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Finite Element Analysis of Induction Heating Process Design for SMART Foundry 2020

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Abstract:

Induction furnace plays a very important role in melting of high melting point metal. This furnace has an ability to quickly and efficiently heating of the material without being in physical contact. Such kind of heating mechanisms offers an appropriate technology solutions to many industrial problems. In this work we are interested in modelling & simulation of an induction furnace in the smart foundry 2020 context. Which uses modern casting technology in design & manufacturing of metallic implants, which is mostly used by medical industries. Finite element analysis of this furnace is performed by heat transfer coupled with induction heating module of COMSOL Multiphysics. This simulation process permits precise description of the current, temperature, electric field & magnetic field distribution in each component of the furnace. These are the governing parameters plays a very important role , which is used to optimize, the geometry of the furnace component (crucible & coil position, number of turns, etc) & efficiency to limit energy consumption, size of electrical generator, so that our in-house smart foundry can respect the safety standards concerning the residual electromagnetic field.

1. Introduction:

Use of induction furnaces has exponentially increased in the past years in industries. Along with this, technological advancements in recent years has led to the groundwork of industrial revolution which is also called as industry 4.0. The industry 4.0 mainly focuses introduction of wireless connectivity with machines such that the system would be able to make decisions on its own. The industry 4.0 mainly comprises of cyber-physical systems, the internet of things, industrial internet of things, cloud computing, cognitive computing and artificial intelligence. By using these concepts the factory would be able to monitor the processes on its own and make the necessary decisions.[1]

Casting is used in operations where production of part is very difficult through machining. It is one of the most important manufacturing method and is used recurrently in every other industry. In this process first the molten metal is poured into the mould which is then allowed to cool. This way the molten metal solidifies and takes up the shape of the mould and the part is thus obtained. Combining the process of casting with industry 4.0 has led to the foundation of smart foundries. Smart foundries not only just automates the process but it also improves the part quality and process efficiency[2]. In induction furnace the process of heating is very complex and it consist different physical phenomena like electromagnetic induction thermal heating with phase change. as induction heating is non contact heating process thus it involves high frequency electricity to heat materials which are electrically conductive[3]. contamination of melting material dose not occurs here as it is non contact process.

high frequency electricity is used to run a large AC current through a coil. this coil is called as work coil. flow of current along this coil create a very intense and fast changing magnetic field in the domain within the work coil and thus the heating of work piece is take place at these domain.[4,5]. The change in magnetic field within the domain induces a flow of current in the work piece sample. this study focus on induction design furnace modelling and variation of magnetic field within the domain have been performed in addition to this effect of change in frequency in induction heating has also been explored.

2. SMART Foundary 2020

(SMART= Sustainable Metal casting using Advance Research and Technology) Foundry system, includes information and materials flow. It comprises three subsystems: (1) For input data preparation (2) Manufacturing and (3) monitoring. Input data include part CAD model, tooling and Method design, and optimal process parameters obtained from simulation of molten metal flow and solidification. Manufacturing sub-system comprises 3D printer (For pattern fabrication), automatic moulding unit (for sand moulding), melting, pouring, shake out and inspection, the process will be monitors using sensor embedded in mould, melting, pouring and other units; the sensor data will be uploaded to the cloud, analysed and viewed in smart phone. there are some advantages of Foundry 4.0 such as Simulations used for casting analysis enhances the quality of casting and further casting optimization processes

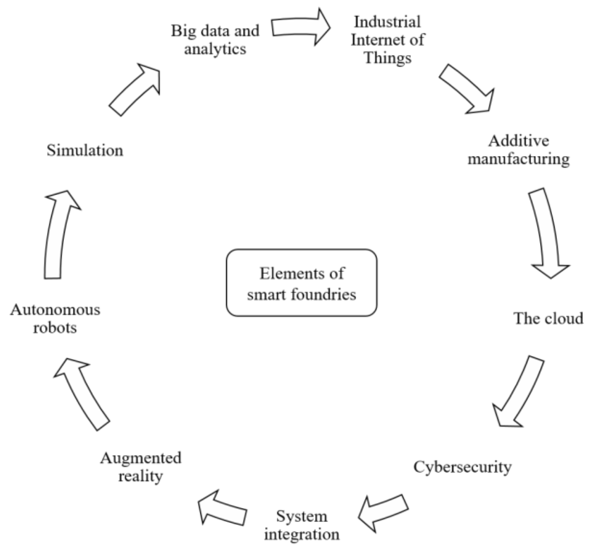

Figure 1: Elements of smart foundries

leads to upscale the production process, thereby increasing the yield. Virtual casting operations can pre-estimate and identify geometrical changes for better productivity. Reduction in shop-floor trials for the development of new castings can be reduced, thereby saving both time and cost of production. Smart technologies add more confidence in decision making and are also a valuable addition to the foundry business. This can further be utilized in several projects and can be shared conveniently between users present at multiple remote locations.[6]

3. Finite element analysis of induction furnace:

This work concerns an induction furnace like the one presented in Fig. 2. It consists of a cylindrical vessel (usually called the crucible) made from a material, surrounded by an inductor coil made of a very conductive material (copper, for instance). The main idea of the process is quite simple: the coil is supplied with alternating current that produces a rapidly oscillating magnetic field which, in its turn, induces eddy currents. These eddy currents, due to the Joule effect, cause heat losses and consequently the electrically conducting materials of the work piece are heated.

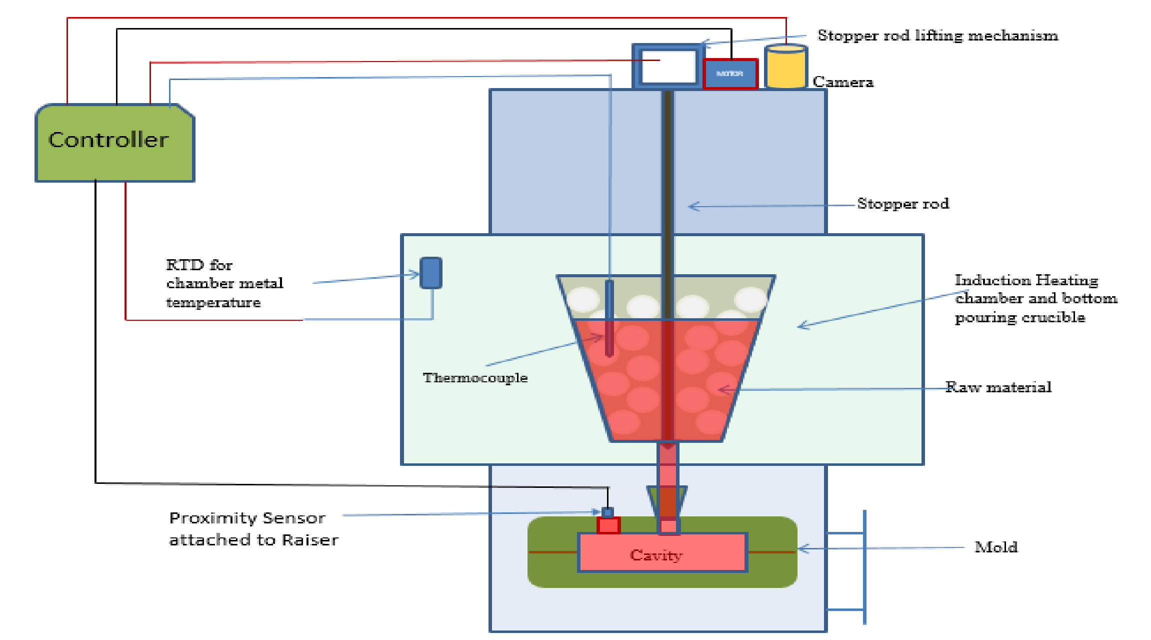

Figure 2: Induction melting with direct pouring and data acquisition

3.1 Governing Equations:

Induction heating can be estimated using modern finite element methods, as indicated previously in Fig. 2. This model directly solves Maxwell's equations in the frequency domain, starting from the magnetic vector potential, the formulation of the problem requires the statement of the electromagnetic field we can be write:

$$\nabla \times \mathbf{H} = \mathbf{J} \quad (1)$$

$$\mathbf{B} = \nabla \times \mathbf{A} \quad (2)$$

$$\mathbf{J} = \sigma\mathbf{E} + j\omega\mathbf{D} + \sigma\mathbf{v} \times \mathbf{B} + \mathbf{J_e} \quad (3)$$

$$\mathbf{E} = -j\omega\mathbf{A} \quad (4)$$

Amperes law

$$\nabla \times \mathbf{H} = \mathbf{J} \quad (5)$$

$$\mathbf{B} = \nabla \times \mathbf{A} \quad (6)$$

$$\mathbf{E} = -j\omega\mathbf{A} \quad (7)$$

$$\mathbf{J} = \sigma\mathbf{E} + j\omega\mathbf{D} \quad (8)$$

Heat transfer in solids

$$\rho C_p \frac{\partial T}{\partial t} + \rho C_p u.\nabla T + \nabla.\mathbf{q} = Q + Q_{ted} \quad (9)$$

$$\mathbf{q} = -k\nabla T \quad (10)$$

3.2 Results:

A number of assumptions are used in defining the model. Firstly, the current in the induction coil are treated as a boundary condition of induction current on the surface and on the inner coil. The maximum temperature of the test article is limited to 600°C during the experiments. Finally, the resistive losses in the copper are treated as a boundary condition in the heat transfer.

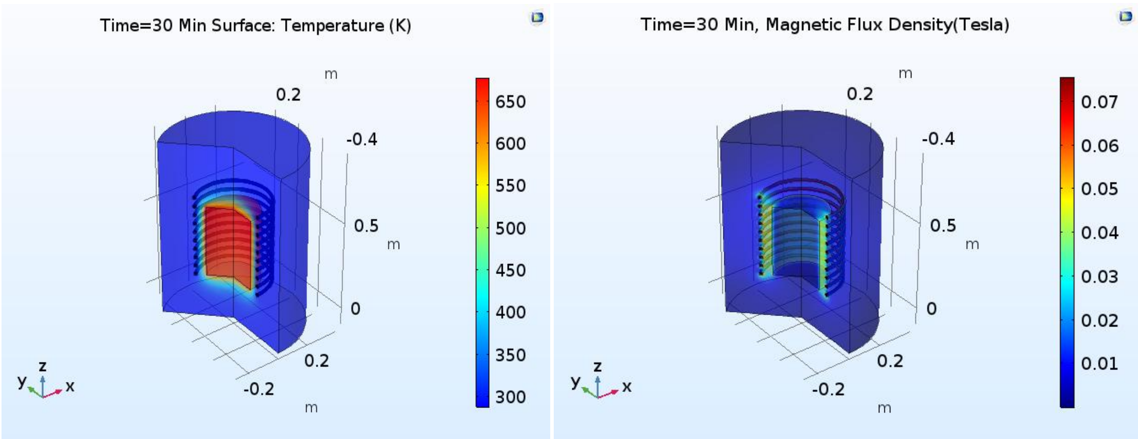

Figure 3: Distribution of Temperature and Magnetic Flux within the Domain

4. Conclusions:

2D axis symmetric induction furnace analysis has been performed using COMSOL multiphysics software. This paper shows how to solve the induction heating problem in the induction furnace with complex geometry. The results of this study have shown that the temperature of the crucible rises to 650 oC in 30Min of heating time at frequency of 10 kHz and current of 2000 A. Hence these conditions are favourable for melting of Aluminium (melting point = 635 °C) in the crucible. Thus this analysis gives highly favourable results, in designing process parameters for Induction Furnace used in SMART Foundry 2020.

References:

[1] C. Snow, Formula for the inductance of a helix made with wire of any section, Ed. US Govt. Print. Off, 1926, p. 91.

[2] M. W. Kennedy, S. Akhtar, J. A. Bakken, and R. E. Aune, *Analytical and Experimental validation of electromagnetic simulations using COMSOL re Inductance induction heating and magnetic field*, Comsol Conference, Stuttgart, 2011.

[3] M. W. Kennedy, S. Akhtar, J. A. Bakken, and R. E. Aune, *Review of Classical Design Methods as Applied to Aluminum Billet Heating with Induction Coils*, EPD Congress, San Diego, California, February 27 - March 3, (2011), 707-722.

[4] T A. Jankowski, D.P. Johnson, J. D. Jurney, E. Freer, L. M. Dougherty, and S. A. Stout, *Experimental Observation and Numerical Prediction of Induction Heating in a Graphite Test Article, Expert from the proceedings of the Comsol Conference, Boston, 2009.*

[5] U. Ludtke and D. Schulze, *FEM software for simulation of heating by internal sources, Proc. of HIS-01 Int. Seminar*, Padua, Italy, Sept. 12-14, 2001.

[6] Saxena P., Papanikolaou M., Pagone E., Salonitis K., Jolly M.R. (2020) Digital Manufacturing for Foundries 4.0. In: Tomsett A. (eds) Light Metals 2020. The Minerals, Metals & Materials Series. Springer, Cham

[7] A. Bermúdez, D. Gómez, M.C. Muñiz and P. Salgado, *Transient numerical simulation of a thermo electrical problem in cylindrical induction heating furnaces,* Advances in *Computational Mathematics* (2007) 26: 39–62.

[8] S. Clain, J. Rappaz, M. Swierkosz and R. Touzani, *Numerical modeling of induction heating for two-dimensional geometries*, *Math. Models Methods Appl. Sci.* 3 (1993) 805–822.

[9] D. Istardi, A.Triwinarko**,** *Induction Heating Process Design Using COMSOL® Multiphysics Software*, ISSN: 1693-6930, *TELKOMNIKA, Vol.9, No.2, August 2011, pp. 327~334.*

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