Multiphysical modelling and validation of VIM for Inconel 718 heating and melting

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***Abstract*—In this abstract, the followed methodology for the multiphysical numerical modelling of the heating and melting processes of Inconel 718 superalloy in a laboratory-scale vacuum induction melting furnace is presented. The theoretical results have been compared with experimental transient temperature measurements for solid and liquid states revealing an adequate agreement.**

***Keywords*—induction heating, vacuum induction melting, multiphysics modeling, experimental validation**

I. INTRODUCTION

During nickel-based superalloys heating and melting, precise temperature control before mould pouring is essential to assure the correct metallurgical composition of the final component. Vacuum induction melting (VIM) is the most suitable technology due to the protective inert atmosphere conditions and higher electrical efficiency, is widely used in the industry. However, the process has inherent difficulties for measuring high transient temperatures, which are over 1500ºC. Therefore, an experimentally validated numerical model is required to study the temperature distribution of the metal and ensure optimum temperature during the process.

II. CHARACTERIZATION

The VIM equipment from MGEP can melt 2 kg of nickel-based superalloys in a ceramic crucible. Considering the industrial standard for a melting cycle, the induced power of a laboratory-scale furnace has been adjusted to fulfil the temperature evolution requirement. Once identifying the Power-Time-Temperature relation, for each power step coil frequencies and currents have been measured. Starting from a bake out of 5kW to melting a phase 16kW the frequencies and currents in the coil ranges between 7-8.5 kHz and 0.5-1.5 kA.

For a precise analysis, it is essential to consider the material non-linearities, Inconel 718 has been characterized thermally and electrically up to 1300ºC and properties implemented as temperature-dependent variables with a built-in function in the model. In contrast, for liquid state bibliographic references have been considered [1].

III. NUMERICAL MODEL

Heating and melting process simulation is a complex multiphysics problem, which requires a strong coupling between the magnetic, thermal, and fluid dynamics fields. As the first approach, the process has been divided into two independent studies one for each state material state. The geometry of study is reduced to a 2D axisymmetric geometry and domains discretized with the FEM method based on the commercial software Comsol Multiphysics®.

A. *Solid-State Model*

Beginning with a cylindrical charge, the electro-thermal problem has been solved whit the induced current as the source term for heating. For a correct calculation of the electromagnetic field, the water-cooled seven turn's coaxial coil and the charge to be melt have been precisely meshed considering the skin effect for the imposed excitation frequencies. Thermal radiation effects have been computed considering the shared views of the surfaces between the crucible and the load. Refrigeration coil water is introduced as a forced thermal convection term.

Preliminary results indicate non-uniform heating, due to the geometry of the crucible and disposition on the coil and load. While the top surface is still around 650 ºC the mid-height area reaches liquidus temperature 1360 ºC. Fig 1. shows the concordance between the initial incipient melting zone and the removed mesh elements corresponding to the exceeded temperature. This substantial temperature gradient is confirmed by the first melting trials.

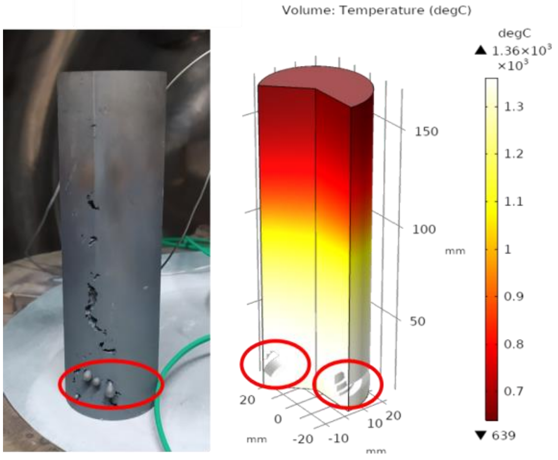

Fig. 1. Temperature distribution and initial melting after 1h of 5 kW.

B. Liquid-State Model

In the second model, the hydrodynamic and free surface problem has been solved separately. Assuming that for a reduced time frame the deformation of the meniscus is insignificant thus the Lorentz force distribution can be considered stationary [2]. With a built-in subroutine, the time-averaged electromagnetic force has been imported to the transient fluid-dynamic model. The multiphase flow has been computed in a fixed grid via the Level-Set method and RANS equations solved with the k-ω turbulence model. The routine is solved iteratively and when the surface displacement in the previous iteration is small enough the transient thermal study is coupled. The accuracy of the solver and routine has been compared with published experimental measurements references [2], [3], and [4]. Fig. 2. Shows the free surface shape for an induced power of 16 kW in the melting phase.

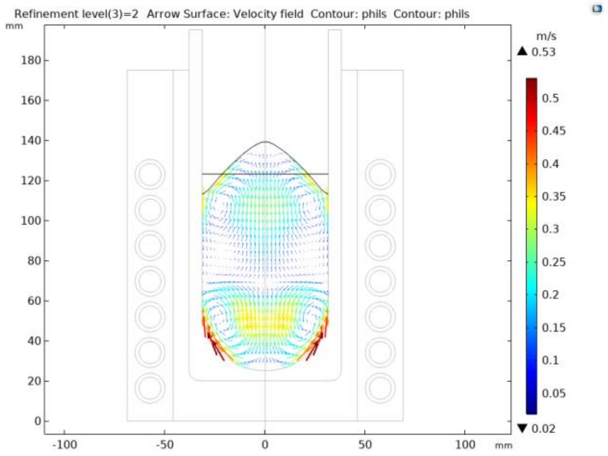

Fig. 2. Velocity field and free surface for a initial height of 95 mm.

IV. EXPERIMENTAL VALIDATION

With the aim to confirm the theoretical results and evaluate the accuracy of the model, an experimental setup has been prepared to obtain data. Four K-type thermocouples, made of Inconel 625, have been attached in the vertical axis of the cylindrical charge and voltage difference measured by the signal conversion unit located inside the furnace. Following the standard heating profile, the first step of 5 kW is applied followed by 11kW, due to the rapid heating; the dynamic response has been studied. Fig 3. reports the comparison between theoretical and experimental for top and bottom thermocouples with a separation of 110 mm. The obtained agreement is acceptable even though the results suggest that the model has lower thermal inertia.

For liquid state, an infrared bichromatic pyrometer pointing to the free surface of the melt is employed which records the maximum temperature of the spot size. Due to the rapid dynamic response melting stage before mould pouring has been computed. First, a 7 minute long heating has been computed with a induced power of 10 kW afterwards it is reduced to 6 kW before pouring and temperature decreased to 1450ºC. In the Fig. 4 can be seen the temperature response for both steps and the measurement done by the pyrometer. The correlation is adequate considering the existence of dross particles that hinder the pyrometer capacity.

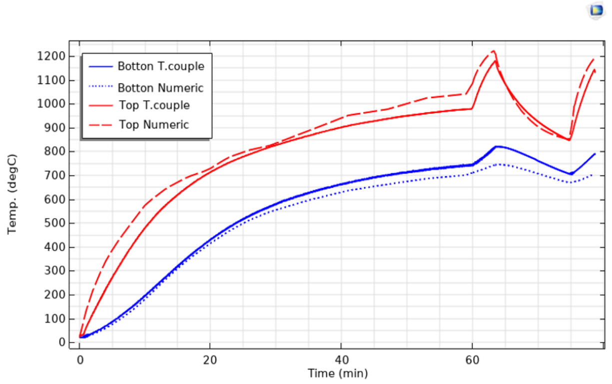

Fig. 3. Comprarison of transient temperature. Blue lines botton probe and red top. Continious lines thermocouple measurements and discontinious model result.

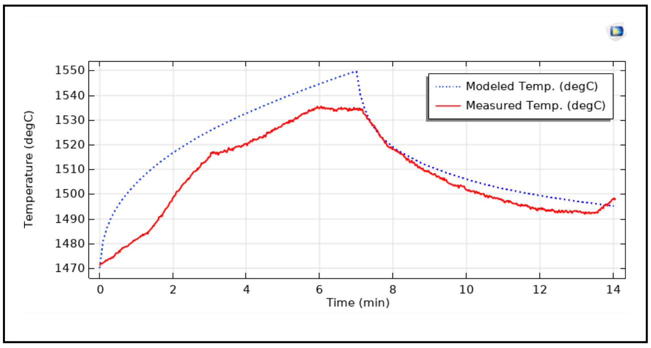

Fig. 4. Temperature transient evolution. Modelede blue dotted and red continious measured.

V. CONCLUSIONS

A multiphysical coupled model that describes the induction heating and melting for Inconel 718 has been proposed. The experimental measurements and validation indicate a satisfactory agreement with numerical results. The global vision provided by the model can be employed as an optimization tool to determine the most efficient melting procedure assuring the correct melt temperature The research confirms that the temperature gradient between solid-liquid transitions is considerable which could lead to overheating and alloying element dissipation. This temperature difference evidences the necessity to model the phase transition solid-liquid physics.

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