International Engineering Research Journal

# Numerical simulation and Experimental study of ingot heating process for time and energy efficiency for quality and productivity of the process

**PriyambadaPraharaj[1], Dr.J.A.Hole[2]**

†PG Student Department of Mechanical engineering, Savitribai Phule Pune University, Pune, Maharashtra, India
‡,Associate Professor, Department of Mechanical engineering, , Savitribai Phule Pune University Pune, Maharashtra, India

***Abstract***

*Steel ingot is extensively used in thermal and nuclear power plants in box furnace or soaking pit for further mechanical processing and rolling operations. The ingot heating time and furnace temperature profile is determined by thumb rules inmost of the steel plants, which are based on time required per unit cross sectional area or diameter of the ingot, and also by trial and error method according to the experience and expertise of the plant engineers. However, ingot heating time can vary widely due to variation of thermal properties of steel according to Grade or composition of steel and phase transformation of steel, which is very difficult to predict by thumb rules. Therefore in most of the cases excess heating time is employed, giving rise to higher energy cost, oxidation or scale loss and lower productivity. Therefore a model based process analysis will significantly reduce the ingot heating time, and also reduce the chances of ingot cracking problems. In this project we are planning to study and develop mathematical model for the ingot heating process, which is highly energy intensive and critical for quality issues like ingot cracking, oxidation and scale loss. The problem of ingot heating becomesmore critical with larger ingots required for Nuclear, and thermal power plants.*

***Key Words*****—**Ingot heating, Energy efficiency, ingot cracking, thermal homogenization.

## 1. Introduction

Steel Ingots are reheated in soaking pit or box furnace for further thermo mechanical processing like forging and rolling operations. Reheating process becomes more and more critical for high grade and large ingots required for nuclear, thermal power plants and other applications. The ingots are heated upto 1100 – 1250 degree centigrade for hot rolling and forging operations. Since this is high temperature and energy intensive process, prolonged or excess heatingwill cause productivity loss, wastage of energy, wastage of energy, as well as oxidation and scale loss. However due to large dimension of ingots, surface temperature during heating can rise much faster than the inner core temperature, and can create excessive thermal stress, which may lead to ingot cracking and distortion further more rapid heating of the surface to attain the specified temperature without providing adequate time for thermal homogenization of the ingot can causeproblem during hot rolling and forging problems .Therefore the aim of the ingot heating process is to avoid any excessive thermal stress in the ingot particularly in the vulnerable range like ferrite to austenite phase transformation temperature, and minimizing the time of thermal homogenization and scale loss due to oxidation.

The proposed project involves mechanical engineering areas like heat transfer under various industrial furnace conditions and metallurgical like phase transformation of steel during heating , which involves latent heat of phase transformation ,anomalous behavior of thermal conductivity of steel, and oxidation and scale loss during heating process.

## 2. Literature Review

Many researcher have mainly focused on the dynamic setting of the furnace heating capacity to fit the fluctuation of production [1].This production process helps to reduce the steel energy consumption.

There are also some development of transient mathematical models for a large scale re-heating furnace using various CFD methods [2].

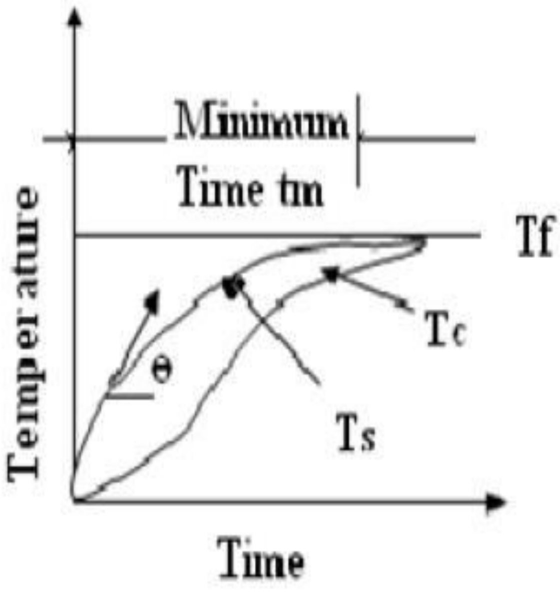
Numerical analysis of slab heating characteristics in a reheating furnace is used in case of complicated geometry. The study showed that the CFD simulation is used effectively to develop and study rolling type reheating furnace [3].

There were also some developments of materials that work under increasing extreme conditions. Hence solarfurnace improves the temperature uniformity by indirect heating [4].

## 3. Methods used for heating ingots

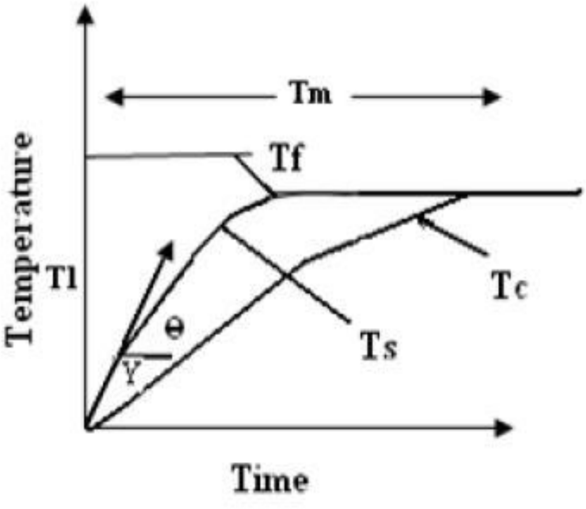
First of all the ingot is heated at a fast rate. In the figure 1(a). One heating curve denotes the surface temperature of the ingot whereas the other denotes the center of the ingot. When the material is bad conductor of heat then some soaking time is needed so that the center also attains the desired heating temperature to be transformed into a homogeneous structure. Even higher and rapid heating may be obtained if the heated furnace is quite above the requisite temperature and when the surface of the part is about to attain the desired temperature of heating. Hence the temperature of the furnace may be allowed to fall the desired heating temperature as illustrated in figure.1 (b).

One heating curve denotes the surface temperature of the ingot whereas the other denotes the center of the ingot. When the material is bad conductor of heat then some soaking time is needed so that the center also attains the desired heating temperature to be transformed into a homogeneous structure. Even higher and rapid heating may be obtained if the heated furnace is quite above the requisite temperature and when the surface of the part is about to attain the desired temperature of heating. Hence the temperature of the furnace may be allowed to fall the desired heating temperature as illustrated in figure.1 (b).




(a)

Fig-1 (a)Heating in furnace kept at reqd temperature, more difference in temperature between surface and centre




(b)

Fig 1(b) Faster rate than (a)

This process has an advantage in continuous furnace practice. This is because the furnace temperature is well above the requisite temperature and passage through the furnace is regulated. Often the batch furnace may be kept heated to much high temperature. When large amount of cold parts are charged into it, it loses heat to the charge and temperature is allowed to fall to the required heat treating temperature. In real practice a rapid rate may be employed, taking care the safety of the experiment.

**4.Layout and design of the set up**

The experimental set up consists of a rectangular muffle furnace which is rectangular horizontal electrically operated furnace and is wound with high quality wires fitted with a metallic cabinet and insulated with cerwool insulation .Outer metal cabinet is duly painted with high resistance paint. The unit is fitted with thermal fusewhich melts and breaks the circuit to the heating element when working temperature is exceeded.Energy regulator is fitted for precise control.

Temperature reading: 950 degrees centigrade works on 230 V AC single phase.

Temperature controls: Pyrometer or digital time proportional controller. Power: 230 V, 50 Hz, AC mains

Fig 2- Experimental Set Up

## 5. Materials Required

Muffle furnace, data logger, Mild steel ingot, and thermocouple.

## 6. Methodology

A mild steel ingot of size 10*5.5*5.5 cm is taken.The ingot is drilled at three points one at the center and two on the sides of the ingot so as to measure the center and the surface temperature.
The three thermocouple is then fixed at the three points by using plaster of paris. The ingot is now put inside the muffle furnace. The muffle furnace is having two holes. The thermocouple measuring the center and one of the surface is put in the center hole and the other in another hole.These thermocouple is then connected to a data logger through three channels. To record the furnace temperature another thermocouple is then connected from the furnace to the data logger to record the furnace temperature. The temperature id now step heated by increasing to first 891 degrees and then to 951 degrees. After about certain increase in temperature regular holding time is given so that we could minimize the center and the surface temperature.
Hence various pilot experiments carried out to validate whether the experiment done has been proper. Now our ingot is ready for other processes. The main objective of this experiment is to equalize the central and the surface temperaturewith minimum loss so that energy is saved and various losses are minimized.

## 7 Results and Analysis

7.1.*Heat conduction in the work piece :*

Thermal properties of materials not only depends on temperature but also on phases like austenite and ferrite.Thermal conductivity of steel is one of the mostimportant parameters for modeling steel treatment.As we know that the composition of steel varies anomalously with phase transformation of steel from ferrite to austenite. This phenomenon have been accurately captured by the model developed.

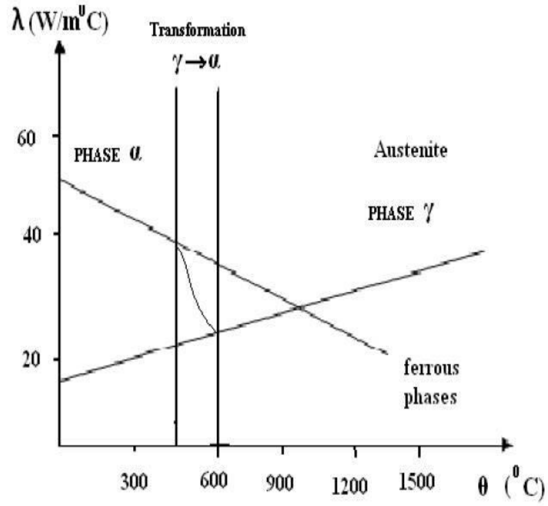



Fig-3 Thermal conductivity of BCC and FCC.

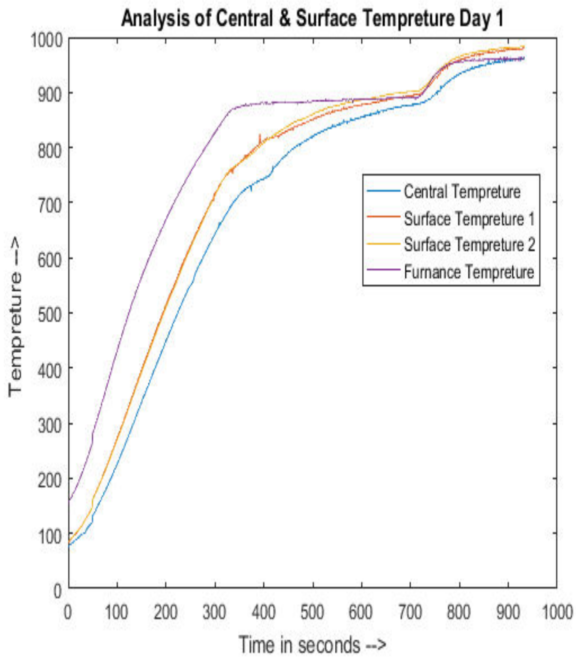
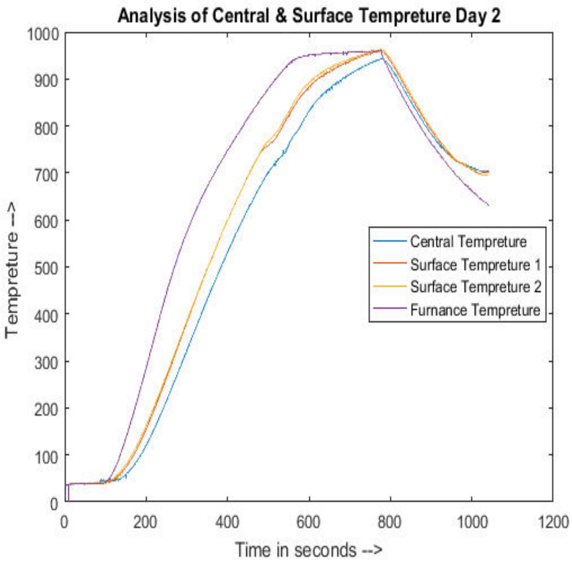



**Fig. 4**Graph-1 Modeling results of heating cycle

From the first graph we see that the temperature difference between the center and the surface is gradually increasing to about 50 degrees.In the first graph we have an intermediate holding of 890 and then increased the temperature to 950 degrees. We could infer the temperature difference between the surface and core is decreasing from 50 degrees to 16 degrees after holding of 1 hour 10 mins.Then the temperature is set to 950 C.The temperature gap increases slightly as temperature increases from 16 to 25 degrees.When the From the first graph we see that the temperature difference between the center and the surface is gradually increasing to about 50 degrees.In the first graph we have an intermediate holding of 890 and then increased the temperature to 950 degrees. We could infer the temperature difference between the surface and core is decreasing from 50 degrees to 16 degrees after holding of 1 hour 10 mins.Then the temperature is set to 950 C.The temperature gap increases slightly as temperature increases from 16 to 25 degrees.When the temperature becomes constant at 950 the gap decreases.




**Fig,5.**Graph 2- Modelling results in heating cycle

In the second graph the heating is continued from 70 degrees to 950 degrees and the graph shows gradual increase in the temperature difference from negative temperature to positive temperature difference between surface and core.There is a kink at around 750 C showing phase transformation from ferrite to austenite. The kink is due to latent heat of phase transformation. During the phase transformation there is a decrease in volume from ferrite to austenite, which may cause bending or crack formation in large ingots. Hence an intermediate holding is given.

7.2. *Numerical methods for process simulation-*

Heat transfer equation for solid ingot:

$$\frac{\partial T}{\partial t} = D\left(\frac{\partial^2 T}{\partial x^2} + \frac{m}{x}\frac{\partial T}{\partial x} + \frac{\partial^2 T}{\partial y^2}\right) + S_p T + S_c$$

This is a 2-D heat transfer equation for both cylindrical (m=1), Cartesian (m=0).

Boundary heat transfer considers heat transfer by radiation and convection as shown in equation below-

$$S_p T + S_c = \frac{h}{\rho C_p}\left(T_{Fur} - T_{Surf}\right) + \frac{\sigma\varepsilon}{\rho C_p}\left(T_{Fur}^4 - T_{Surf}^4\right)$$

The equations are solved by finite difference method using crank Nicolson technique for time discretization.

**8.Acknowledgements-**

The authors would like to thank JSPM'sRajarshiShahuCollege of engineering for providing all the facilities for this project.The author would sincerely thank Dr. N.K Nath for his constant support for the project

## 9. **Conclusion and Future Scope:**

Hence by carrying out this model based experiment for the two extreme varieties of steel we can optimize for all other grades of steel by numerical simulation.

Hence this would help us to give a proper time for a particular grade of steel in the ingot heating process. As we know that excessive time given for heating could not only bring about wastage of energy but also chances of ingot cracking and other losses.

Therefore this model based experiment would avoid excessive heating time that is otherwise employed by trial and errormethod or by experience or expertise. Hence depending upon the various grades or composition of the steel we can control the heating rate and time. This is a very important aspect because it not only saves energy but also gives high productivity.

The mathematical optimization techniques for this ingot heating process would be highly beneficial in nuclear and thermal power plants where the problem of ingot heating process becomes more critical with larger ingots employed for commercial purposes.

**References:**

[1] Yukun Hu.(2015)et al"*Development of transient mathematical models for a large-scale reheating furnace using hybrid zone-CFDmethods*".ScienceEnergy Procedia 75 ( 2015 ) 3076 – 3082

*[2]* Y.J. Liu,(2016)et al."*A numerical analysis of slab heating characteristics in a rolling type reheating furnace with pulse combustion*".Applied Thermal Engineering 107 (2016) 1304–1312

[3] F.A.C. Oliveira,(2016) et al"*Temperature uniformity improvement in a solar furnace by indirect Heating.*"Solar energy140 (2016) 141–150

[4] A.AGomi (2009)"*Steel Forming and heat treating handbook*",Sao Vicente, Brazil

[5] Vijendra Singh (2007*)."Heat treatment of metals*; *Standard Publisher",New Delhi*

*[6]* Jun Li (2013) et al "*Simulationof macrosegregation in a 2.45-ton steel ingot using a three-phasemixed columnar-*

*equiaxedmodel*”,International Journal of Heat and Mass Transfer 72 (2014) 668–679

[7] KuldeepAgarwala(2015)et al”*Process-structure-microstructure relationship in hot strip rolling of steels using statistical data mining*.”Procedia Engineering 81 ( 2014 ) 90 – 95

*[8]* MersedehGhadamgahi(2014)etal. *“Design optimization of Flameless-Oxyfuel soaking pit furnace using CFD technique”* Energy Procedia 61 ( 2014 ) 611 – 614

[9] Takao Koshikawa,(2016) et al.”*Experimental study and two-phase numerical modeling of macrosegregation induced by solid deformation during punch pressing of solidifying steel ingots.*“Acta Materialia 124 (2017) 513e527

[10] Mudassir M. Rashid,(2015) et al”*Multi-rate modeling and economic model predictive control of the electric arc furnace*.”*Journal of process control.*