To study heat transfer across cross-section of a sintering furnace for reducing ferrite rejections

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Abstract— The product quality of a soft ferrite after going through the sintering process in a continuous furnace depends on the temperature distribution, heat transfer, pressure conditions, oxygen content etc. among other factors. The heat given by the heaters placed at the top and bottom of the furnace may not allow a uniform temperature distribution across the cross-section of the furnace resulting in defects in some of the products due to over or under heating. This could be avoided by facilitating uniform distribution of heat across the tray carrying the product. The scope of this paper is to study the actual heat transfer process taking place in a furnace and to propose changes that can help in achieving uniform temperature distribution across the cross-section which can help in the reduction of the defects. It deals with studying the nature of rejections in ferrite bars which are used in a number of automobile applications. It mainly focuses on the unground ferrite bar rejections which usually takes place due to non-uniform shrinkage in the preheating and earlier heating zones (800 °C to 1100 °C). Simulation was carried out for temperature distribution and air flow patterns in the concerned region. The temperature results obtained from the simulation are in good agreement with the experimental data. Also it has been concluded that the unground rejections is mainly due to the temperature variation across the product tray which is causing non-uniform shrinkage. It was found that the ferrite bars on the inner side undergo more shrinkage as compared to the ones on the other side. This issue can be sorted by changing the design of the heater coil by increasing the number of coil turns in the region where more heating is required to facilitate uniform heating.

***Keywords*:**Ferrite bar, unground rejections, shrinkage defects, temperature distribution, heat transfer.

I. INTRODUCTION

Sintering process involves gradual heating and cooling of the product to attain required amount of hardness and properties. Often, the conditions under which sintering takes place help in developing a desired microstructure in the product which have an influence in its properties. Improper sintering conditions may cause a number of defects such as shrinkage defects, cracks, external and internal shining spots, bending etc. which leads to a large number of rejections. The reason for the rejections can be found out by through study of the heat transfer conditions in the furnace. Non-uniform heat transfer across the furnace even causes geometrical variations among products, increasing the amount of time andeffort for their solution. Thus, a study of the heat flow phenomena would help in obtaining uniform temperature distributions and ways in which the rejections can be reduced. This project aims to analyze the heat flow conditions in a soft ferrite sintering furnace and find ways in which the conditions can be changed to mitigate the problem of ferrite bar rejections. The concerned sintering furnace is 32 meterslong which is a continuous pusher type producing soft ferrites which have many applications in automobile industry. It is installed at Mahindra CIE, Bhosari Plant, Pune.

A lot of research has been done to study the heat transfer in furnaces. Amathematical model for gas flow and heat transfer in ladle furnace (LF) lid based on 3-D Navier–Stokes equations and k–ε two equation turbulent models as well as energy conservation equation ,in order to verify the reasonableness of off-gas pressure and wall temperature was developed by S. F. Zhang *et al*(2009).Dag Mortensen *et al*(2013), presented computer simulations of a directional crystallization furnace producing 100 kg ingots. Temperatures, fluid flow, stresses and deformations were calculated.M. Yang *et al* (2015), investigated numerically the forming mechanism of gas velocity and temperature deviations from the perspective of nonlinear flow characteristics in an ultra-supercritical utility boiler.Artur Blaszczuk, Wojciech Nowak (2015), conducted heat transfer experiments to evaluate the contributions of particle convection, gas convection, cluster convection and also radiation from cluster and dispersed phases to the overall heat transfer coefficient in a furnace chamber of a large-scale supercritical CFB reactor.MingYan Gu *et al*(2014), describeda simple method to study the slab heating process in a regenerative walking beamreheating furnace. E. Hachem *et al* (2013), presented a three-dimensional computational fluid-dynamics model for simulating complex industrial furnaces. The focus was set on the mathematical modeling of heated solids inside the furnace. A stabilized finite element method was used to numerically solve time-dependent, three-dimensional, conjugate heat transfer and turbulent fluid flows.In order to simulate the fluid–solid interaction, they proposed the immersed volume method combined with a direct anisotropic mesh adaptation process enhancing the interface representation.Jiin-Yuh Jang, Jun-BO Huang (2015), performed a two-dimensional mathematical heat transfer model for the prediction of the temperature history of steel slabs in order to obtain the optimal heating pattern of these slabs with minimum energy consumption in a walking-beam type reheating furnace.

Xuemin Liu *et al*(2015), investigated the effect of the pressure drop across the furnace on heat transfer inside large scale CFB boilers with 1-D CFB combustion model that was developed at Tsinghau University.Rene Prieler *et al*(2016), investigated a natural-gas fired walking hearth type furnace for the reheating of steel billets. A novel numerical approach was used to predict the gas phase combustion, heat transfer and transient heating characteristics of the billets in the furnace.Mauricio Carmona, Cristobal Cortes (2015), made detailed numerical simulations to estimate the thermal behavior of an aluminum holding furnace heated by a system of electrical resistances.

This project aims at reducing the unground rejections by studying the heat transfer process taking place in the concerned sintering furnace. It further focusses on suggesting ways to reduce these rejections from the conclusions arrived after the study.

II. METHODOLOGY

The methodology for this project is as follows:

1. To study the nature of the ferrite bar rejections and finalize the type of rejection that has to be focused.
2. Study the temperature distributions, and other conditions required to obtain proper sintered ferrite bars.
3. Analyze the heat flow process by CFD simulations.
4. Validate the simulation results with experimental results.
5. Implement ways in which the problem can be mitigated, first by simulation and then by experimentation by changing the furnace conditions.

III. EXPERIMENTATION

Experimentation for the study was carried out in two phases. First of all, it was necessary to identify the various causes of rejections and finalize the cause of rejection which has to be focused on which in this caseis ‘unground’ rejections. Second phase includes finding the cause of this rejections by studying the temperature and shrinkage variation.

3.1 Study of pattern of rejections

It has been found that an average of 11 % of various ferrite bars are being rejected. Although a total of 23 rejections are considered in cases of ferrite bars of which sintered chipping, firing crack, binder crack, white spot, pin holes, shining spots, unground, step are the major ones. The distribution of the major rejections causes is show in Fig. 1.

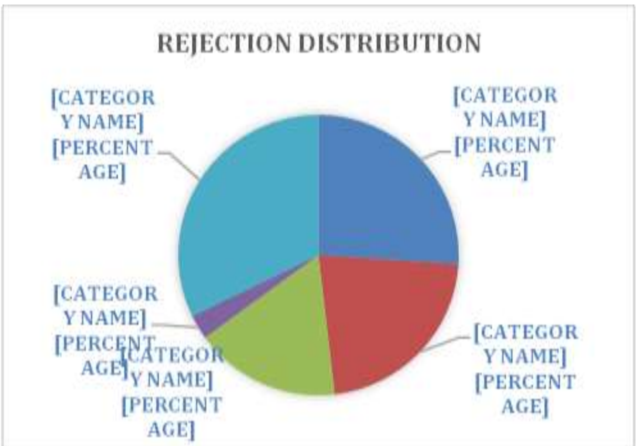

Fig. 1 Rejection distribution in ferrite bars

The experimentation was carried out by sending 10 trays each on A and B sides and then studying 10 samples from each tray. Out of the above rejections, unground rejections are caused due to non-uniform shrinkage in the sintering furnace. The cause of this rejection will help in obtaining uniform shrinkage which will in turn eliminate the entire grinding process of the ferrite bars thus saving a lot of time and money.

3.2 Study of temperature and length variation

The second phase included finding the cause of the unground rejections. Temperature variation cross a product tray may be one of the reason for non-uniform shrinkage. To study this, two trays with bottom, middle, additional and top decks are send through A and B side of the furnace, one on each side. For the measurements of temperatures at various positions, rings made of special material are placed at those positions which gives the maximum temperature at that position when the trays come out of the furnace. Fig. 2 shows the temperature variation across the product trays on A and B sides. It can be seen that the difference between the maximum and minimum temperature is more than 10 °C.

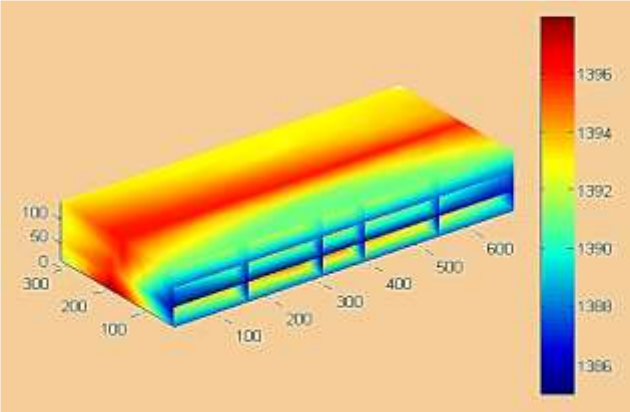

Fig. 2 Temperature variation across product trays

The next step is to study the length variation of the ferrite bars with respect to their positions. For this, a single tray with a single deck was passed through both A and B sides, each tray consisting of 42 ferrite bars. This bars were then inspected for length variation as the variation in width and thickness was almost negligible. Fig. 3 shows the length variation across the product trays on A and B side. It can be seen length of the ferrite bars is more on the outer side of the furnace as compared to the inner side. This means the ferrite bars on the inner side are shrinking more as compared to that present on the outer side. Thus, if uniform temperature distribution can be obtained, then the problem of unground rejections can be reduced.

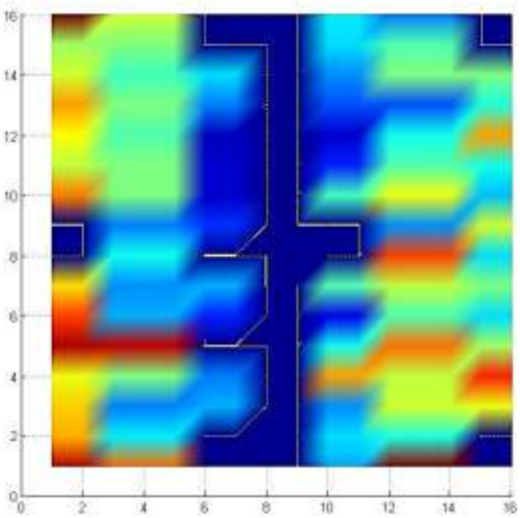

Fig. 3 Length variation across product tray

IV. SIMULATION

It has been found that the ungrounded rejections occur due to non-uniform shrinkage of the ferrite bars. This is due to the temperature variation across a product tray as shown earlier. Usually, the phenomenon of the shrinkage occurs in the pre-heating and earlier heating zone where temperatures are in the range of 800°C to 1100 °C. Hence the simulation is carried out for this particular region as shown in Fig. 4.

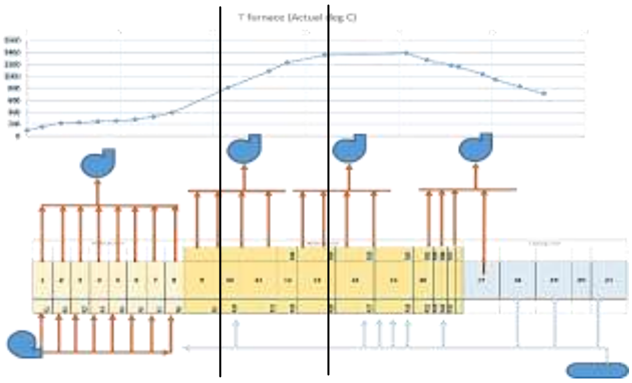

Fig. 4 Simulated length of the furnace

Fig. 5 shows the CATIA model of the concerned furnace length which has to be simulated.

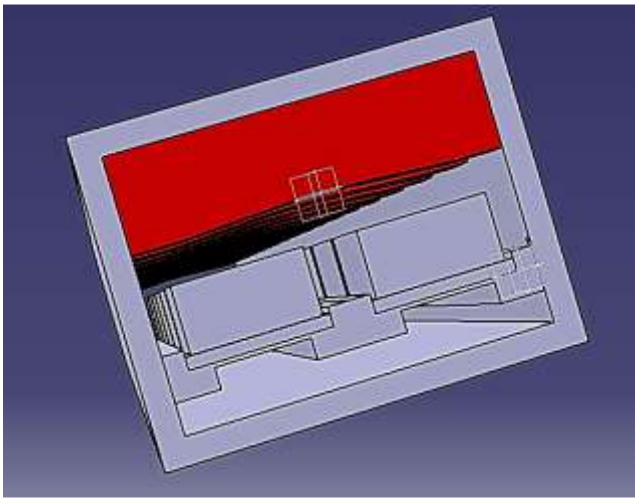

Fig. 5 CATIA model of the furnace length to be simulated

Fig. 6 gives us the air volume for which simulation has been carried out for temperature variation and air flow patterns.

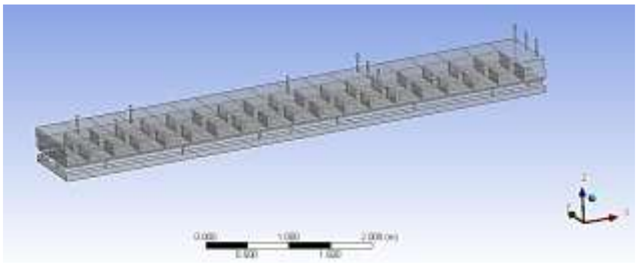

Fig. 6 Air volume for CFD simulation

Fig. 7 shows us the meshing which has been carried out in ICEM. The 4, 54,400 tetrahedral computational cells are adopted. For grid independence, the number of computational cells is varied from 343, 849 to 582, 453 in various steps. It is found that the results almost have no variation. So, the refinement of the grids does not produce any significant differences in results.

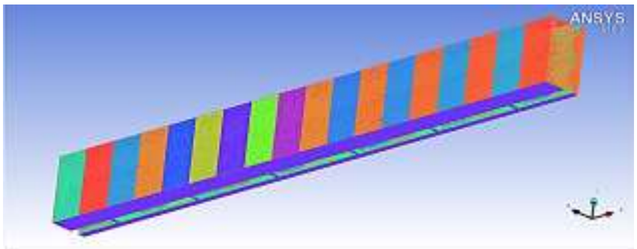

Fig. 7 Meshing in ICEM

The simulation was carried out in FLUENT 16.0. There are 18 heaters each at both top and bottom in the concerned region. Also there are nine outlet ports at the top at various positions and 2 inlet ports on A-side and bottom of the furnace length considered. The various boundary conditions applied are shown in Table 1.

Table 1 Applied Boundary conditions

Part name	Boundary condition
Top heaters (1-18)	Wall(Heat flux = 11457 W/m^2)
Bottom heaters (1-18)	Wall(Heat flux = 11457 W/m^2)
Side walls	Wall (Adiabatic)
Rail bottom	Wall (Adiabatic)
Rail top	Wall (Adiabatic)
Port Walls	Wall (Adiabatic)
Air slots	Wall (Adiabatic)
Product	Wall (Adiabatic)
In	Pressure-outlet (P_g=0 Pa and Temp = 300 K)
Out	Mass flow rate (m = 0.01771 kg/s and P_g = 30 Pa)
Outlet ports	Pressure-outlet (P_g=0 Pa)
Bottom inlet 1	Velocity- inlet (1 m/s)
Bottom inlet 2	Velocity- inlet (2 m/s)
Side inlet 1	Velocity- inlet (1 m/s)
Side inlet 2	Velocity- inlet (2 m/s)

The solution controls for the discretization of the domain include second order scheme for pressure, first order upwind scheme for turbulent kinetic energy and dissipation rate as well as SIMPLE for pressure- velocity coupling. The under-relaxation factors, which are significant parameters affecting the convergence of the numerical scheme, are set to 0.3 for pressure, 0.2 for the volume fraction, 0.2 for turbulence kinetic energy and its dissipation rate and 1.0 for the DO (Discrete Ordinates) radiation model. The convergence of the equations are monitored by the whole field residual of each variable, and the convergence criterion is selected 1×10^{-6} for energy and DO- intensity, 1×10^{-3} for other residuals.

V. RESULTS AND DISCUSSION

The best way of validating the simulated results is to compare the experimentally measured temperature values with that obtained from simulation. The temperature values are measured with the help of thermocouples which are already present at suitable distances along the furnace length for measuring and controlling the set temperatures inside the furnace. Fig. 8 shows the experimental and simulated values of the furnace domain considered. The average difference in the temperature values was found to be about 12 %.

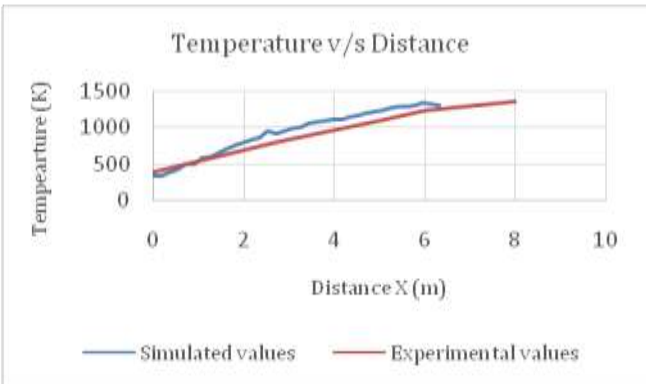

Fig. 8 Experimental and simulated values of temperature along the furnace length

Fig. 9 shows the temperature variation across furnace cross-section in air volume along the furnace domain considered.This agrees with the fact that non- uniform shrinkage is taking place which is causing unground rejections as concluded by experimentation too.

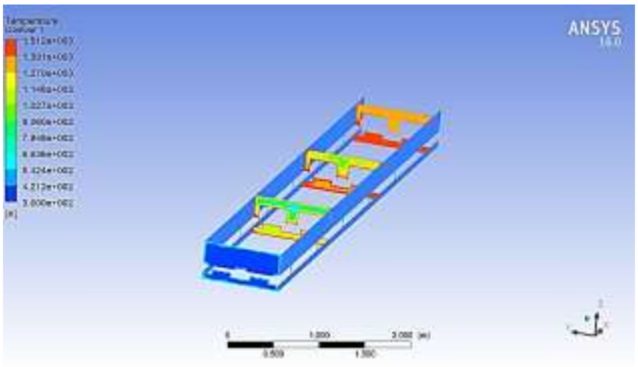

Fig. 9 Temperature variation across furnace cross-section along the furnace domain

Fig. 3 shows the air flow patterns across the furnace domain considered for the analysis.

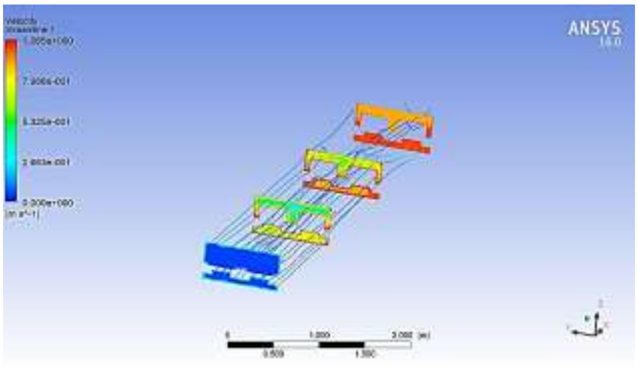

Fig. 10 Air flow patterns in the furnace domain

The variation in the temperature along the furnace cross-section is evident from Fig. 11, which shows the temperature variation on A-side, Middle and B-side of the furnace cross-section along the considered length of the furnace.

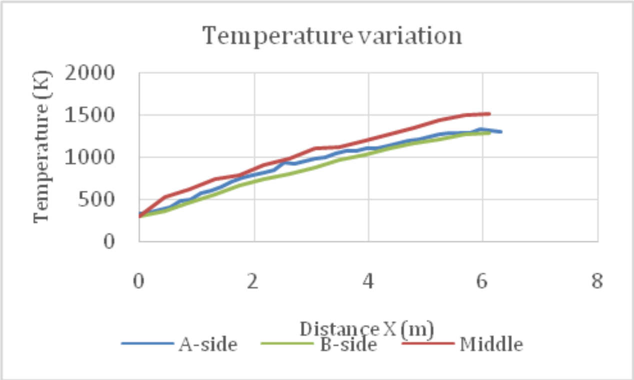

Fig. 11 Position-wise Temperature variation

Fig. 11 shows that the temperature at the side of the furnace cross-section is less as compared to that available in the middle region. This high temperature at the middle is causing more shrinkage in the middle as compared to the ferrite bars present at the sides. The temperature variation can also be attributed to the variation in the heat transfer coefficient. One of the way to reduce the temperature variation is to change the design of the heater. The fact that the inner side ferrite bars are undergoing more shrinkage as compared to the ones present on the outer side shows that the heater should be such that it can provide more heat in regions where temperature are less, that is on the outer sides of the furnace. This can be achieved by increasing the number of coil turns in those regions.

VI. CONCLUSIONS

Thus it can be seen that both experimentally and by CFD analysis, the main cause for the unground rejection is due to the temperature variation in the furnace cross-section. This can be reduced by ensuring proper temperature distribution by enabling proper heat transfer. One way of achieving this is to change the heater design by increasing the number of coil turns on the outer side of the furnace, which will provide more heat and thus ensure uniform shrinkage thus reducing the unground rejections.

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