"In-situ observation" of melting and solidification process of Cold Crucible UO_2

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Abstract: The electromagnetic cold crucible (EMCC) technology enables to melt and directional solidification of reactive and high-temperature materials with no contamination. The solidification of nuclear waste by cold crucible is beneficial to reduce the environmental risk of radioactive waste. In this paper, a 3-D EMCC model for investiagting the physical fields of UO2 were established by finite element method. The whole process of UO2 solidification was simulated. The results show that the maximum magnetic flux density mode of the charge increases with increasing power, as does the maximum temperature, and the turbulent kinetic energy of the melt. As the power increases, the vortex range expands and the melt is stirred adequately.

Keywords: electromagnetic cold crucible; nuclear waste; magnetic field; numerical simulation

1 Introduction

The electromagnetic cold crucible is a revolutionary, highly efficient, and environmentally friendly melting technique. It is particularly beneficial when melting refractory materials and high temperature active metals [1, 2]. The issues of refractory melting of some wastes can be resolved by using electromagnetic cold crucible technology for the solidification of nuclear waste [3, 4]. Currently, one of the most important aspects of treating nuclear waste is the application of electromagnetic cold crucible solidification technology.

From the current research, for various aspect ratios of the cold crucible, Yang et al. [5] established a 2-D model to study the temperature field for Ti-Al alloy. The magnetic induction intensity inside the cold crucible was approximated by Huang et al. [6]. Due to the lack of research on the visualization of the melting and solidification process of UO_2. In this paper, the coupled calculation of magnetic field, temperature field and flow field under different power input parameters, and the law is systematically analyzed.

2 Experimental procedure

3D Model of EMCC

As shown in Figure 1(a) a circular inner cavity crucible is taken as the research object. Meanwhile, the 1/20 symmetric structure is used for modeling to improve the computational efficiency substantially. Impedance boundary conditions as well as coil excitation are added at the coil in the computational domain, no-slip conditions as well as radiative heat dissipation are added at the wall. The crucible temperature is initially 303.15 K, and the material physical parameters vary with temperature.

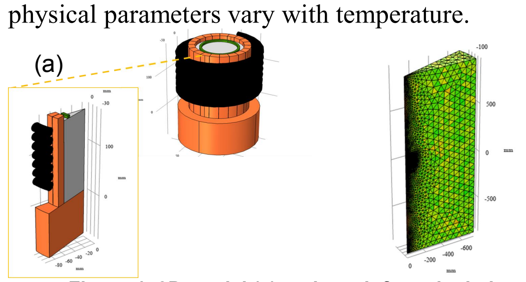

Figure 1 3D model (a) and mesh for calculation (b)

3 Mathematical Mode

The electromagnetic field is described by Maxwell equations [7].

$$\nabla \cdot \vec{J} = 0 \tag{1}$$

$$\vec{J} = -\sigma \frac{\partial \vec{A}}{\partial t} - \sigma \nabla \phi \tag{2}$$

$$\nabla \cdot H = \vec{J} \tag{3}$$

$$B = \nabla \times \vec{A} = \mu_0 \vec{H} \tag{4}$$

where, $\vec{J}$ is the current density; σ is the permeability of the magnetic fluid; $\vec{A}$ is the magnetic potential vector; t is the time; φ is the electric potential; $\vec{H}$ is the magnetic field strength; $\vec{B}$ is the magnetic flux density; μ_0 is the magnetic permeability of the medium.

The temperature change can be described by the classical transient heat transfer equation:

$$\rho C_p \frac{\partial T}{\partial t} = \nabla(\lambda \nabla T) + q_{in} \tag{4}$$

where, ρ is the material density; c_p is the material specific heat capacity; λ is the material thermal conductivity.

The flow in the molten pool in the electromagnetically cooled crucible satisfies the N-S equation:

$$\nabla \cdot \vec{v} = 0 \tag{5}$$

$$\frac{\partial(\rho\vec{v})}{\partial t} + (\vec{v}\cdot\nabla)\vec{v} = \mu_v \nabla^2 \vec{v} - \nabla p + \rho \vec{g} \beta_T \Delta T + \vec{F}_d \tag{6}$$

4 Result and discussion

The ingot is installed in the crucible, and the magnetic flux density is calculated at different powers. The calculation results are shown in Figure 2. The calculation results show that the induced current in the load increases with the increase of power.

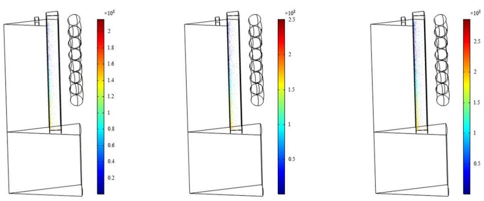

Figure 2 Induced current cloud diagram: (a)300 A; (b) 350 A; (c) 400 A

The temperature field and turbulent energy on the melt is calculated and the results are shown in Figure 3 and Figure 4.

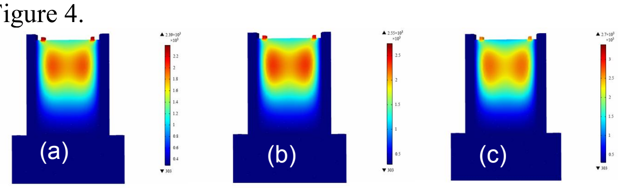

Figure 3 Temperature field variation with power: (a)141.34 kW; (b) 166.18 kW; (c)193.25 kW

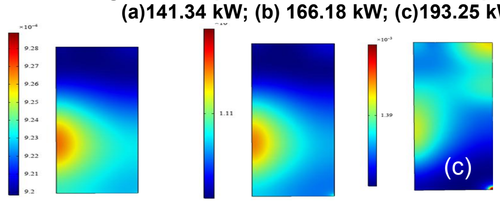

Figure 4 Variation of turbulent energy with power: (a)141.34 kW; (b) 166.18 kW; (c)193.25 kW

5 Conclusion

In this paper, the main conclusions are summarized as follows: 1. The induced current at the load center increases with the increase of power. 2. Along the height direction, the magnetic field increases first and then decreases. 3. As the power increases, the highest temperature and turbulent kinetic energy of the melt increase. When the power increased to 166.18 kW, a vortex appeared in the core of the melt.

6 Acknowledgments

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