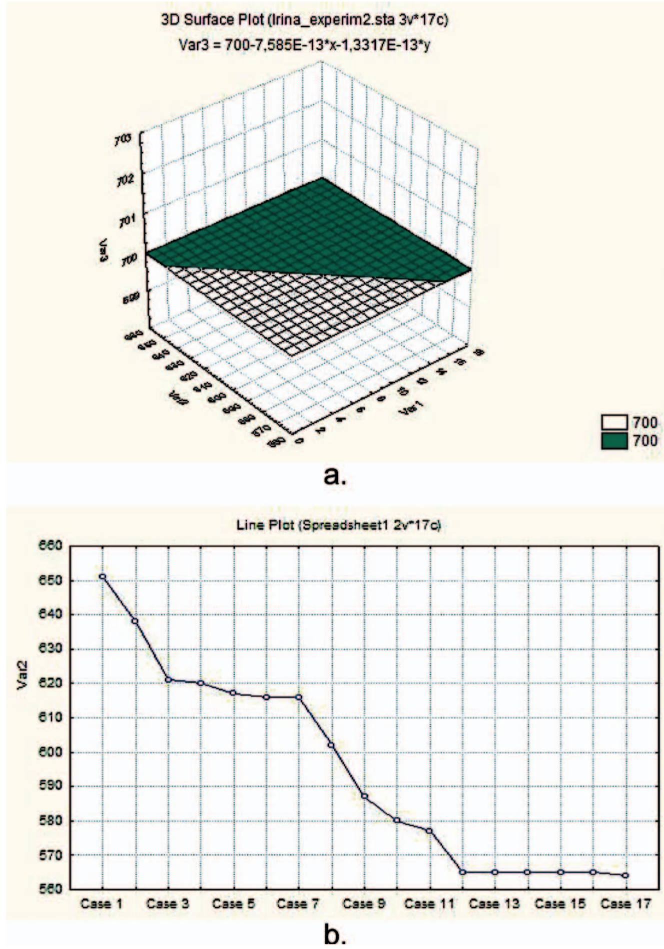

Figure 6. Surface-response and the variation of the variables (Experiment 2).

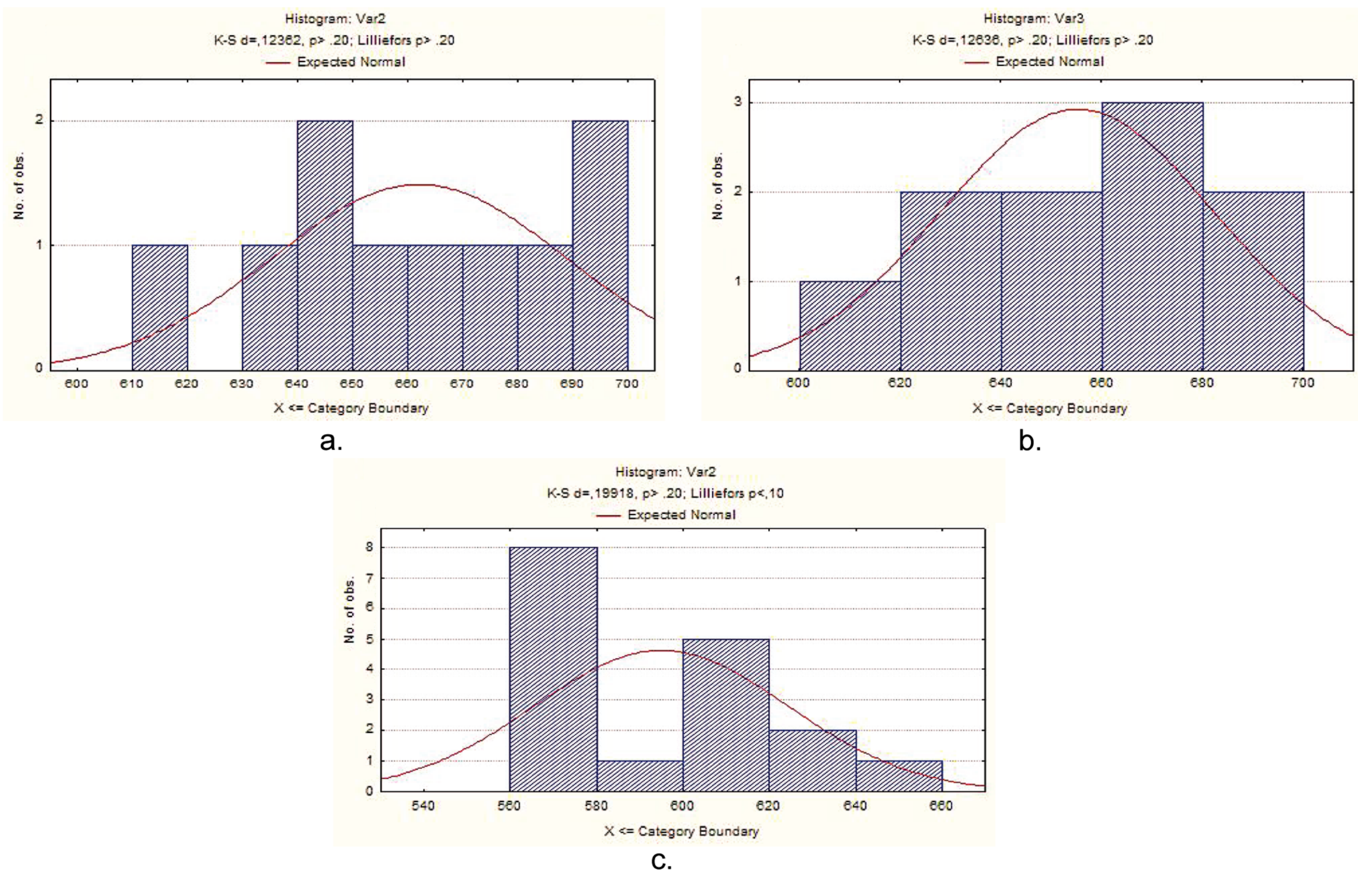

Figure 7. Histogram for variables taken into account.

4. Conclusions

The thermal field at microwave heating can be evaluated according Fourier law only for temperatures below 600 ^{0}C to avoid the thermal runaway phenomena. If the undesired phenomena occurs, the temperature will increase more than the mathematical model can predict.

According to surface analysis, the evolution of the temperatures for both pyrometer is a linear one. That is explained by the action of the automatic tuner which will increase or decrease the influence of the three-stub tuner in order to obtain the best match impedance of the electrical circuit and therefore the maximum transfer of the injected power from the microwave generator to the load. Also the barium ferrite type W has very good microwave absorbance properties. On the other hand, materials with major internal defects, in terms of polar particles, are exposed more than other materials to the thermal runaway phenomena.

The microwave heating of the Fe powders cannot be done by using pure microwaves action due to their reflection properties. However, if the samples are placed in a ceramic crucible, the heating process can be developed but, according to Figure 6b, the trend is strong non-linear. This issue confirms that how difficult is to heat metallic materials.

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