Analysis on inoculation to improve the properties of material and cooling rate

G Purushotham Gowda[1], Abhishek S[2], Srinivas S[3],

1,2-Student, School of Mechanical Engineering, REVA University, Bengaluru, Karnataka, India
3-Assistant Professor, School of Mechanical Engineering, REVA University, Bengaluru, Karnataka, India

ABSTRACT

The Components used in In-stream inoculation are dispensing unit, hopper, slot, helical screw and dispenser. Earlier to our idea the Tensile strength was found to be 380MPa, Hardness strength of 120-150BHN, 0.2% Proof strength was 280MPa and %Elongation was found to be 6%. In order to improve this In-stream inoculation we designed a Powder dispensing unit having a dimension of (102x40x253) in mm. Which consists of a load cell, strain rosette, hopper, helical screw conveyor and mixing chamber by satisfying industrial standards. By simulating this we achieved the Tensile strength of 480MPa, Hardness strength of 160-210BHN, 0.2% Proof strength of 310MPa, %Elongation of 10%.

1. Introduction

The aim is to improve the properties of material by using inoculants. Inoculation is a process of introducing small particles called inoculants into molten metal to improve its solidification and resulting microstructure, particularly in cast iron. This process helps to control the formation of graphite, improves the mechanical properties of the casting and machinability. Types of Inoculation method used: 1) Ladle inoculation in this technique the inoculant is added directly to the molten metal in the treatment ladle before pouring into the mold. 2) In-stream inoculation is a method of adding an inoculant to molten metal as its being poured into a mould. Steps involved in Inoculation: Choosing the inoculant, Preheating, Ladle Inoculation, In-stream Inoculation, Monitoring & adjustment. Types of Inoculant used: 1) Ferro-Silicon inoculation this is the most prevalent type & inoculation used in foundries. Ferro - Silicon is incorporated into the molten to enhance the formation, Graphite & enhance the microstructure of casting. 2) Rare Earth inoculation in this method of inoculation, rare earth element like Ferro Silico Magnesium, Ferro Magnesium is added to the molten metal, rare earth inoculation is utilized to enhance microstructure & mechanical properties of the casting. Benefits of Inoculation: 1) Improved Mechanical Properties: By Controlling the Graphite structure, Inoculation Enhance tensile strength, yield strength & Impact resistance of the Casting. 2) Reduced Chill tendency: Inoculation prevents the development of hard. 3) Better Machinability: A properly inoculated casting is simpler to machine due to the improved Graphite distribution.

2. Literature Review

M. Bedel et al. [1] presented a paper on "A Model Study of the Impact of the Transport of Inoculant Particles on Microstructure Formation during Solidification." This paper investigates how the movement of inoculant particles during casting affects the grain structure in aluminum alloys. Using a multi scale two phase model, they show that convective transport of inoculant particles during solidification significantly influences the final microstructure. Their simulations, performed on Al–22 wt. %Cu alloys, demonstrate that moving inoculant particles lead to finer grain size of 0.003–0.004 mm and increased microstructural heterogeneity (like Fe-C-Si alloys), while grain motion helps to homogenize the structure achieves through high diffusion and slow cooling. The study highlights the critical importance of considering both inoculants Carbon (C): ~3.2–3.6 wt%, Silicon (Si): ~2.0–2.8 wt%, Iron (Fe): balance and grain transport in order to accurately predict grain size of 0.003–0.004 mm distribution and improve casting quality.

N. Shashikantha et al. [2] presented a paper on “Effect of Inoculants on Grey Cast Iron.” This paper studies the influence of various inoculants like calcium silicide, ferrosilicon, aluminum silicon, and silicon carbide. Calcium silicide was found to be the good inoculant, raising the eutectic cell number by 8–10 times and the tensile strength by about 40%. It also changed the graphite structure to A-type with 4–6 flake sizes. Ferrosilicon also enhanced the eutectic cell number by 5–6 times and tensile strength by 25–30%, yielding A-type graphite with comparable flake sizes. Aluminum silicon had a lesser impact, raising the eutectic cell number by 3–4 times and tensile strength by 15%, but had little effect on graphite structure. Silicon carbide, on the other hand, had no impact on the number of eutectic cells or modification of graphite and recorded a lower tensile strength than the other inoculants. The research went on to establish that the incorporation of calcium silicide and ferrosilicon minimized the depth of chill to almost zero, which is better solidification control. While hardness values were not significantly different across the inoculants, the findings emphasize that calcium silicide is the best inoculant for enhancing both the microstructure and mechanical properties of grey cast iron, while silicon carbide was ineffective.

Imre Kiss [3] presented a paper on "Constructive Improvements in the In-Ladle Treatments a Comparative Industrial Study." This paper discusses how constructive improvements in ladle treatment methods can enhance the production of ductile (nodular graphite) cast iron. The study explores various in-ladle techniques such as the Trigger method (with 1, 2, and 4 covered pockets) and Tundish-Cover methods to improve magnesium (Mg) assimilation during nodularization. By introducing multi-pocket ladles and covering the ladle during treatment, the magnesium recovery is increased significantly, leading to better homogeneity of the cast iron. The experiments, performed using Fe-Si-Mg and Nodulin type pre-alloys at a treatment temperature of 1480°C, showed that nodulizer consumption can be reduced while improving the mechanical properties of the final casting. The paper highlights that the use of improved ladle construction and careful control of nodulizing treatments can optimize casting quality, enhance production efficiency, and result in cost savings for foundries.

Imre Kiss [4] presented a paper on “Comparative Study on the In-Ladle Treatment Techniques for Nodulizing the Iron’s Graphite.” This paper examines different in ladle treatment methods used for nodulizing graphite in ductile iron production. It compares techniques like plunging, open ladle, sandwich, trigger, and tundish-cover methods based on magnesium assimilation efficiency, environmental impact, and cost. The study highlights that the tundish-cover method achieves the highest magnesium recovery (up to 58%) with reduced smoke emissions, making it the most efficient and environmentally friendly. The research also discusses the role of magnesium-ferrosilicon alloys and light pre-alloys like Nodulin 5.8 in achieving optimal graphite nodulization. Overall, the study provides insights into selecting the best nodulizing method to improve ductile iron quality while maintaining economical and eco-friendly operations.

Doru M. Stefanescu et al [5] presented a paper on “Recent Developments in Understanding Nucleation and Crystallization of Spheroidal Graphite in Iron- Carbon-Silicon Alloys” This review paper focuses on the recent developments in understanding the nucleation and crystallization of spheroidal graphite (SG) in Fe-C Si alloys, with about 15% dedicated to graphite's crystal structure and bonding, including lattice types and anisotropic growth behavior’s. Around 20% discusses growth mechanisms such as platelet formation, 2D nucleation, spiral growth, and defects. Another 15% analyses different graphite morphologies like foliated, dendritic, and hopper structures, with parallels drawn from analogous materials. Approximately 10% covers the asymmetric coupled zone in the Fe-C-Si diagram and its effect on undercooling and solidification behavior. The role of melt impurities and minor elements in influencing graphite nucleation and degeneration is discussed in about 15% of the paper, while another 15% focuses on nucleation mechanisms and the identification of effective nucleates using advanced microscopy and crystallographic theories. Finally, about 10% provides historical context and industrial relevance, especially highlighting SG iron's growth in applications like wind turbine castings.

Jon Sertucha et al [6] presented a paper on "Chunky Graphite in Low and High Silicon Spheroidal Graphite Cast Irons–Occurrence, Control and Effect on Mechanical Properties" This paper explores the formation and control of chunky graphite in spheroidal graphite cast irons, with 25% covering the experimental setup and methodology. Around 20% focuses on the effects of silicon and rare earth, showing higher Si which promotes formation of chunky graphite while controlled rare earths reduces it. About 15% each is dedicated to the roles of antimony and tin both suppress chunky graphite but may cause spiky graphite. Microstructural classification and analysis methods make up 10%, mechanical property impacts another 10%, and the remaining 5% discusses prior studies and industrial relevance.

Jin-Su Ha et al [7] presented paper on "The Effect of Boron (B) and Copper (Cu) on the Microstructure and Graphite Morphology of Spheroidal Graphite Cast Iron" This paper examines the effects of trace boron (B) and copper (Cu) on spheroidal graphite cast iron, with 20% on experimental setup, 25% on microstructural changes showing B increases ferrite and graphite surface area, and 15% on thermal analysis revealing B alters phase transformation enthalpies. About 20% covers mechanical properties, noting B reduces strength but enhances elongation and ductility, while 15% involves SEM/EDS-based elemental analysis. The final 5% highlights sustainability potential using B-containing scrap in casting.

3. Problem Identification

The manual cone pouring ladle has leading the formation of less graphite structure, uneven microstructure and rejection of casting. To overcome this challenge we have designed a Powder dispensing machine which will be mounted on treatment ladle the hopper has a dimension of Ø90mm x 119mm (diameter x length). This hopper is supported by a helical screw conveyor, this is connected to a shaft and the shaft is interconnected to a load cell which can sense the load up to 20Kgs. The material of ladle and screw conveyor and powder dispensing to be consider as stain less steel with insulators.

4. Objectives

- To design a new Powder dispensing machine and reduce wastage of powder.
- Compare Ladle inoculation technique and In-stream inoculation technique to study the machinability of product.

5. Methodology

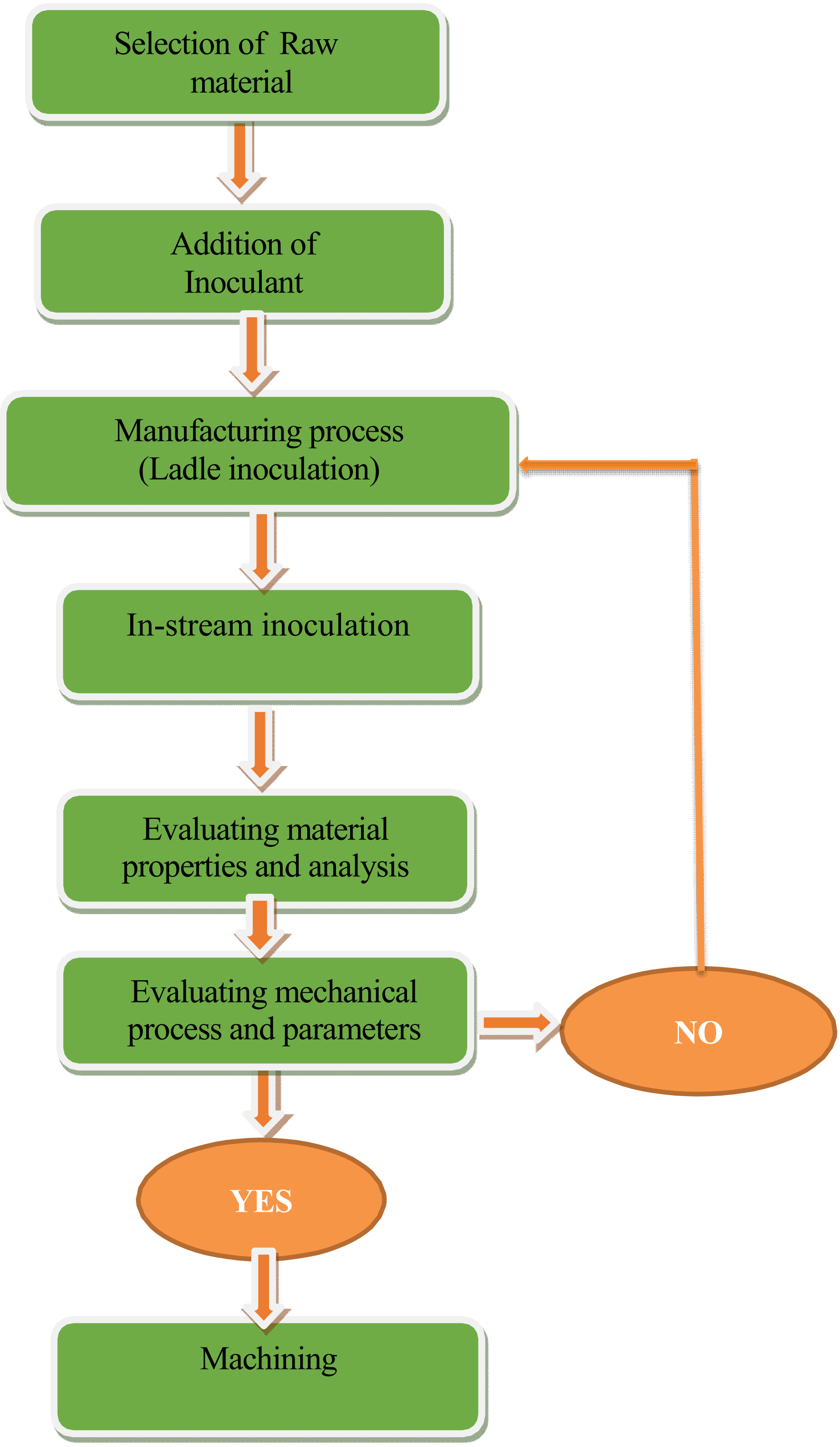

Figure 1: Methodology Flow Chart

6. Calculation of Powder dispensing machine

Powder Details:

- Material: Silicon
- Particle Size: 0.2 mm – 3.5 mm
- Flow behaviour: Easy flows

Dispensing Requirements:

- Accuracy: High
- Batch Size: 0.1 g – 1 g
- Flow Rate: 50 g/sec

Archimedes Screw Parameters

- Screw Diameter (D): 159.6 mm
- Screw Pitch (P): 20 mm
- Lead (L): 20 mm (Single start screw)
- Screw Length: 350 mm
- Helix Angle (β):

$$\beta = \tan^{-1} (\text{Lead}/\pi \times \text{Mean Diameter})$$
$$= \tan^{-1} (\pi \times 159.620) \approx 1.27^{\circ}$$

Motor Requirements:

- Required Torque (T): T=0.306Nm

Load Cell:

- Capacity: 20 kg
- Type: Strain gauge
- Used for: Measuring dispensed weight accurately.

Electronics & Control:

- Power Supply: 120 V
- Motor Type: DC Motor (matched to 3.2W).

7. RESULT AND DISSCUSSION

The inoculation of spheroidal graphite cast iron resulted in significant improvements in both microstructural and mechanical properties. The powder dispensing machine used in castings showed a higher number of uniformly distributed graphite nodules with refined shapes, which contributed to enhanced mechanical strength and reliability. Inoculation effectively minimized the presence of carbides and undercooled graphite structures, promoting a predominantly ferrite or pearlite matrix depending on cooling conditions. Mechanical testing confirmed increased tensile strength, elongation and improved hardness values in inoculated samples, validating the critical role of proper inoculation in producing high-quality SG iron.

8. CONCLUSION

The rejection of parts which played a key role to improve the overall efficiency of the casting process. This study concludes that proper inoculation is essential for achieving optimal microstructure and mechanical properties in SG cast iron. Effective inoculation not only refines graphite shape and distribution but also prevents the formation of carbides and undercooled structures, which are detrimental to performance. The choice of inoculant and the method of application significantly influence the outcome were superior due to minimized fading and precise timing. Ultimately, adopting the right inoculation strategy ensures improved strength, ductility, and reliability in ductile iron castings for industrial applications.

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