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Microwave Heating at the Grain Level

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Abstract: The microwave heating and processing of heterogeneous material is usually simulated using a set of coupled PDE equations in a homogeneous medium. Nowadays it is possible to describe more accurately the process with a suitable description of the heterogeneities that is at the grain level.

Many authors work with spheres (circles) to represent the grains but it is difficult to achieve an acceptable value of the proportion in volume of each component for instance the pores.

This paper shows how it is possible to deal directly with the meshing produced by COMSOL to get a description of the grains, the pores and other components. Let us start with a homogeneous volume and apply a coarse meshing. Then COMSOL is able to export a doc.txt with the matrices of nodes and elements. The needed value, for instance, of porosity can be obtained by homothety.

Examples in the area of microwave sintering and drying are given in the paper.

Keywords: Meshing, PDE's, sintering process, drying process.

1. Introduction

The modeling of physical processes needs a good representative drawing in order to apply multiphysics equations. Usually the process is described only by the equations themselves together with their coupling. The grain level approach adds another description which is the geometry as seen from a microscopic image when possible or just by the imagination of the operator. This is the case of this paper and the trick is to use the very meshing exported by COMSOL. It's easier to start from a coarse meshing but it is clear that all the extended meshes are equally good. It is just a question of time and memories.

2. Description of the Drawing

To draw the grain model we directly use the meshing produced by COMSOL. For any meshing, COMSOL Multiphysics exports two matrices, one of them describes the coordinates of each node, and the other one contains the number of the nodes belonging to each element (tetrahedron or triangle). Starting from these data any model can be constructed. For example we can build capillaries for the drying and thin layers surrounding the grains, as nano powders for sintering. In both cases the solution was to apply a homothetic reduction to each element of the initial meshing in order to achieve the right proportions.

For instance Fig.1 shows an initial meshing and Fig.2 gives two examples of the new drawings: (a) is suitable for sintering and (b) for drying

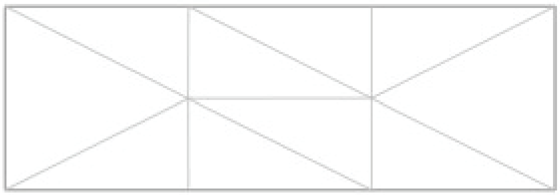

Figure 1. The initial coarse meshing

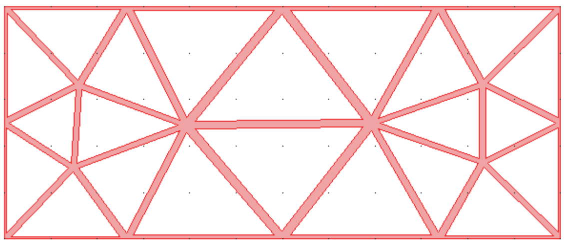

Figure 2(a). Drawing model for sintering

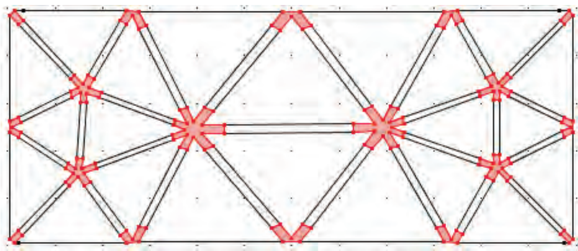

Figure 2(b). Drawing model for drying

In both of them, the triangles represent the grains separated by pores. Obviously the mathematical treatment can provide any desired grading of the grain sizes.

Fig.2(a) fits well to the experimental sintering we got mixing micro particles of alumina produced in France with nano ones produced in Russia. The nano particles are supposed to be in red. Fig.2(b) is convenient for drying, for instance, of sand mixed with wet clay represented in red. The remaining part of the pore is fulfilled with any fluid supposed to be not microwave absorber.

3. Application to sintering

Let's consider the model represented by Fig.2(a) which was used for modeling the sintering process. By using this simulation we expect to optimize the real process described underneath.

The materials used were two kinds of alumina powders: nanosized and submicron fractions. Alumina nanopowders was synthesized by explosion technique. The properties of these powders were studied in detail in [1, 2]. As a submicron fraction a commercial P172SB alumina powder (Pechiney, France) was used. Properties of the powders are already published [3].

The composition of nano and microsized fraction, which gives the best mechanical properties, was first experimentally determined $Al_2O_3^c$(P172SB)–10% vol. $Al_2O_3^f$ [4] and adjusted after simulations. The powders was mixed, and then compacted into a disk of 16 mm diameter by cold uniaxial pressing at 200 MPa.

A special microwave oven was designed: it introduces homemade lossy ceramics in order to add an infrared heating of the sample surface necessary to get a homogeneous temperature profile. The heating process included different steps: an heating slope of 100°/mn up to 1300°C, a dwell for 30 mn (to transform $\delta+\theta$ alumina into α phase), and then the last slope of 100°/mn up to 1600°C and a last dwell during 30 mn. The temperature is slowly decreased, in the oven, during 2.5 hours. The temperature in the microwave furnace was controlled by a pyrometer directly focused on the sample surface.

The Fig. 3 shows the threshold process around the smallest grains. A thin layer of air is assumed to surround these grains; the difference of permittivity produces a high electric field, shown by the blue lines, which starts the electric conduction simulated by $\sigma \approx \sigma_0(|E|>E_0)$, E_0 is the threshold field. This conduction dissipates electric energy which increases the temperature shown by the two red points and after some time the conductivity/dielectric losses also appears in the micro grains. And then σ is supposed to follow the temperature T as

$$\sigma=\sigma_0\,(T-T_0)^2.$$

The threshold process fairly spread in the sample acts like a heating seed, which produces an increase of the electrical conductivity so that the heating is very homogeneous.

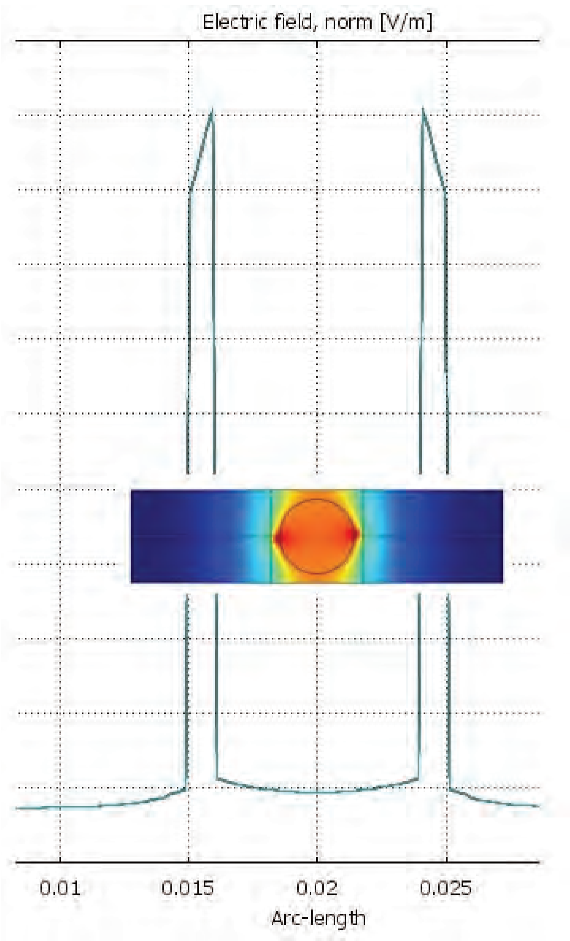

Figure 3. Threshold process

The following figure shows the increasing of temperature during the process of sintering.

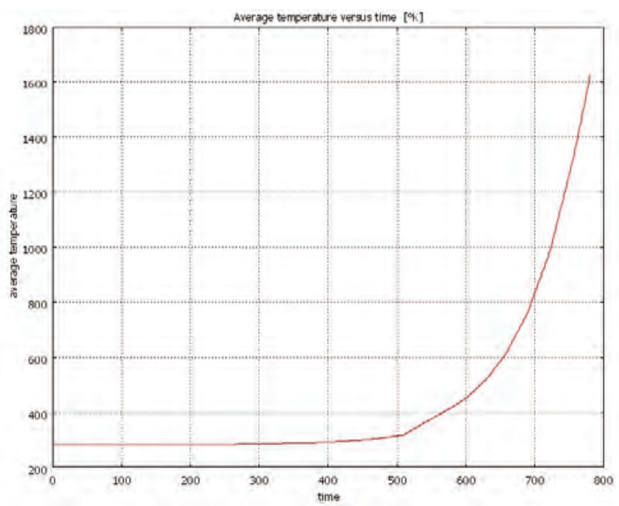

Figure 4. Mean temperature versus time.

The modeling was very helpful to understand the exact role of the nano powders and to suggest temperature profiles. The obtained density had a value close to the exact theoretical value.

4. Application for Drying

Another way of utilizing the constructed model is drying. Here we consider a granular material; triangles represent grains, and free space among them is capillary net filled by fluid, red plugs represent wet clay which closes up capillaries (Fig. 2 (b)).

To get an opportunity to extract the fluid we begin to dry the plugs by utilizing the microwave heating. In this case we consider the model like a classical capacitor between the two horizontal surfaces. Let V be the voltage between the two plates and let us assume that the two vertical surfaces are isolated. With these conditions and with respecting the properties of the materials the following distribution of temperature field is obtained (Fig. 5):

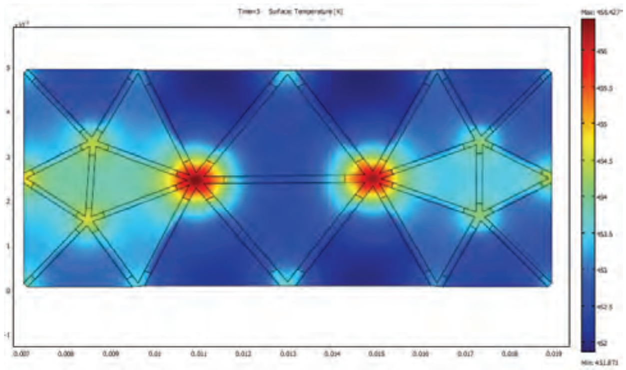

Figure 5. Distribution of the temperature

It has to be noticed that a classical modeling never gives such result which shows the game played by each component.

Notice that the temperature is higher in the plugs than in the rest of the sample since the microwave energy is located there; as a result of the drying, the shrinkage of the clay produces cracks and the fluid can be extracted.

A lot of macroscopic parameters can be obtained through this simulation. For instance, the mean permittivity is calculated knowing the boundary conditions (i.e. voltage V) and using the current I given by COMSOL. The Ohm law Y/V=jωC gives immediately the mean permittivity and its dependence versus the drying. The obtained value can be used in another modeling at the level of the piece.

Similarly the mean value of the fluid permeability can be computed knowing the pressure applied on the boundaries and the flux calculated by COMSOL through the surface.

5. Conclusion

In the case of heterogeneous materials, this paper shows the interest of adding to the normal set of PDE's, information on the geometry that is modeling at the grain level. For instance in the case of drying, pores occupy no more than 20% of the total volume; the remaining 80% are occupied by sand which is completely closed for migration of fluid, nevertheless in classical models it is supposes to be transparent.

Moreover, in heterogeneous materials there are always interfaces interactions which can't be taken into consideration.

By now it is impossible to imagine to deal at the grain level the totality of the domain, that is why the computation of the mean value of the parameters has to be done in order to be introduced in a new homogeneous material.

6. References

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