Review Paper on Numerical Analysis of Induction Furnace

Nihar Bara
Department of Mechanical Engineering
RK University, Rajkot, Gujarat, India

Abstract- A new generation of industrial induction melting furnaces has been developed during the last 25 years. Present practices followed in Induction Furnaces are discussed in this paper. Through a literature review account of various practices presently being followed in steel industries using Induction Furnaces has been carried out with a view to gather principal of working. This paper is related with the modeling of induction process and its development is discussed. The computational techniques available for the modeling the process and the various methods for optimization is also discussed in this review paper.

Keywords – Induction Process, Thermal Analysis, Heat transfer, Wall thickness.

I. INTRODUCTION

A furnace is a device used for heating. The name derives from Latin fornax. The development of Induction Furnaces starts as far back as Michael Faraday, who discovered the principle of electromagnetic induction. However it was not until the late 1870's when De Ferranti, in Europe began experiments on Induction furnaces. Induction furnaces are used in a wide range of production and manufacturing facilities such as foundries and metallurgy plants. Induction furnaces are used primarily because they are fairly clean, can melt materials quickly, and are generally affordable to maintain and operate. They also allow for precise temperature and heat control. Because they gain heat very quickly they do not have to be left running between operations and thus save on energy resources and help manage operating costs.

Induction furnaces may be used to melt, braze, solder, treat, or shrink fit any material that is suitable for use with induction heat. Treating materials may include annealing, hardening, or tempering. Induction heat may be used to braze or solder copper, bronze, brass or steel. Shrink fitting may involve fitting parts for precision manufacturing. Melting processes can be done on ant material that is compatible with induction heat. Such metals include steel bronze, copper and brass.

The rest of the paper is organized as follows. Proposed embedding and extraction algorithms are explained in section II. Experimental results are presented in section III. Concluding remarks are given in section IV.

II. TYPES OF INDUCTION FURNACE

The two basic designs of induction furnaces, the core type or channel furnace (Fig 2) and the coreless (Fig 3), are certainly not new to the industry. The channel furnace is useful for small foundries with special requirements for large castings, especially if off-shift melting is practiced Induction furnaces have increased in capacity to where modern high-power-density induction furnaces are competing successfully with cupola melting. There are fewer chemical reactions to manage in induction furnaces than in cupola furnaces, making it easier to achieve melt composition. Induction melting produces a fraction of the fumes that result from melting in an electric arc furnace (heavy metal fumes and particulate emissions) or cupola (wide range of undesirable gaseous and particulate emissions as a result of the less restrictive charge materials).

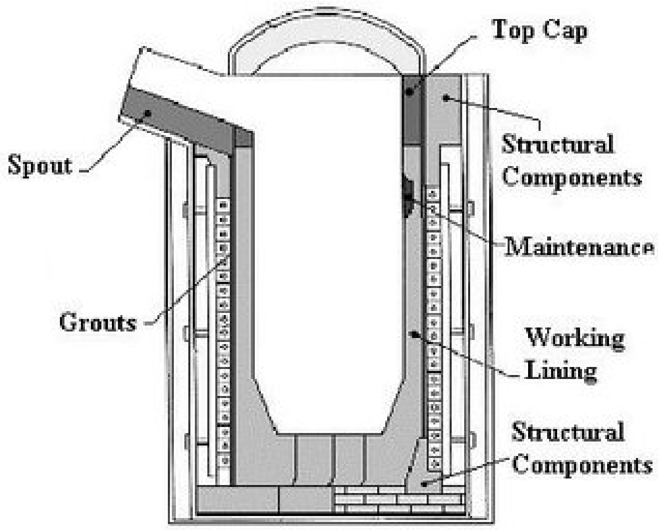

Figure 1. Furnace used in Industries

The induction furnace provides a complex challenge for the researchers for the mathematical modeling since it involves the different fields of physics together and its inter action is not fully understood till date. The researchers around the world have provided their own modeling method and have verified with experimental results with good accuracy.

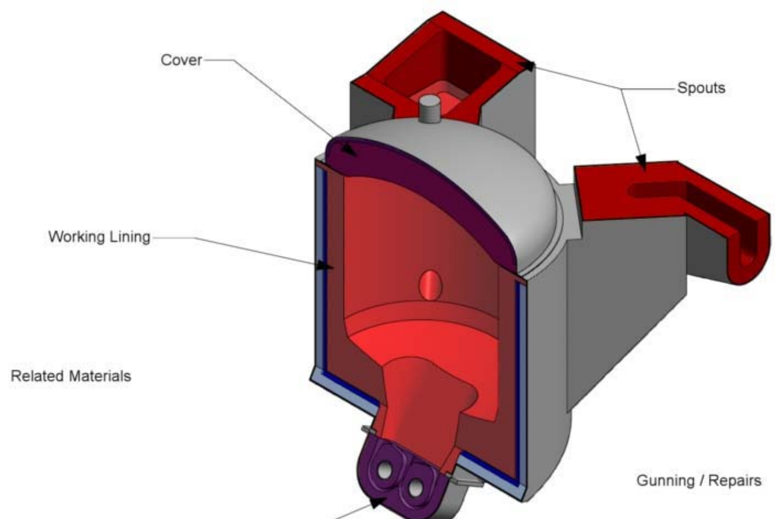

Figure 2. Channel Induction Furnace

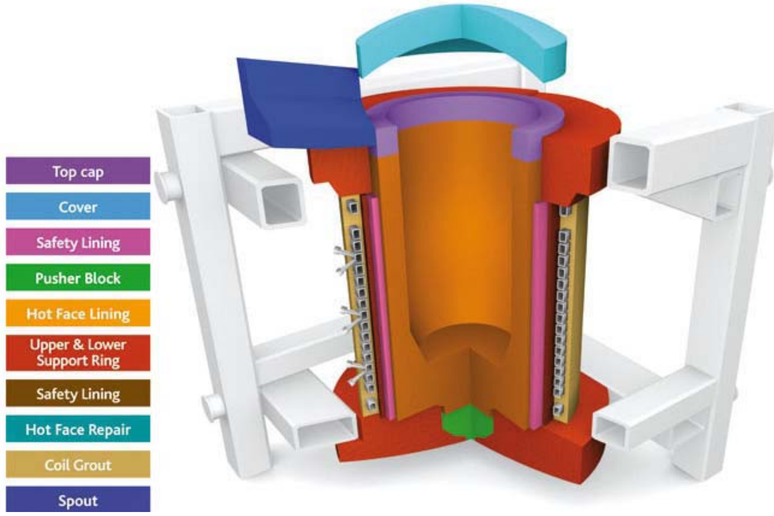

Figure 3. Coreless Induction Furnace

Induction heating processes have become increasingly used in these last years in industry. The main advantages of using these processes when compared to any other heating process (gas furnace.) are, among others, their fast heating rate, good reproducibility and low energy consumption [1]. The induction heating process basically consists in transmitting by electromagnetic means, energy from a coil through which an alternative current is circulating. Induced currents in the conductive part due to the well-known Foucault law then heats the workpiece thanks to the Joule effect. Induction heating processes are mainly used either at low frequencies (around 50 Hz), usually in order to reach a temperature distribution as uniform as possible within the material before any forming process, or at much higher frequencies (10^4–10^6Hz) in order to heat very locally near the surface, usually for heat treatments [2]. Most induction heating processes are set up using engineering experience and a trial-and-error procedure in order to achieve the corresponding goal (grain size control, uniform prescribed temperature, hardness map, etc.). Induction heating process simulation, which couples electromagnetic and heat transfer equations, can be of great help for a more in depth understanding of occurring physical phenomena. So far, various numerical models have been developed coupling electromagnetism and heat transfer. Most models involve the well-known finite element approach [3–5] or mixed finite element and boundary element approaches [6–8]. Even though mixed methods are interesting due to their inherent ability to take into account open domains and inductor displacements, the global finite element approach has been preferred since it involves sparse matrices (leading to reductions in terms of CPU time and memory requirements) and is more suited for parallel computing. Most authors use the harmonic approximation, assuming that all electromagnetic fields are sine waves when the input current is a sine wave. This approximation, valid when considering linear magnetic materials, can yield to large errors when dealing with highly ferromagnetic materials [3,9]. That is the reason why the time-dependent formulation has been preferred. Time dependent integration being very time consuming when using a traditional weak coupling between all problems, the ultra-weak strategy has been developed.

IV. REVIEWS

H.K.Jung has designed the optimal inductive coil in the induction heating process of A356 (ALTHIX) alloy billets of 76 mm diameter and 90 mm length to reduce the temperature gradient of the billet and to obtain a globular microstructure was theoretically proposed and tested by reheating experiments. The optimal reheating conditions to apply the thixoforming process were investigated by changing the reheating time, holding time, holding temperatures, the capacity of the induction heating system, and adiabatic material size. This study shows that, the larger the pellet size, the better the multi-step reheating, and the heating time and the capacity of the induction heating system must be increased. In case of the three-step reheating process, the final holding time is the most important factor and 2 min is suitable to maintain a globular microstructure.

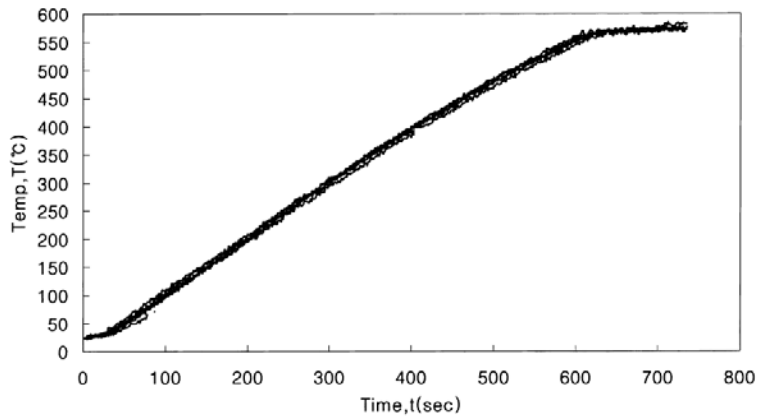

Figure 4. Temperature distributions in the one-step reheating process of semi-solid alloy (fs.50%, ta1.10 min, Th1.5848C, th1.2 min): (a) Q.7.796 kW.

The analytical technique has been developed by Dae-Cheol Ko et al.[3] in order to investigate the behavior of semi-solid material considering induction heating of the workpiece. The induction heating process is analyzed using the commercial finite element software, ANSYS. The finite element program, SFAC2D, for the simulation of deformation in the semi-solid state is developed in the present study. The behavior of semi-solid material is described by a viscoplastic model for the solid phase and by Darcy's law for the liquid flow. Simple compression and closed-die compression processes considering induction heating are analyzed. To validate the effectiveness of the proposed analytical technique, the results of simulation are compared with those of experiment.

A general automatic optimization procedure coupled to a finite element induction heating process simulation has been developed by Y. Favennec et al. [5] The mathematical model and the numerical methods are presented along with results validating the model. The first part of this paper presents the direct induction heating mathematical model, the related main numerical choices and especially the ultra-weak coupling procedure. The general optimization problem is then presented with the full detailed transposition of the ultra-weak coupling procedure for the adjoint problem. Numerical results provided at the end prove the efficiency and robustness of the adjoint model in optimizing induction heating processes.

Double-channel induction furnaces are used extensively in many processing industries due, mainly, to their relatively low operating costs. However, thermal stresses in the refractory lining caused by high temperatures during the loading cycle can cause erosion of the lining and premature inductor failure. Prevention of premature failure by close monitoring of the thermal regime of the inductor is very important to operators and relatively simple and reliable tools need to be developed to this end. J.I. Ghojel [6] developed a such a tool using a thermal modelling software and unidirectional axial channel flow speeds of the melt that are estimated from analysis based on the first-law of thermodynamics. This analysis reduces the cost, complications and uncertainties associated with coupled multiple field analysis approach. The results of the analysis show reasonable correlation with reported flow data and a comprehensive set of scenarios can be devised on the basis of the developed approach to simulate start-up, transient operation and steady state operation of double-channel induction furnaces.

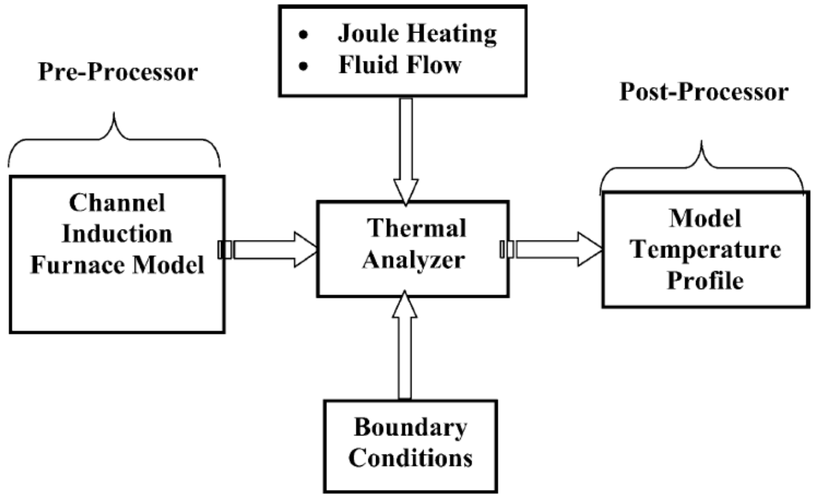

Figure 5. Single field sequential thermal analysis scheme.

The cold crucible, or induction skull melting process as is otherwise known, has the potential to produce high purity melts of a range of difficult to melt materials, including Ti–Al and Ti6Al4V alloys for Aerospace, Ti–Ta and other biocompatible materials for surgical implants, silicon for photovoltaic and electronic applications, etc. A water cooled AC coil surrounds the crucible causing induction currents to melt the alloy and partially suspend it against gravity away from water-cooled surfaces. Strong stirring takes place in the melt due to the induced electromagnetic Lorentz forces and very high temperatures are attainable under the right conditions (i.e., provided contact with water cooled walls is minimised). In a joint numerical and experimental research programme, various aspects of the design and operation of this process are investigated to increase our understanding of the physical mechanisms involved and to maximize process efficiency. A combination of FV and Spectral CFD techniques are used at Greenwich to tackle this problem numerically, with the experimental work taking place at Birmingham University. Results of this study, presented here, highlight the influence of turbulence and free surface behaviour on attained superheat and also discuss coil design variations and dual frequency options that may lead to winning crucible designs.

Cold crucible induction melting is evolving as a promising technology for vitrification of high level radioactive waste because of high temperature availability and long melter life. Natural convection in the inductively heated glass pool plays a significant role in the performance of such melters. Experimental investigations were carried out by G. Sugilal to study the nature of flow patterns and temperature profiles in a sodium borosilicate glass pool inside an engineering scale cold crucible induction melter. Flow patterns were obtained for power levels in the range of 50 to 110 kW. The average surface velocity was found to vary from 5 mms^{-1} at 50 kW to 22.5 mms^{-1} at 110 kW. Experimentally measured temperature profiles in the glass pool indicated a well-mixed zone above a thermally stratified layer.

Kee-Hyeon Cho presented a study on coupled electro-magnetic and thermal model for numerical analysis of an induction heating system including the workpieces moving relative to the inductors. In this paper, a finite element method-based numerical analysis of a low-frequency (60 Hz) induction heating system for the one-dimensional solution of a stationary circular billet and the two-dimensional solution considering the dynamic effect of circular billets moving along the skid rails with constant speed are presented and compared against each other. The non-linearities of both the electro-magnetic and thermal material properties are also taken into account in the model. The computational results have been compared with experimental data. As a result, it is suggested that the presented numerical model may be a very cost-effective tool in predicting the temperature of a workpiece in a variable flux field where the interested workpieces undergo an arbitrary change in the electro-magnetic fields. It is possible to obtain some preliminary results more accurate than those calculated from previous works using a stationary model on electro-magnetic field and temperature distribution of workpieces by applying the presented numerical model.

Conclusion

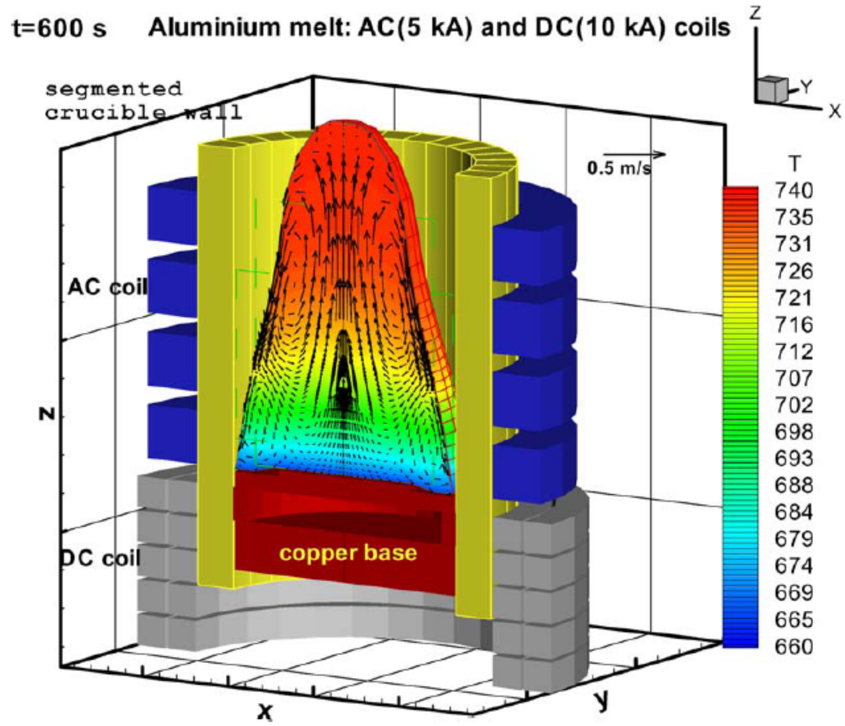

Figure 6. Arrangement with DC coil placed below the AC induction coil—superheat increases to 740 ºC.

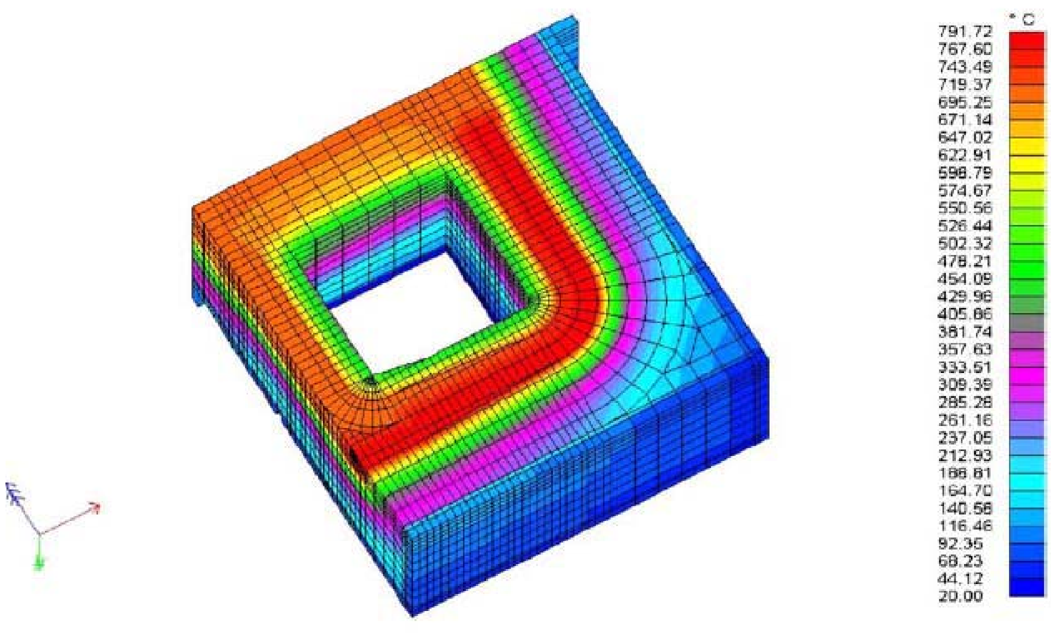

Figure 7. Temperature contours in the inductor with a thermostat.

IV.CONCLUSION

The reviews has been performed using various research work published. The computation methods and experimental techniques available were discussed and it is been observed that the finite element method is very much efficient method for the modeling. The modeling using FEM also facilitates the optimization of the induction furnace. The research works reveals that the induction furnace requires proper optimization and composite wall technique can used for enhancing the heat transfer charactrerisitics.

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