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Application of New Technologies in Thermal Analysis and Simulation of Sand Casting Process to Reduce Rejection Rate

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Abstract

The foundry industry has been performing thermal analysis for many years but frequently they face complicated thermal defect such as shrinkage, porosity, blow holes. Rejection data analysis from foundries shows the significant evidences of its relation with thermal analysis which are contributing to PPM rejection. To overcome these problems, the process improvement using latest technologies available in casting is needed to reduce the rejection rate and improve yield. Analysis of defect has been studied by using Pareto chart to find out the root cause and put countermeasure for defective component due to incorrect casting material properties. Solidification of alloy, cooling curve analysis was studied by means of thermal analysis to adjust and monitor the chemical composition of casting alloys. MAGMA simulation software has been used to reduce the defects like increase in the carbon percentage, porosity etc. and also suggested the modification of gating system and results shows temperature distribution, porosity, filling time, nodule count and hardness in the casting process. The rejection percentage and the PPM have been reduced after modification of gating system. Mechanical properties such as hardness, microstructure, tensile test of casting product have been validated. So this project aims to suggest the process improvement using thermal analysis implementation in current set up which will result in increased quality of parts and reduction of PPM and also focuses on efficient use of simulation software analysis which are then compared with the experimental reading of temperature, time and found to be good agreement.

Keywords: Shrinkage, Blow hole, Thermal technology in casting, Process simulation.

1. Introduction

Thermal analysis shows real behavior of solidification of iron. Combine thermal analysis and chemical analysis which gives more accurate and precise corrections of the base iron. There are various defects occur in casting, some of the defect can bear or else they be eliminate. Foundry engineer is to make an optimized geometric casting design and choose correct process parameter that eliminate porosity enlargement. There is a need for some predict method which will forecast the location and size of the porosity.It also includes various numerical methods for casting solidification simulation. Also there are different methods for location based forecast of shrinkage porosity. Different Thermal analysis method are used in the everyday production of cast iron as well as in monitoring the melting of aluminum and steel alloy thermal analysis also called as cooling curve analysis can be provide a more complete imminent in the dynamic change occurring upon melting and during melt treatment of cast iron. Differential thermal analysis without sample can predict not only chemistry of the melt but also the nucleation prospective and shrinkage porosity. Process improvement using latest technologies available in casting to reduce rejection rate and improve yield.latest technologies available in the area of casting and suggest the appropriate ones for implementation in current set up to improve processes which will result in increased quality of parts and reduction of PPM. Simulation technique is used for solidification process for identification of casting defect. Casting simulation using magma software has been carried out. It is observed that the Temperature variation is a very important fact which affects the mechanical property of the casting.

2. Objectives

- Study of part wise, defect wise and cavity wise rejection analysis.
- To determine root cause and put countermeasure for defective component due to incorrect casting material properties.
- Study of latest thermal analysis technologies available in the area of casting and suggests its implementation in current set up to improve processes and critical defects areas which are analyzed using Pareto charts to increase the quality of casting parts.
- Use Magma simulation for identification of the defect and for the further improvement in the product.
- Experimental investigation of casting product such as mechanical properties (tensile test, hardness, microstructure).
- Reduce the PPM percentage.

3.Scope

- Finding out modern thermal technologies available in casting.
- Study of Material and resource flow.

- Suggest appropriate up gradation considering current set up.
- Maximum utilization of available system.

4. Literature

M. Stefanescu[1] et., al. explained on the extraordinary technique used in casting foundry industry and thermal analysis of casting in which cooling curve analysis has been studied. Thermal analysis is used to identify with the solidification changes occur due to compositional variation such as CE, Mg, and Si addition. Dynamic changes take place because of melting and melt treatment of casting alloy, and also the DTA study is about temperature, time, temperature difference.

J. Talamantes-Silvabet., al. [2] explained on the solidification of cast iron through thermal analysis. The study was about effect of silicon on temperature which will indirectly affect the mechanical properties of the casting product such as microstructure characteristics. Cooling curve was recorded with an inserted thermocouple and registered with computer driven data. To decide the configuration of pre-eutectic dendrites, it is found that the silicon influence the Temperature.

C M Choudhari, et., al. [3], explained on the solidification process in sand casting and explained regarding heat flow within the casting as well as from the casting to mould. ANSYS software is used to obtain thermal distribution inside the casting which is transient thermal analysis. And also did the optimization of riser and the gating system by the simulation software to eliminate the defect and increase the efficiency.

F. Berto [4]explained on the effect of in-mould inoculants on the microstructure and fatigue performance of ductile cast iron. Metallurgical analysis has been carried out and important parameters that affect mechanical properties such as nodule count, modularity were measured. Also studied the investigation of fraction surface of the component in order to identify the cracks. In-mould inoculation strongly influences the alloy microstructure.

Uday A. Dabade[5]explained the design of experimental and computer assist casting and studied Simulation is combining to investigate the defect in sand casting. Process parameters are considering moisture content, strength, permeability of sand and mould hardness. Taguchi method is for the experimental use and analysis carried out by using ANOVA. The software (ANOVA) indicate the parameter which are affecting the casting and casting defect and the percentage of analysis. New gating system was introduced for the shrinkage porosity analysis. with the new gating system shrinkage is reduced by 15% and yield by 5%.

Harshil Bhatta[6] studiedthe simulationsolidification of cast iron and optimization of feeding system and feeding and the gating system in the casting are very significant for the better quality of the casting. Designs involve the decision about exact number of riser and location of riser to be used. Simulation technique used to analyze the chance of defect at the locations for the existing and new feeding system. Feeding system is modified and simulation results were satisfactory. This reduces the cost of increasing the method for overall cost of developing the method for latest casing by minimizing time and labor.

Dr.B.Ravi [7] had studied the defects in casting and for Zero defect castings can be produced by collaborative design of part, tooling, methods and process parameters using a user-friendly system.The methods designincludes semi-automatic design and 3D modeling of feeding and gating system, followed by mold filling andcasting solidification, to predict quality issues more accurately.

Radomila Konecna et., al. [8] had done the investigation on surface conditions and the fatigue behavior of nodular cast iron. Analysis of the fatigue behavior of pearlite/ferrite NCI specimens having different surface conditions,and observed that fine-ground surface achieve the best fatigue performance, with as-cast and shot blast surfaces associated to reduced strength.

Andrea Zonato et., al. [9] explained the new approach to process control in cast iron foundries through thermal analysis.The modern thermal analysis systems, like for example ITACA meltDeck and ITACA8, can generate an enormous contribution, allowing to reduce and manage the variance in the melting shop.

Future expectations to reduce shrinkage rejection from 2.1% to 0.5 % after effective implementation of thermal analysis. Improvement from 2.1% to 0.5% has been referred from the some of the live examples of foundries which has implemented thermal analysis; detail testimony has been given in research report.
FonderieGlisenti (Italy), Foundry specializes in the production of castings of high and medium series, small and medium size (upto 70 kg) in ductile iron. The melting shop consists of 5 induction melting furnaces. On some castings, this heavy control of the base and final iron using thermal analysis technology has allowed us to reduce the porosity, returning within the parameters defined by the client.

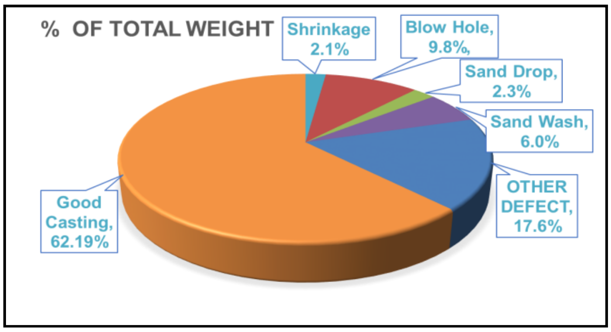

Fig.1 Percentage of total weight

5. Analysis of Defect-

Pareto analysis is the technique used to depict the cause and effects. Ituses the Pareto principle(also known as 80/20).on the X-axis it represent defect and PPM value on the Y-axis.

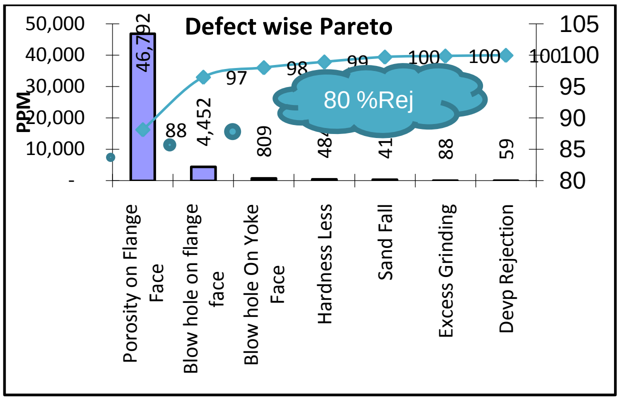

Fig.2 Defect wise Pareto analysis (Porosity)

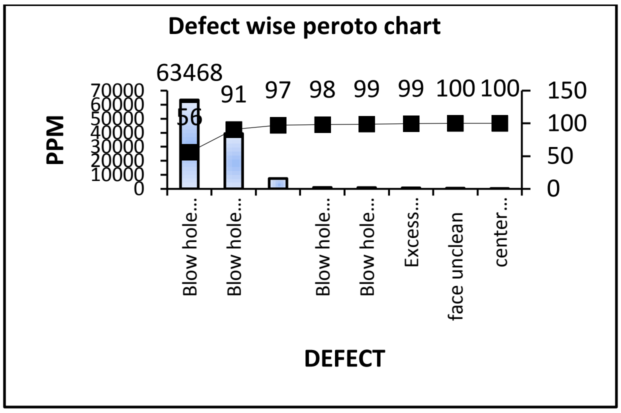

Fig.3 Defect wise Pareto analysis (Blow hole)

From Fig1 and Fig2 it shows the defect analysis of casting product, by Pareto chart. By using 80/20 rule of Pareto chart shrinkage defect and blow are occur more frequently and it has high rejection quantity. It is observed that there is 80% rejection of shrinkage defect due to improper mixing of charge. Sousing this technique we could identify the defect and action plan will be implemented.

5.1 Root and Cause analysis of defects

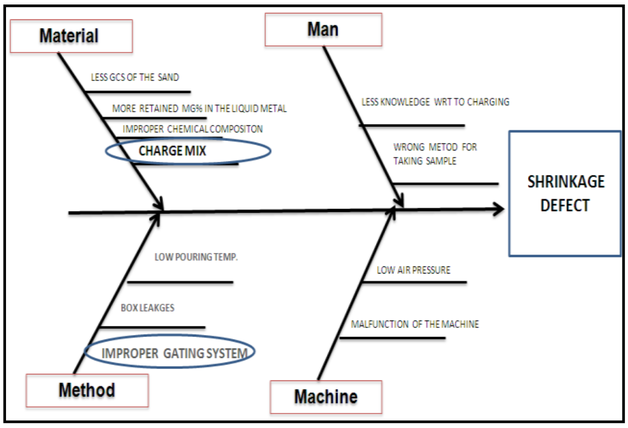

Fig.4 Ishikawa diagram (Root and cause of shrinkage)

From Fig.3 the entiredefect is due to material and the method used in casting. This leads to loss of productivity. Following are some remedies are suggested for minimization of losses.

- Shrinkage-Gating modified bottom pouring provided to avoid shrinkage in product.Gating modified, single riser made double riser to avoid shrinkage.
- Blow hole-Gating modification i.e. vents provided to avoid blow hole on product face.
- Slag-Gating modification in gate andEnd risers modified to avoid box leakage."V"groove provided to match plate to avoid leakage.
- Others- ladle preparation:-Pre heat the ladle to cherry red colour (700^0 C)FE-SI-MG maintained to 1.1% & ladle cleanliness prior to addition of FE-SI-MG, and to maintain shrinkage factor 3.9%Maintain tapping temperature 1570^{0}C-1590^{0}C, sand parameter to maintain:-Compatibility 38-42.
- Low carbon equivalent.
- Lack of fluidity.
- Metal turbulence and slow pouring of molten metal.

Defect Observation-

Fig.5 Identification of Defect

From Fig.4 it is observed that the shrinkage porosity is always in the form of feeding neck. Rejection is more due to shrinkage porosity.

6. Thermal Analysis Implementation

Increasing customer requirements because of vicious competition in the market and to cut the cost of poor quality, it is time to improve the current suppliers with the latest technologies to meet inflexible technical requirements set by OEMs. Current processes and machines are not aligned with the current technical development so it resulted in higher rejection rate. To reduce the PPM rejection and improve the processes, this project has been undertaken.

6.1 Cored wire technology

It consists of several individual systems that can be integrated individual system works independently as shown in Fig.5.
Control and monitor the process, generally with a high degree of automation.
Central Control Unit

- Control base iron by using advanced SG iron thermal analysis.
- Combine thermal analysis & chemical analysis which gives more accurate and precise corrections of the base iron.
- Receives real time feedback from the pouring lines with trends of metallurgical defects & trends of pouring tempt.

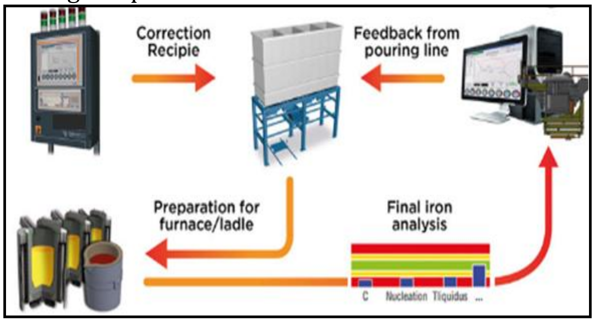

Fig.6 Cored Technology Process

This technology designed for automatic corrections of the base iron and it dispenses corrections without operator involvement with high precision and speed.

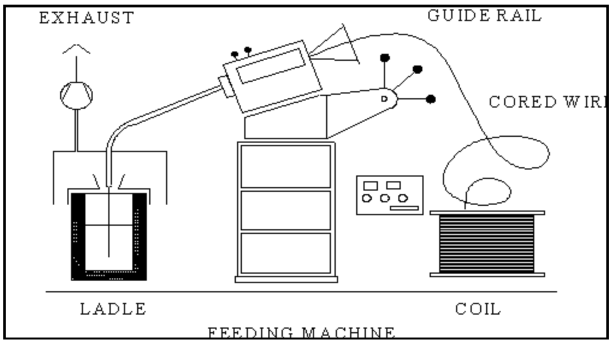

Fig.7 Schematic of cored wire

Customizable cored wire feeding system for Mg treatment and inoculation and dynamic approach can be automated by CWTC and reduces fluctuations in the final iron and in the castings as shown in Fig.6.
Control parameter: wt% Mg, target wt% Mg, current weight in the ladle, wt% Si in base iron treatment temperature.
Stream inoculation unit-
Introduce an inoculation rate as a function of the nucleation status of the iron, stream with a brushless motor with high precision that makes it possible to rotate the outlet pipe in position and uses a variable flow rate in function of the pouring time to ensure the inoculation is consistent and traceable.
The process of dynamic control is to measure solidification behavior and feedback control action can be determined and then implemented before the castings are poured to improve consistency and cost effectiveness.

Advantages of thermal technologies-
- Improved product quality.
- Less remelting and refinishing.
- Shortened lead time & increased production.
- First Time Right.
- Metallurgical property prediction.
- Solve the problems.
- Reduce the use of harmful materials in the progress.
- Less energy consumption per casting can achievable.

7.Simulation of Casting Product

The use of MAGMA software for casting simulation, the overall production process can take benefits from effortless model generation, part optimization during development, optimization of the casting process at An early stage, reduction of scrap, optimization of cycle times.
There are different Steps involved in simulation of given casting in magma software.
- Cad model (import Stl-file).
- Pre-processor (materials and geometries (domains) were easily created).
- Meshing (mesh generators mesh it automatically)
- Parameters (Mold material, initial temperatures and filling definition).
- Post-processor (mold filling analysis, temperature distribution, velocity, fraction of solid, porosity).
- Analysis.
- Decision.

When molten metal is poured into a mould, the fluid flowsthrough runners and gates and then fills the casting cavity.This is governed by the conservation equations of massand momentum viz., incompressible Navier-Stokesequations:

1. Conservation of mass-

$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho V) = 0$$

2. Conservation of momentum-

$$\frac{\partial (\rho V)}{\partial t} + \nabla \cdot (\rho V V - \mu \nabla V) + \nabla P = B + S_\vartheta$$

3. The energy equation for heat transfer process

$$\rho C_p \frac{\partial T}{\partial t} = \frac{\partial}{\partial x}\left\{k\frac{\partial T}{\partial x}\right\} + \frac{\partial}{\partial y}\left\{k\frac{\partial T}{\partial y}\right\} + \frac{\partial}{\partial z}\left\{k\frac{\partial T}{\partial z}\right\} + \dot{Q}$$

Boundary conditions-
Iron composition-
- carbon-3.5-3.75%
- silicon-2.50-2.80%
- Manganese-0.4-0.7%

Initial Temperature-1400-1500^{0}C
Filling time-8-10 sec

Post processing Results:

7.1 Temperature gradient

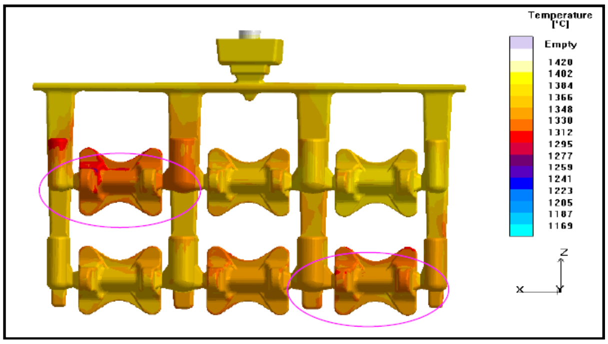

Fig.8 Temperature Gradient

It has been observed from Fig.8 that temperature drop at the highlighted area with red circles. Recorded temperature is 1300^{0}C to 1350^{0}C at those areas. Notice here for temperature gradient difference while filling which may leads to pin holes and cold shut or blowholes depending on the initial temperature. During filling temperature should not fall below liquids temperature.

7.2 Velocity magnitude

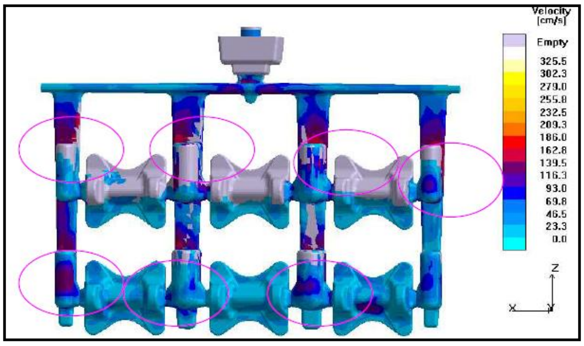

Fig.9 filling velocity magnitude

From Fig.9Recorded velocity at highlighted areas is above 180cm/s. excessive metal flow velocities will lead to air. Entrapment and mould/core erosion which as shown hitting continuously at marked areas causes to mould erosion, turbulences and sand inclusion casting quality problems.

7.3 Gas porosity
From Fig.10 it is observed that porosity location at the face.

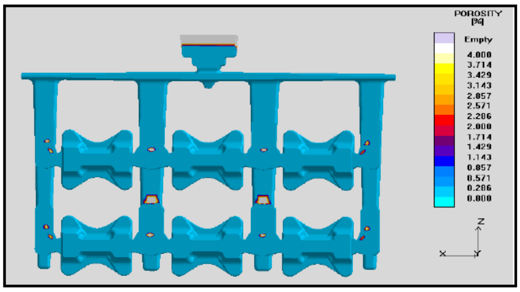

Fig.10 Porosity (micro porosity)

7.4Temperaturegradient (old gating)

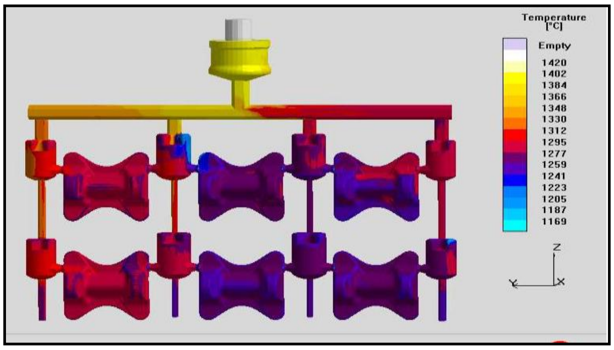

Fig.11 filling temperature gradient

In this tooling simulation temperature drop at the highlighted area with blue circles as shown in fig.11 And there recorded temperature is 1240^0 C to 1270° C at those areas.

7.5 Velocity magnitude

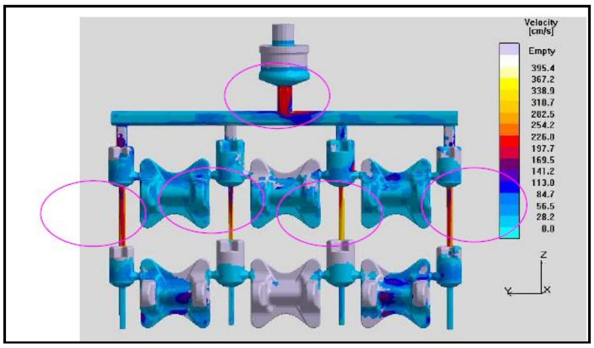

Fig.12 filling velocity magnitude

From Fig.12 recorded velocity at highlighted areas is above 250cm/s, recommended velocity is 100 to 150cm/sec for smooth gradual bottom up filling which is recommended.

7.6 Gas porosity (old gating)
From Fig.13 it is observed that more porosity location at the face of old gating.

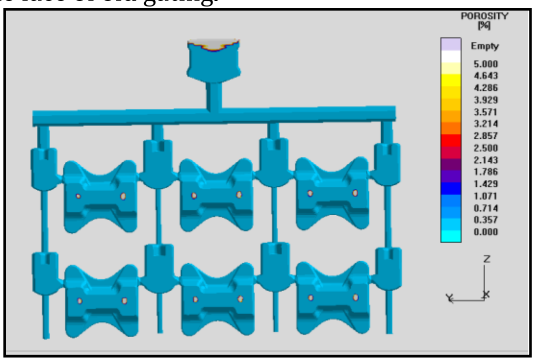

Fig.13 Porosity (micro porosity)

8.Experimental Procedure-

8.1 Sand preparation and molding

Sand is packed in sand mould box to made cope and drag. The following are the green sand mixture with property-
Silica sand of AFS grain fineness number: 60 to 75
Clay content: 13 to 16%

Moisture content: 3.6 to 4%
Permeability: 65 to 120
Compatibility-36 to 40

8.2 Pattern making

Pattern resembles the real casting to generate cavity inside the mould.

Fig.14 Pattern

8.3Melting and Pouring

The furnace is used for melting of ductile cast iron. It is the addition of small percentage of amount to molten iron. Inoculation is used to add in molten iron to increase the mechanical properties of the cast iron.The molten metal pouring in ladle. The temperature range of 1390˚c to 1420˚c depend on composition of the material.

Fig.15 Manual Pouring

8.4 Shot blasting and cleaning of casting

It is used to removal of sand and excess metal from the casting and then casting is separated from the moldings and after it has solidification and transfer to the cleaning department.
8.5 Bunch photos
Fig.16 shows the bunch photos after experimental investigation.

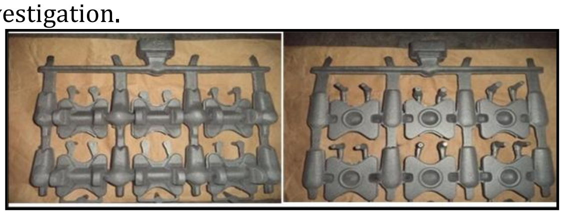

Fig.16 Bunch after Trail
8.6 Experimental details

Table -1 Experimental trail

	Action	Remark
1	Risering fleering to be increased by 20mm near neck on middle four riser &10 mm on side four risers.	We have produced 5nos boxes and send ok castings (244 No) for machining on. Internal rejection observed 16.37%
2	Out of 8 ingate side 4 ingate to be removed.	We have produced 5 no's boxes and send ok castings (14 no's) for machining on .The pouring time observed 13-14 sec as against 9-10 sec.Internal rejection observed 12.5%
3	Both c% increased from 3.75 to 3.85%	Rejection percentage reduce to 3.8%
4	Gating modified so to reduce shrinkage rejection	16 out of 114 parts rejected, the percentage of rejection is 14%
5	New metallic pattern made & gating done as per simulation done using magna software	29 no's out of 2000 were rejected, and percentage of rejection reduces to 1.5%
6	1.one box water cooled in hot condition	1.Microstructure observed pearlitic matrix with carbides.
7	2.second air cooled	2.Microstructure observed perlite matrix without carbide

New Parting Line-

New parting line is introduced as shown in Fig.17.to reduce the rejection of shrinkage defect and blow holes on the casting product. Basic reason to change parting is riser moving towards the high section thickness for feeding purpose.
This trial gives improving trend from 25-30 % to 8-9 %.

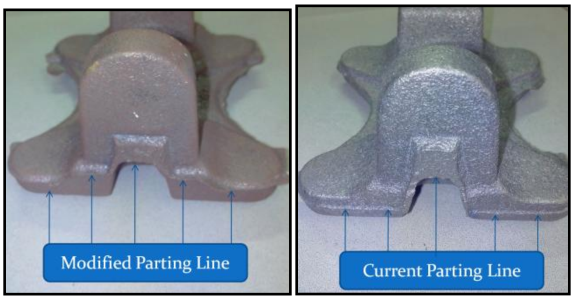

Fig.17 Parting Line Modification

9. Results and Discussion

1. Hardness test: Rockwell hardness testing machine is used for hardness testing of ductile cast iron casting using 3000kg test force and 10mm diameter carbide ball.And observed the value 269-285BHN.

2.The tensile universal machine used for the test the applied tensile load is recorded for the calculation of stress and strain. and the test result are shown in table 2.and graph shown in Fig 18 represent elongation properties.

Table.2 Mechanical Test Result

Parameters	Specified	Actual
1) U.T.S N/mm^2	MIN.690 N/mm2	868.18
2) Y.S N/mm^2	MIN.483 N/mm2	656.62
3) % Elongation	MIN.3.0%	5.28
4)Hardness(BHN)	235 - 293	269-285

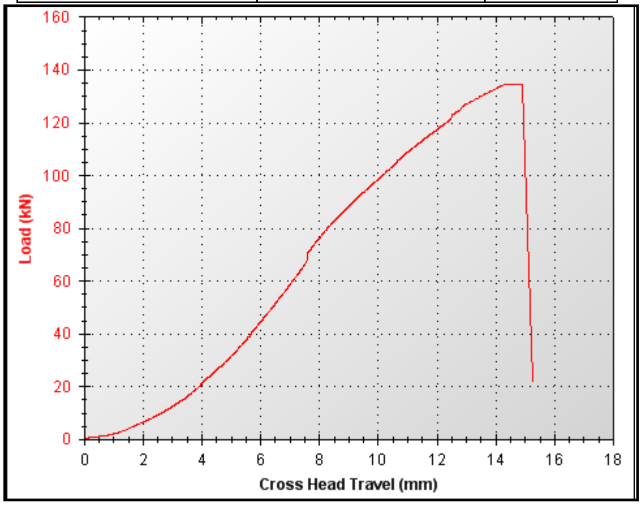

Fig.18 Tensile Test

3. Microstructure: Microstructure shall be of randomly and uniformly dispersed graphite nodules surrounded by ferrite in a fine pearlitic matrix. No detrimental primary or cell boundary carbides are permitted. Standard results required for microstructure are shown in Table.2

Table.2 Microstructure Results

Parameters	Specified	Actual
1) % Nodularity	80 TO 100	90
2) Nodule Count	100 TO 200	350
3) % Pearlite	75 TO 100	95%
4) %Ferrite	0 TO 25	5%

1. Water cooled in hot condition and Air cooled

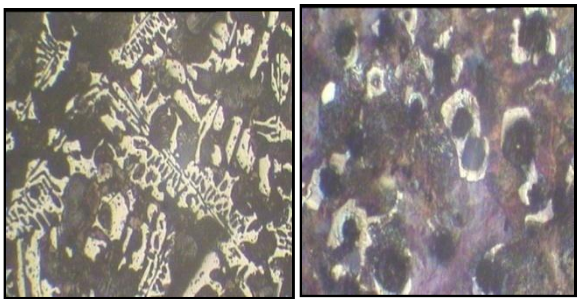

Fig.19 Water Cooled and Air Cooled Structure

4. PPM Trend

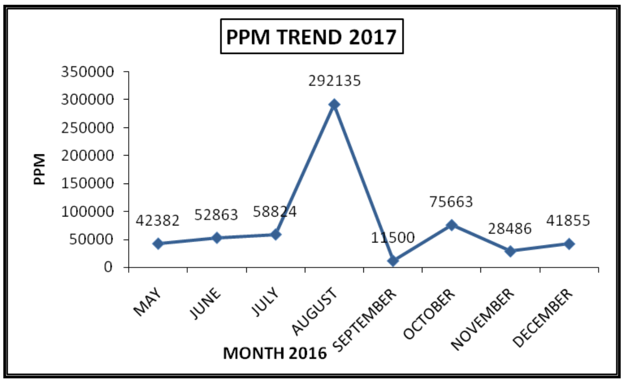

Fig.20PPM Trend (2016)

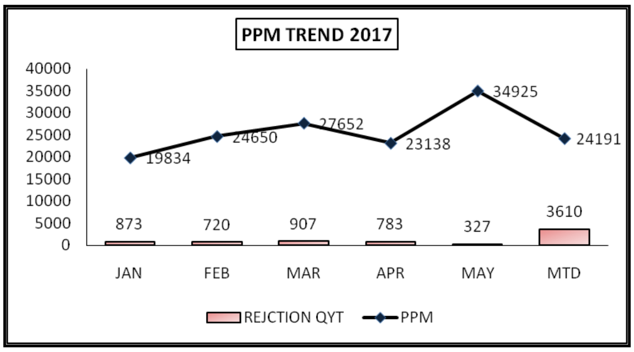

Fig.21PPM Trend (2017)

From Fig.20 and Fig.21 it is observed that PPM trend is decreasing. After the gating system change, so the rejection of this product is now reduced.

10. Conclusion

Thermal analysis is a good technique to control carbides, shrinkage and micro-shrinkage formation.Thermal analysis gives real behavior of casting solidification. Which is used to improve product quality ,less melting and refinishing, shorten the lead time and increase the production and also useful for metallurgical property prediction. Simulation technique is used for solidification process for identification of casting defect. Casting simulation using MAGMA software has been carried out. It is observed that the temperature variation is a very important fact which affects the mechanical property of the casting. and with increasing the percentage of carbon it observed that defect has been reduced.

Modification of gating and analysis of new gating system by MAGMA software and experimental trial conducted results in less rejection percentage in casting product. Reduce the manufacturing risks by considering the metallurgical treatment and composition of the melt.Microstructure observed predominantly pearlitic matrix without carbide when poured without post inoculation, poured with inoculation at low temperature and poured without inoculation at low temperature.After modification of gating PPM percentage is reduced and also the productivity of casting is increased.

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