Induction heating of cladded material using a low Curie point: electromagnetic simulation

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High-frequency induction heating of very thin magnetic susceptors bonded by cladding high- and low-Curie point materials would provide efficient heating, low-cost technology, and temperature control capability by using the impedance variation with temperature. This problem is addressed by electromagnetic modelling after showing that it can be reduced to a 2D axisymmetric case. The results focus on the behaviour around the low-Curie point and the effect of material characteristics on heating and temperature control performance.

Keywords: induction heating; electromagnetic modelling; temperature regulation; low Curie point material; cladded SMM

1. Introduction

Induction heating has long been used in metallurgy and even in cooking [1]. Its qualities of safe and efficient heating, and flexibility of use push its development towards ever-changing applications: shaping of composites and plastics, heating-welding of materials with high electrical resistivity or even self-regulation of cookware temperature by a low Curie point (Tc) alloy [2]. Axes of progress are as well the design of an inductor - magnetic susceptor solution efficiently transferring the magnetic losses to the medium to be heated, as the steady state temperature regulation of this medium. Electromagnetic modeling now makes it possible to deal with this type of complex problem [3] and is fully used here.

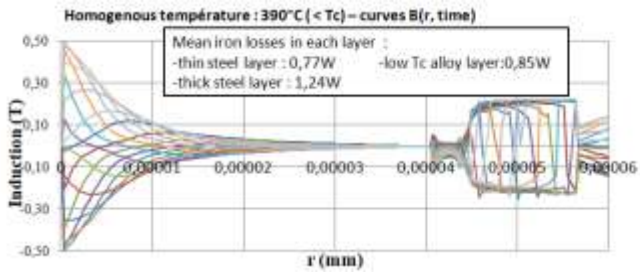
This work is carried out at high frequency HF allowing rapid energy transfer, at low susceptor thicknesses <0.1mm) to adapt to the frequency, with temperature control T by using impedance variation Z(T) and a trilayer used as susceptor, one of the layer having a low Curie point close to the targeted steady-state temperature. The paper deals with the validity of the chosen modeling hypotheses as well as the study of magnetic diffusion in such a susceptor around the Curie point or the effect of the characteristics of magnetic materials.

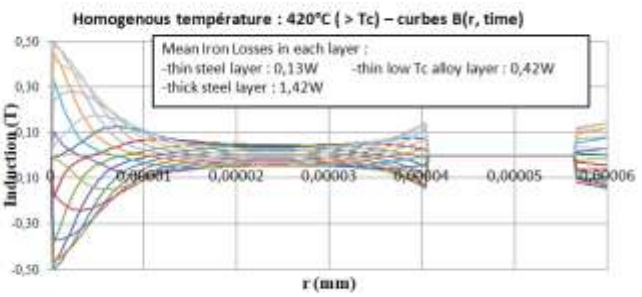
2. Results and discussion

We consider a large axial overlap of the inductor on the svery thin susceptor : prior modeling shows that this HF inductive problem can be treated as a sequence of states at homogeneous temperature T (updating the material character-ristics at each T level): then a weak magneto-thermal coupling is sufficient to solve the problem. Induction heating is treated by the Maxwell's equation resolution, according to the finite element method using the Altair FLUX® computer code.

3D modeling is required when the susceptor does not have the same symmetry as the inductor, but in this case of micrometric skin depth and layer thicknesses, 3D is known to bring significant problems of meshing, convergence or calculation time. 2D is to be preferred if its relevance is demonstrated. In the case of a ferromagnetic susceptor heated by a cylindrical inductor, by comparing 2D axisymmetric and 3D modeling on the one hand, a cylindrical susceptor with or without an axial slot and a plate on the other hand, we show that in terms of instantaneous magnetic losses as a function of time W(t) ① the qualitative behavior P(t) with and without a slot is the same in 3D with a 50% difference in average power, ② the cylinder without a slot is identical in 3D and in 2D axisymmetric, ③ W(t) is similar for a cylinder with a slot and the same cylinder unrolled into a flat plate, with average losses 10% higher. It is therefore demonstrated that a non-axisymmetric case of a plate heated by a cylindrical inductor can be modeled in good approximation by cylindrical coaxial suceptors and inductors.

The case of asymmetrical multilayer susceptors heated by a high-frequency inductor and comprising a low-Tc alloy is then studied, particularly around Tc: magnetic diffusion phenomena are represented at 6 MHz for layer thicknesses ranging from a few µm to 10ths of µm. In particular, the magnetic field-reflecting role of the low-Tc internal material on the losses induced in the outer layer is highlighted when the thickness of this layer is close to the skin thickness and when T<Tc (figure). Finally, the effects of the layer thicknesses (cladded material) and of the layer magnetic characteristics is presented, aiming at controlling the susceptor temperature through the variation of Z(T).





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