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# Mathematical Model based Software System for Optimization of Steel Slaband Ingot Reheating in Walking Beam Furnace

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***Abstract:*** *Reheating of continuous casting slabs, billets and blooms in walking beam furnace is an important step for further processing of the slabs by thermo-mechanical techniques like hot rolling and forging operations. The slabs are heated up to 1100 – 1250 $^{o}$C, and since this is a high temperature and energy intensive process, prolonged or excess heating will cause productivity and energy loss, as well as oxidation and scale loss. On the other hand if it is heated very fast causing significant temperature difference between the surface and the core temperature, it can lead to excessive thermal stress, cracking or distortion. Furthermore, rapid heating of the surface to attain the specified temperature, without thermal homogenization of the slab can causes problems during hot rolling or forging operations, which may lead to cracking, roll stuck and forging problems. Therefore the aim of the heating process is to avoid any excessive thermal stress, particularly in the vulnerable ferrite to austenite phase transformation range, and also to minimize the time for thermal homogenization. To analyze this process by numerical simulation, a two dimensional axi-symmetric mathematical model is developed and the results are projected through graphical user interface in this application.*
***Keywords:*** *Numerical simulation, Walking Beam furnace, Thermal stress, Crack formation, Energy efficiency*

## I. Introduction

Ingots are heated in furnace for further thermomechanical processes like rolling, forging and extrusion. Depending on the size of ingot, the time for heating cycle varies. The furnace started heating and along with that the ingot outside and inside temperature get increased. The heating process must produce homogenized temperature throughout the ingot from surface to core.

This prediction and automation model (Windows Application), is built in Microsoft .NET 2.0 and Fortran 6.5. The mathematical prediction model is done in Fortran 6.5. This software calls the Fortran DLL and gets the output from that after calculation. The input to the Fortran DLL is given by a text file written in .NET taking the user inputs. After taking the outputs, the UI plots 3 curves in a graph on UI for Furnace, Ingot inside and outside temperature in y-axis and time in x-axis. From the graph the total time taken for that particular ingot to be heat treated can be determined and be followed.

## II. Existing Technology and its Limitations

Before this project came added to the industrial process, the time and required temperature for homogenized heating for Ingot was determined by the experienced people in this field. There was no specific mathematical and calculated methodology to determine the time of heating.

So, with this manual system, there was always a possibility of human error. Moreover, as there is a lot of financial, labour and time involved for each heating, there was always a tendency to keep the heating time more than required for a boundary which consumes more power to heat.

With this application, the error and trial method is replaced with a more technical and reliable process which predicts the time of heating and saves extra safety time and power. This application added value to the industry in different aspects like financial, technical, dependability, error free and accuracy.

## III. Slab or Ingot Heating Process

Slab or ingot heating is the one of the important processing step after solidification of steel. Ingots as well as continuous cast ingots like slab and billets are heated to high temperature in the range of 1000$^{0}$C-1200$^{0}$C for hot rolling and forging operations. Since this is a high temperature and energy intensive process, prolonged or excess heating will cause productivity loss, wastage of energy as well as oxidation and scale loss of the ingot. However due to the large dimensions of ingot, surface temperature during heating can be much higher than the inner core temperature and rapid heating can create excessive thermal strain, which may lead to ingot cracking. Also rapid heating of the surface to attain the specified temperature, without providing adequate time for homogenization of the ingot can causes problems during the hot rolling or forging operation which may lead to ingot cracking, roll stuck problem and forging problems. Therefore the aim of ingot heating process is to avoid any excess thermal strain in the ingot particularly in the vulnerable phase transformation region like ferrite to austenite transformation, temperature homogenization and minimization of scale loss.

Experimental evaluation of the ingot heating is time consuming and difficult since, measurement of the core temperature by drilling hole up to the center of the ingot is necessary. The thermal conductivity varies with composition, and also due to ferrite to austenite transformation. Therefore we have to conduct experiments for each grade of steel, which multiplies the experimental effort. Therefore numerical simulation of the process considering the variation of thermal conductivity with temperature, compositions or grade of steel significantly helps in analyzing, planning and optimization of the process. A details study for developing a two dimensional mathematical model for ingot heating process is presented here.

## IV. Methods used for Heating the Ingots

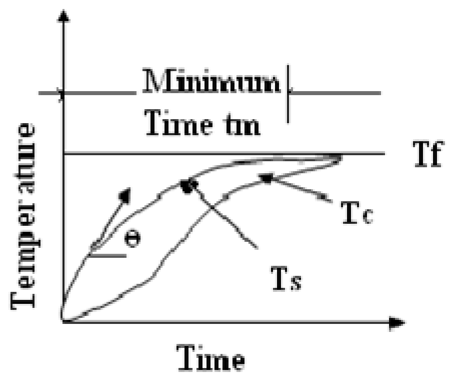
The first step in any heat treatment cycle is to heat the parts to a predetermined temperature.
The following are the principle of heating methods of metals and alloys:

**4.1 Heat the parts in a furnace which has already been heated to required heat treating temperature**

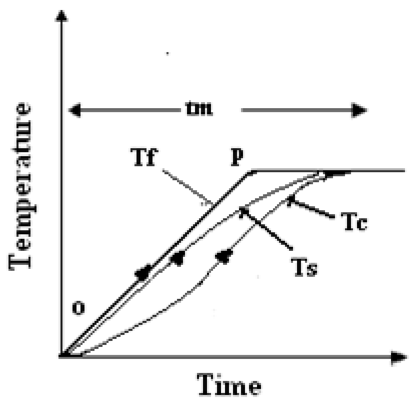
The ingot get heated up at a fast rate. Figure (a) illustrates one heating curve for the surface of ingot and other for the center of the ingot, if it is an thick parts or and if it is made of material relatively bad conductor of heat. Some soaking time is needed here so that the center also attends the desired heating temperature and transforms to a homogeneous structure. A still more rapid heating may be obtained if the heated furnace is well above the required temperature and when the surface of a part is about to attain the desired temperature of heating the temperature of the furnace may be allowed to fall to the desired heating temperature as illustrated fi(b).

Advantage is taken of this later principle particularly in continuous furnace practice. Where the temperature of furnace is kept well above the desired temperature and passage through the furnace regulated. Quite 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 and made to maintain at that temperature till the part get heated up to the required heat treating temperature.

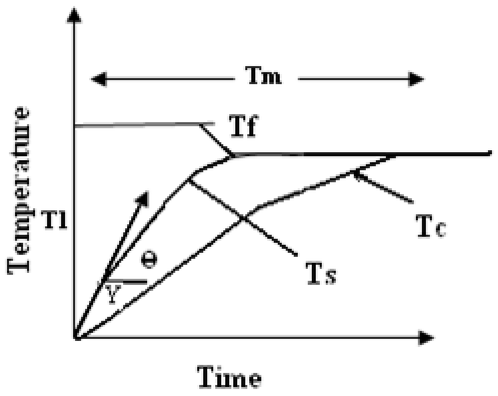
In practice, Much more rapid heating may be employed but in such cases the safety of the practice must generally be determined by experiment. Generally the safe rule of heating time of one hour per 25 millimeter is employed.



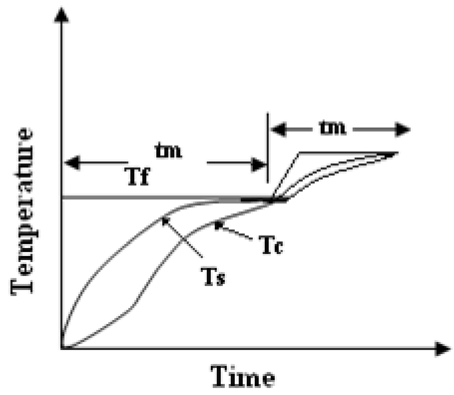

(a)




(c)




(b)




(d)

(**a**)heating in furnace kept at required temperature ,more difference of temp between surface and center (**b**)Faster heating than (a); (**c** )slower heating than (a)and (b); (**d**) tending to decrease distortion during heating

**Figure 1:** Heating of ingots at slower and faster heating rates [1].

**4.2Heat the part along with the furnace at a required rate of heating**

The principle of which is illustrated in the **Fig.** 1 (c ) .it is a much slower rate of heating than **Fig 1**( a) or( b.)

On a temperatures time graph a constant rate of heating is shown by a straight line with a slope such as shown by line OP for the heating of the furnace in fig.(c) If the slope is higher then the rate of the heating is higher. The actual rate of heating of the part may not be always constant, but varying with time.generally in practice instead of instant heating rate, the average heating rate is used, which is calculated based on the total temperature interval divided by the time taken for that temperature rise ,that is, the rate of heating

$$Va = \frac{Tm - T0}{t}$$

Of the methods illustrated in **Fig. 1**(a)(b)(c) , the maximum difference of temperature between the surface and the centre at any instant is in case (b) which is the highest of three rates of heating and the difference is minimum in **Fig 1**(c) though the alter takes much more time in heating to the required temperature.

**4.3 Step heating**

Heat the parts in a furnace to a temperature much below the heat treating temperature and when the centre of the parts also attains the first stage heating temperature as illustrated by curve *Tc*in fig (d).The heating of parts along width the furnace is done to the desired heat treatment temperature.

Many times the heating of the parts may be done in more than one step in between. as high speed steels have very low thermal conductivity, large tools of intricate shapes made from such a steel are heated in three stages

1) Preheat the parts in batch furnace kept at a temperature of around 350-400 $^0$C

2) Preheat in a molten salt bath furnace kept at temp 800 $^0$C holding time is around 15-30 second per mm of diameter

3) Heat at required heating temperature 1260 $^0$C to 1290 $^0$C in a molten salt bath furnace, watching the time till the tool changes its colour to that of molten salt bath.

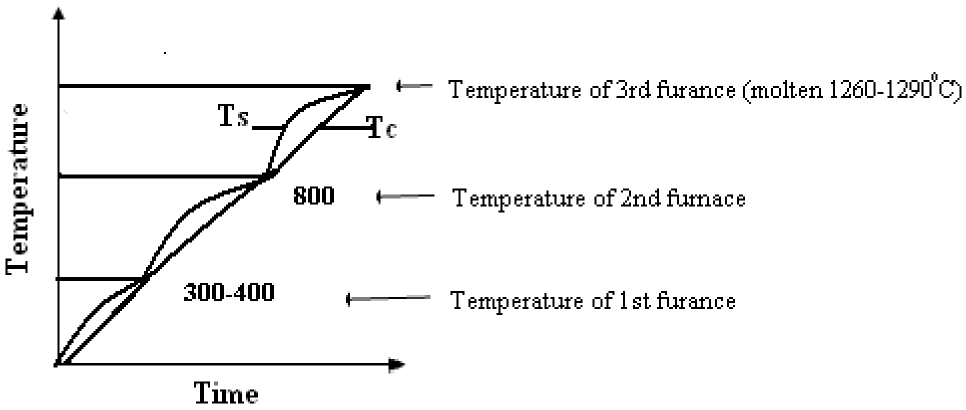



**Figure 2:** heating method of high speed steel (step heating )

**1.4 Factors affecting Surface and Core temperature of ingots** :
Difference of temperatures between the surface layer and center of the ingot depends on the following factors :
1)Thickness of ingot: The larger is the thickness greater shall be the difference in temperature between surface layer and center of the ingots.
2)Thermal conductivity : Poor thermal conductors have greater difference of temperature between the center and surface of the ingots. The thermal conductivity of steel becomes less as the 'C' content and amount of alloying element increase in the steel.. **Table 3** shows, the thermal conductivity of some steels at room temperature ,

**Table 3:** Thermal Conductivity of different Steels.

| *Steel, condition* | *Thermal conductivity,Cal/cm sec $^0C$* |
|---|---|
| Pure iron | 0.180 |
| 0.8 % C steel (annealed) | 0.115 |
| Hardened 0.8 % C steel | 0.100 |
| 18/8 austenitic steel | 0.035 |

**4.5 Slab Reheating in Continuous Furnace**

In a continuous furnace the component to be heat treated are almost continuously charged at one end of the furnace and then discharged at the other end of the furnace after heat treatment is over .The component are moved through the furnace as a rule by mechanical means .These furnace are generally operated at permanent temperature conditions and thus are invariably used to heat the same component, made of the same grade of steel and subjected to the same heat treatment cycle ,i.e., only to annealing ,to hardening, to normalizing ,or carburizing ,etc ,i.e., these furnaces are specialized furnaces. Thus these furnaces can be easily programmed and are typical of plants which heat treat high volume component ,or for mass production . Continuous furnace may or may not have controlled atmospheres. The initial cost of such furnace is high but the running costs are low due to reduced labour cost and efficiency of flow of charge, particularly if the furnace is run 24 hours a day.

A continuous furnace may have different zones ,necessitating proper control on travel of the component through the zones .for example ,for carburizing , the furnace may have separate chamber for heating , for carburizing and for the diffusion process.

In a continuous furnace movement of the component may have to be done from the charging door to the discharge door .Two general design of furnace could be one having the rotating heart and the second a straight chamber furnace .

**4.6 Annealing**

Annealing is general refers to heating the material to a predetermined temperature for a definite time (i.e soaking ),and then cooling it slowly normally in a furnace by switching it off. The aim of annealing even in steel could be varied and that is why ,there are a number of types of annealing heat treatments. The nature of processes occurring during each type of annealing depends upon the type of steel, temperature of annealing, history and state of steel before annealing.

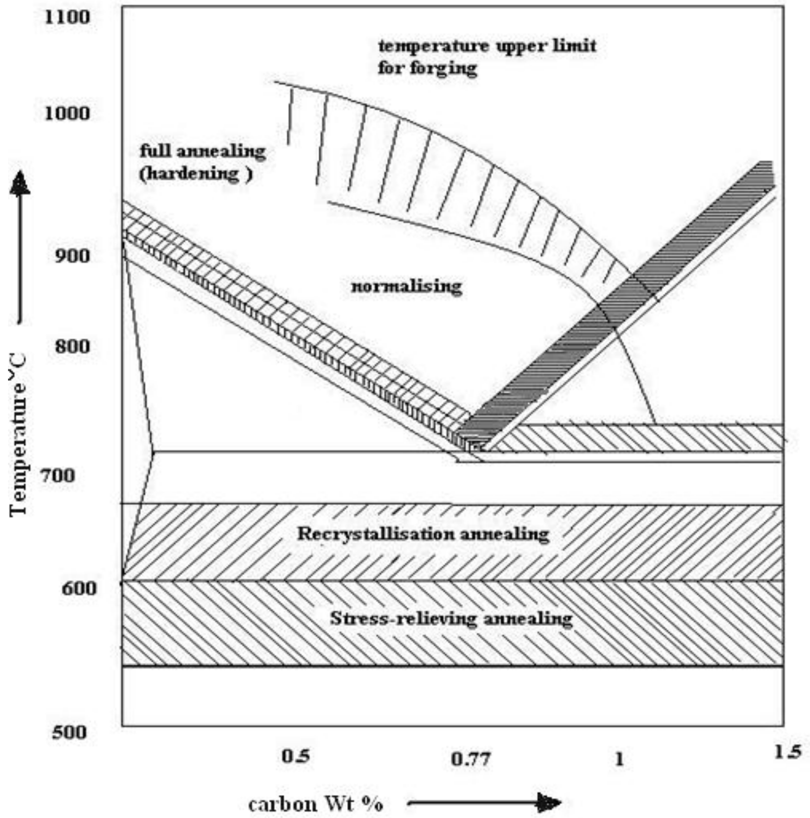



**Figure 3:**Ttemperature range fot heat treatment cycles on Fe-Fe$_3$C diagram [1].

The purpose of annealing may involve one or more of the following aims:
1. To soften the steel and to improve machinability.
2. To relieve internal stresses induced by some previous treatment (rolling, forging, uneven cooling).
3. To remove coarseness of grain.

The treatment is applied to forgings, cold-worked sheets and wire, and castings. The operation consists of:

a. heating the steel to a certain temperature,
b. "soaking" at this temperature for a time sufficient to allow the necessary changes to occur,
c. cooling at a predetermined rate

**4.7 Heat conduction in the workpice**

Thermal properties of materials not only depends on the temperature but ,in case of hardenable steel, also on the phases . For example, the raw material ,austenite ,ferrite/pearlite ,martensite and tempered martensite and bainite [2].

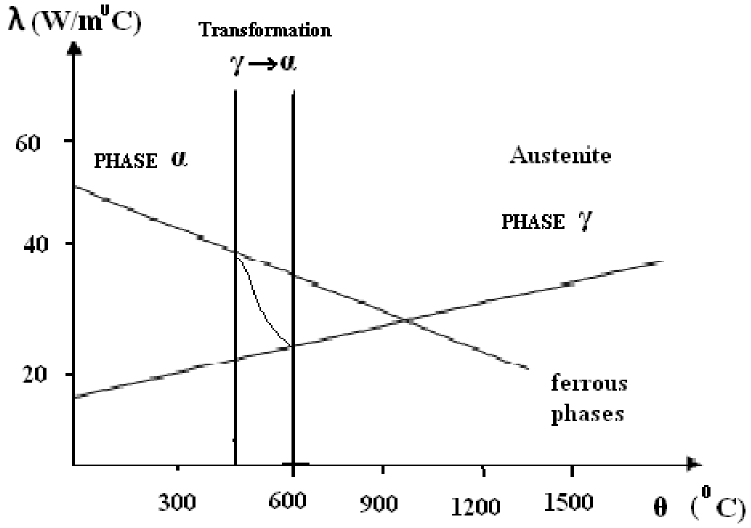
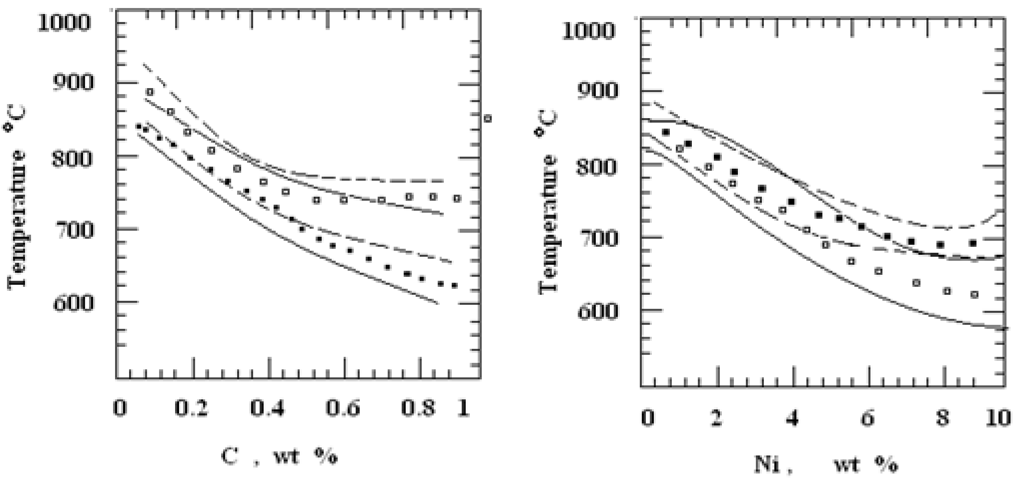



Fig 4 Thermal conductivity of face-centerede cubic (α phase) and body-cenerede cubic iron lattice ( γ phase )

Latent heat taken into consideration in case of microstructure transformations and melting /solidification. Latent heat influences the transient temperature field. Modeling of non-linear thermal boundary conditions such as convection, radiation and sometimes thermal contact, is important fir simulation.

**4.8 Effect of alloying elements on Ac1 and Ac3 Temperatures**

Nickel is an austenite stabiliser and judging from the phase diagram both $Ac_1$ and $Ac_3$ temperatures should decrease with increasing Nickel concentration .



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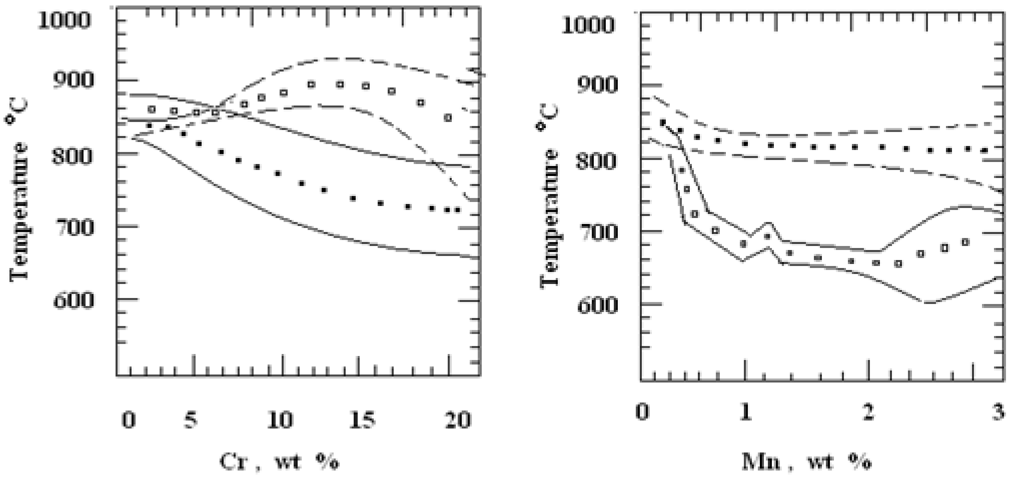


**Figure 5:** Effect of alloying element on $AC_1$ and $AC_3$ temperature [3,4].

## V. Grid And 2d Thermal Profile Of Ingot

*Heat transfer equation for solid :-*

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

*Boundry heat transfer by radiation and convention*

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

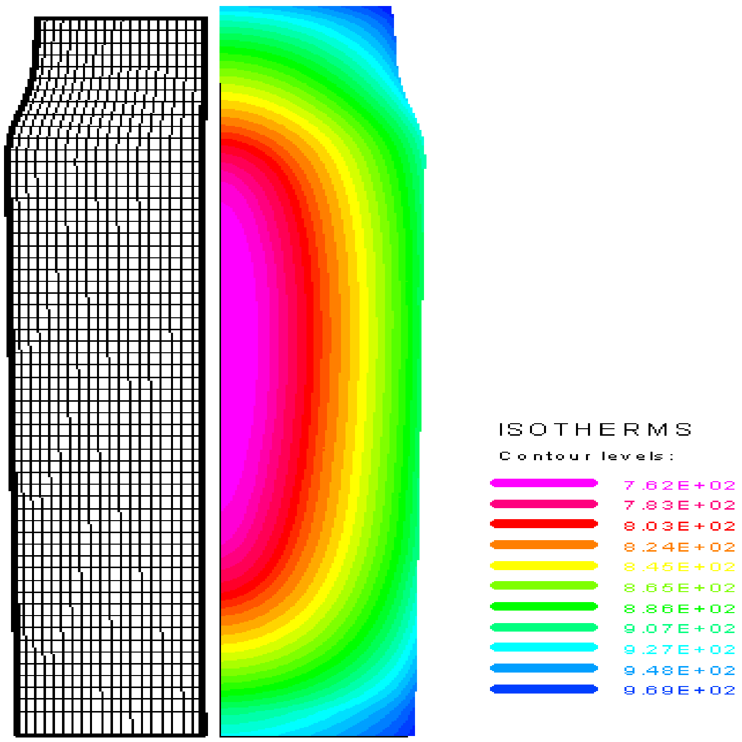


**Figure 6:** Grid and 2D thermal profile

## VI. System Design

The system is designed in such a way so that it can be compatible in working with a Fortran 6.5 DLL, reading .in files and show the final result in a graph. The process flow is shown in Figure 7 given below.

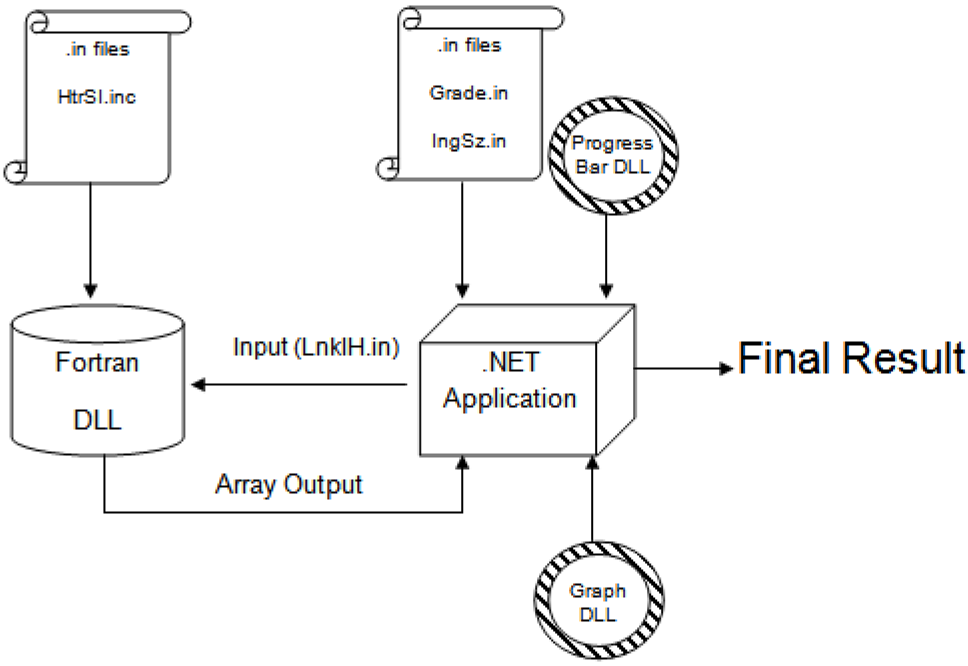


**Figure 7:** Software Architecture for the Slab reheating furnace.

## VII. Coding

There are mainly two parts in this application.
1. NET Application
2. Fortran Application

The .Net application part is coded in robust OPP (Object Oriented Programming) style. In there, all the necessary parts are coded in Public or Private functions and then those are called in the required places. The Fortran DLL is called in the .NET application by using one of the richest .NET feature InteropServices.

In the .Net application there is another .NET DLL used which is the Graph DLL. This DLL is added in the main application by adding that through reference. Then the Graph DLL is created as a User Control and added in this application. Then there are different public functions of this Graph DLL are being used to draw the graph. This User Contral then put in the main form and shows the graph for Furnace, Ingot inside and Outside temperatture Graphs from there the Optimized time can be observed.

The Fortran Programming part followed the conventional Procedureal Programming. The Fortran part reads input files and then it gets other required inputs from the .NET application through LnkIH.in files. Then it calculates the time required for homozanized heating and returns back mainly 3 arrayes with data which the .NET application captures and then send those to the Graph User Contral and it shows the graph.

## VIII. Software Grphical User Interface (GUI)

The graphical user interface for the software is shown in Figure 5. The GUI can be used for data entry by the user or the plant engineer, to get the optimized thermal treatment cycle for the slab.

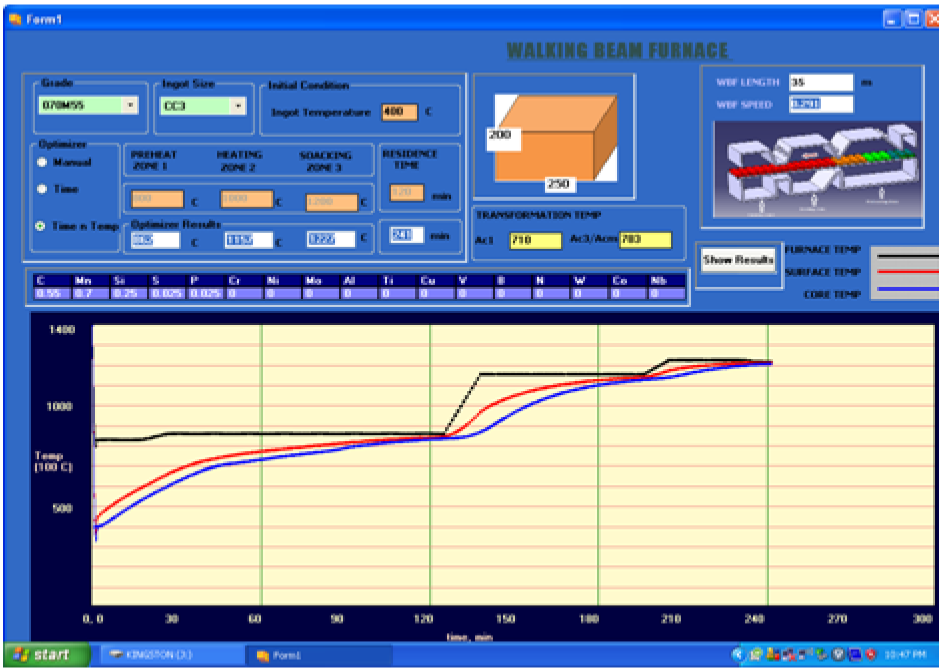


**Figure 8:** Graphical User Interface for the Slab or Ingot reheating in Walking beam furnace.

## IX. Result and Discussion

1) The variation of experimental Ts and $T_f$temperature as a function of heating rate is shown for three different morphologies of pearlite. These results suggest that both Ts and $T_f$increases with increasing heating rate.
2) As shown in figure for the large size ingot or ingot having low thermal conductivity, we used step heating so that the difference of temperature of surface and center of ingot is minimized in order to avoid crack format
3**)** If the temperature exceeds a certain value during heating then the microstructure starts to transform to austenite .The lattice changes from BCC to FCC , the specific volume is smaller and carbon from dissolved carbides dissolves in the austenitic structure .The start temperature and the degree of austenitizing depends upon the respective heating speed and austenizing temperature increases with increasing heating rate.

## X. Conclusion

This Project is to enhance the industrial process to an extent where the process can expect an error free, optimized, reliable and more scientific result.

This application can be used in the steel industry, and this can provide significant savings in the use of power and time for Ingot heating. Overall this application is a significant step towards Industrial automation.

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