A Comprehensive Examination of Defect in Continuous Cast Billet and Analysis Using Quality Control Tool

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Abstract – *The steel industry is of paramount importance in the infrastructure development of a nation. Within this industry, the continuous casting method is employed to create semi-finished products such as slabs, blooms, and billets. The quality of steel billets is crucial for the production of superior steel goods. Flawless billets result in the manufacture of high-quality steel products, while imperfect ones lead to a decrease in mechanical properties and the overall quality of the rolled product. In a recent project, common defects found in steel plants were identified in steel billets, and the causes of these defects were analyzed through a cause-and-effect diagram.*

***Key Words*: Continuous casting, Billet, Cause and effect diagram, Blooms.**

1.INTRODUCTION

The iron and steel sector has a lot of significance in India, contributing greatly to the country's industrial landscape. Steel, a vital and versatile material, plays a pivotal role in the development of infrastructure. India stands as the world's second-largest steel producer, with this industry accounting for roughly 2.5% of the national GDP, providing employment opportunities for approximately 2.5 million individuals both directly and indirectly. At its core, steel is an alloy of iron and carbon, with carbon levels ranging up to 1.5%. The process of continuous casting serves as a crucial intermediary between steel production and rolling. This method efficiently creates semi-finished products by transforming molten steel into large blocks known as billets. Automation largely drives this process, ensuring a continuous supply of metal through a mold, resulting in the production of billets or blooms that are further utilized in the rolling phase. Defects in a steel billet during continuous casting can significantly impact the quality of the final rolled product. This study delves into the analysis of defects in continuous cast billets, leveraging statistical quality control tools like cause-and-effect diagrams to identify and addressing root causes. The Cause-and-Effect Diagram, also known as the Ishikawa or fishbone diagram, visually represents the relationship between a specific outcome and the various factors influencing it.

2 LITERATURE REVIEW

1. Defects of the steel billet in continuous casting.

Author: Anh-Hoa BUI and Van-Hung NGUYEN

The primary goal of this research is to identify deficiencies in the continual casting of steel billets, a critical aspect that impacts the quality of rolled products. The study was carried out to explore the flaws in 130×130 mm2 billets and to analyze their causes and preventive measures. The formation of defects and cracks was predominantly influenced by the temperature distribution and cooling process of the casting strand. Notably, caster, rhomboidal billets, and off-corner cracks constituted the major portion of defects observed during production. The chemical composition of the molten metal and the secondary cooling procedure played crucial roles in the development of these defects.

2. Reform the Performance of a Billet Quality by Reducing its Defects at SAIL-SCL Kerala Limited

Author: Abdul Haseeb NC, Alex P Jacob, Arvind Kumar, Dibin Vincent

Explored the different procedures within the industry and successfully executed a project to enhance the quality of billets, resulting in a reduction of significant losses for the company. The primary challenge encountered by the industry pertains to defects arising during the casting of billets. Defective billets can only be repurposed as scrap, leading to substantial losses. Analyzed the underlying causes of these defects and proposed solutions tailored to each scenario. Put forth the idea of utilizing a field mixing technology for blending molten metal in accurate proportions, thereby reducing defects by approximately 75%. Additionally, recommended alternative approaches to enhance the overall quality of billets.

3. Analysis of the Defect of Crack in Casting

Author: Vijay Pandey

This research delves into the various kinds of internal and external fractures that can persistently emerge during steel casting. Each category of a fracture is analyzed concerning the operational and metallurgical factors that can impact the development of fractures due to the robust high-temperature mechanical attributes of steel and an understanding of the stresses that arise within the solidifying shell.Fractures tend to be associated with two specific zones of low steel ductility, notably a high-temperature area beyond 1340 °C, predominantly accountable for most fractures, encompassing all internal fractures, and a low-temperature region ranging from 700 to 900 °C, which leads to issues of transverse surface cracking. By combining this comprehension with the stresses produced during continuous casting, feasible mechanisms of fracture formation can be proposed and linked to operational and metallurgical factors.

4. The Control of Pinhole and Crack Defect on the Surface of Cold Heading Steel Billet

Author: WeiZhang, Liqiang Zhang, Ali Naqash2, Aonan Zhao, Chaojie Zhang.

The research project was focused on experiments conducted on 10B21 boron-added cold heading steel, which showed some cracking issues during production. The examination through various methods, including macroscopic evaluation, microstructure examination, scanning electron microscope, energy spectrum analysis, revealed that defects like pinholes and cracks on the billet surface were primarily caused by the presence of N and O elements, electromagnetic stirring, protective slag, and temperature variations. An optimization procedure was suggested to mitigate these defects successfully. By implementing this optimization process, the flaws like pinholes and surface cracks in the cast billet were effectively resolved. Consequently, the wire rod exhibited a uniform structure with a grain size exceeding grade 8, and the forged rod's compliance rate reached 100%.

5. Metallurgy of Continuous Casting Technology

Author: Dr.T.R. Vijayaram

The discussion presented here covers the process description, mechanism, and control of continuous casting. It delves into the hydrodynamics, heat transport, thermal analysis, solidification control, and heat transfer involved. Additionally, it explores the various product types, sections range, and the benefits of employing continuous casting technology in both ferrous and nonferrous foundries. Continuous casting is a method that converts molten metal into a solid form continuously, encompassing several crucial industrial procedures. This technology, which involves the constant casting of metal, is known for its efficiency and cost-effectiveness, making it a popular choice for manufacturing various semi-finished metal shapes. Once the metal is cast, it can be further processed accordingly. Moreover, all tasks can be easily automated and monitored, facilitating adjustments to the quality and characteristics of semi-finished products by altering parameters such as the pulling speed.

6. Studies on Production of Quality Billets for Constructional Steels

Author: Sachin ahammed.C Dr. N. M. Nagarajan

"In this study, an effort is undertaken to examine steel billets for the production of high-quality steel, specifically constructional steel widely used in building construction and various industries. The primary focus is on identifying defects in continuous cast products, investigating surface imperfections and control measures, analyzing the chemical composition, and determining the mechanical properties of the billets. The quality of the billet plays a crucial role in the manufacturing of structural steel, influenced by factors like surface and internal cracks, elemental composition, and billet strength. Chemical composition analysis of the billets is performed using an optical emission spectrometer to identify the percentage of elements present. Non-Destructive Testing methods reveal surface cracks and internal imperfections. Mechanical properties such as ultimate strength, yield point, and elongation percentage are determined using a Universal Testing Machine (UTM)."

7. Defect Reduction in an Arc Welding Process Using Cause and Effect Diagram

Author: Muhammed Raazick, Noorshan, Rashid K, Rumaisa C M Sanmishal P K, Jibi. R

In this project, welded samples are subjected to nondestructive testing to detect any defects present in the welds. Ultrasonic testing, dye penetrant testing, and magnetic particle inspection techniques are utilized for defect identification. Any defects found are then examined using a cause-and-effect diagram, one of seven quality tools. This diagram serves as a root cause analysis tool, facilitating the structured investigation and resolution of underlying issues that contribute to the problems discovered.

3 METHODOLOGY

The methodology stands crucial for maintaining project flow and achieving desired outcomes. Essentially, it serves as a structured framework integrating project elements aligning with objectives and the project's scope. A well-designed framework offers a comprehensive project overview and streamlines data retrieval processes. This encompasses conducting literature reviews, examining the company's background, applying various methods to identify defects, and conducting defect analyses using cause and effect diagrams.

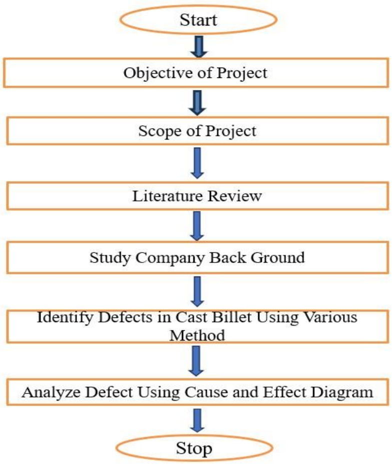

Fig 1: Project Methodology

4. COMPANY PROFILE

Kenza TMT, established in 1991, is a private steel manufacturing company situated in the Palakkad district of Kerala. Renowned for its production of TMT steel bars, Kenza TMT has earned recognition for its commitment to excellence, as evidenced by its Bureau of Indian Standard (BIS) certification. Focused on the construction steel sector, Kenza TMT utilizes continuous casting technology to produce 100X100 mm square billets through an electric arc furnace. These iron billets serve as the foundation for various steel products used in construction materials and other industrial applications. The company offers TMT bars in a range of sizes including 8mm, 10mm, 12mm, 16mm, 20mm, 25mm, and 32mm. Fe550D garde steel bar are producing with following basic composition.

Constituent	Percentage Maximum
Carbon	0.25
Sulpher	0.04
Phosphorous	0.04
Sulpher and Phosphorous	0.075

Table 1: Main composition of Fe550D TMT

- **Billet manufacturing process**

The journey of steelmaking from scrap begins with the collection and sorting of steel scrap. Steel scrap comes from various sources, including end-of-life products, manufacturing trimmings, and defective items. The collected scrap is sorted based on its properties and composition, which is crucial for ensuring the quality of the final product. Once sorted, the scrap is charged into an induction furnace. An 8-ton induction furnace is typically used for medium-scale production. The scrap is loaded into the furnace using a charging bucket, and care is taken to ensure that the scrap is clean and free from non-metallic materials. The melting process begins once the scrap is fully charged. Induction furnaces use electromagnetic induction to produce heat by passing alternating electric currents through coils surrounding the furnace. The melting temperature for steel is around 1,370°C to 1,540°C. However, the exact temperature can vary based on the grade of steel being produced by the company as it manufactures 2 grades of steel Fe500 and Fe550D. The voltage applied during this process is critical and is adjusted according to the furnace's design and the type of scrap used. Typically, voltages can range from 200V to 700V. After melting, the steel undergoes refining to remove impurities and adjust its composition. This is achieved through various processes, including oxidation, where oxygen is blown through the molten steel to remove carbon. The refining process also involves adding alloying elements like manganese, silicon, and carbon to achieve the desired steel grade. During the refining process, samples of molten steel are taken periodically for analysis. This is done to monitor the chemical composition and quality of the steel. The samples are analyzed using spectrometers and other laboratory equipment to ensure that the steel meets the required specifications. Once the steel has reached the desired composition and temperature, it is tapped from the furnace. Tapping involves pouring the molten steel into a ladle for transport to the next stage of the process. The tapping temperature is usually higher than the melting point to ensure fluidity, typically around 1,600°C to 1,650°C. Secondary refining, or ladle metallurgy, follows tapping. This process further adjusts the steel's composition, removes inclusions, and controls the temperature before casting. Techniques used in secondary refining include vacuum degassing, argon stirring, and ladle furnace heating. The refined steel is then cast into various shapes. Continuous casting is the most common method, where the steel is solidified into slabs, blooms, or billets. These semi- finished products are then ready for further processing, such as rolling. In the CCM, the steel is poured into a water-cooled mold where it begins to solidify. As the steel exits the mold, it enters a series of rollers that gradually reduce the steel's thickness while it continues to solidify. The final shape of the steel is determined by the dimensions of the CCM.

Fig 2: Billet Manufacturing Section

➢ **Plant layout**

This figure explores the layout of the billet manufacturing section at Kenza TMT. This section plays a crucial role in the overall production process, transforming scrap steel into billets, the primary feedstock for subsequent stages. By analyzing the layout, gain insights into the production flow.

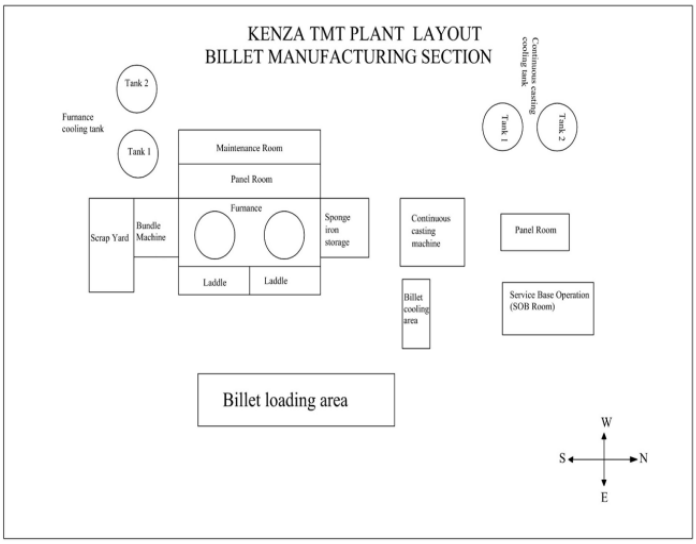

Fig 3: Plant Layout

Raw Material Handling and Preparation

Scrap Yard: This specified location functions as a storage area for scrap metal before it undergoes processing into billets.

Bundle Machine: Positioned in close proximity to the scrap yard, this device compresses scattered scrap metal into organized bundles to streamline the process of loading furnaces efficiently.

Electric Furnace Operations and Maintenance

Electric Furnace Functionality: The diagram illustrates the presence of two electric arc furnaces. However, only one furnace is utilized at a time to melt steel scrap efficiently, minimizing energy consumption, while ensuring continuous production capacity.

Command Centre: Positioned behind the electric furnace, this section accommodates the systems responsible for controlling the furnace's operations. The command centre facilitates meticulous regulation of temperatures and constant monitoring of the melting process.

Equipment Maintenance Facility: Situated adjacent to the command centre, a specialized maintenance area guarantees the seamless functioning of the electric furnace. Skilled technicians can conduct preventive maintenance and promptly address arising issues.

Steel Refinement and Casting Operations

Primary and Secondary Water Reservoirs (Left of Maintenance Facility): Strategically located, these reservoirs supply cooling water for dual purposes. One set of reservoirs helps in cooling the coils inside the electric furnace, maintaining ideal operational temperatures.

Sponge Iron Stockpile: On-site storage houses sponge iron, a porous iron variant with minimal carbon content. Specific quantities of sponge iron can be incorporated into the molten steel bath during the melting process as necessary, regulating the final steel billets' carbon content.

Continuous Casting Machinery (CCM): The molten steel from the electric furnace is transferred to the CCM for casting. This machine continuously shapes the liquid steel into elongated solid forms known as billets. The casting process parameters are vigilantly supervised and adjusted from the adjacent CCM control panel and operational base.

Billet Cooling and Handling

Cooling Section for Billets: Following the continuous casting process, newly formed billets are transported to a specific area designated for cooling. It is in this space that the billets are allowed to naturally lower their temperature to a controlled level before moving on to the next stage of handling.

Water Reservoirs for Cooling (Located Behind the CCM Control Panel): These primary and secondary water tanks, similar to those near the furnace, are responsible for providing the necessary water for the cooling of steel billets during the continuous casting operation.

Billet Loading Zone: Serving as the final destination within the billet production area, this zone is where the cooled billets are typically loaded for transportation to the subsequent processing phase, often involving the rolling mill for their transformation into steel bars.

5.WORK DONE

Non-destructive testing (NDT) encompasses a range of analytical techniques utilized to assess the properties of a material without causing permanent changes to the material under inspection. This method, which includes visual inspection, liquid penetrant testing, magnetic particle testing, ultrasonic testing, and radiographic testing, proves to be invaluable in terms of saving time and money. Non-destructive testing is synonymous with non-destructive evaluation, nondestructive analysis, non-destructive examination, and non-destructive inspection. Following Non-Destructive testing conducted over the billet.

1.Visiual inspection 2. Liquid penetrant test. 3.Magnetic particle test. 4.Ultrasonic test. 5.Radiographic testing.

Visual inspection: Visual inspection, for instance, involves a straightforward and cost-efficient approach to examining the surface and internal characteristics of a casting, allowing for the identification of any apparent defects through a meticulous assessment with the naked eye or a magnifying glass. These defects may be pinpointed in a 100x100mm square casting billet through visual inspection.

- Piping

Fig 4: Piping Defect

- Corner Crack

Fig 5: Corner Crack

- Transverse Crack

Fig 6: Transverse Crack

- Longitudinal Crack

Fig 7: Longitudinal Crack

- Slag Inclusions

Fig 8: Slag Inclusions

- Shrinkage Cavity

Fig 9: Shrinkage Cavity

- Deformation (Bending)

Fig 10: Bending

- Rhomboidity

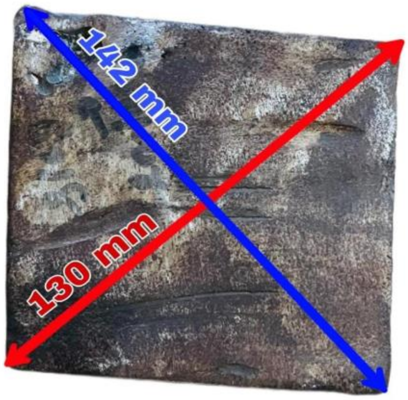

Fig 11: Rhomboidity

Liquid penetrant test: The liquid penetrant test is a non-destructive examination method used to detect surface discontinuities in various materials, including ferrous and non-ferrous metals, as well as non-metallic substances like ceramics, plastics, and glass. These processes can identify flaws such as cracks, seams, laps, cold shuts, and laminations. The use of liquid penetrant for flaw detection is becoming more prevalent across industries, emphasizing the need for general recommendations to guide its application effectively.

Fig 12: Liquid penetrant testing cleaner, penetrant And developer

Procedures

a) Pre-clean part

This involves cleaning the part, ranging from grinding or wire brushing to wiping it with a cloth dampened with a cleaner or remover. The surface must be rid of any dirt, rust, scale, paint, oil, and grease, ensuring a smooth surface free of any penetrant residue.

Fig 13: Pre-cleaning Process

b) Apply penetrant.

Fig 14: Penetrant Applying

c) Remove penetrant.

Thoroughly clean the part by using clean, dry, lint-free rags to remove all penetrant until no traces remain visible. Utilize cleaner/remover sprayed on a fresh rag to eliminate any remaining penetrant, ensuring a spotless surface.

Fig 15: Penetrant Removing

d) Developer application.

Apply a light, thin coating of developer on the part under examination. Allow time for the dye to escape flaws and create a visible indication in the developer. The developer should be left for a dwell time of 10 to 60 minutes for optimum results.

Fig 16: Applying Developer

Following defected are identified by liquid penetrant test.

- Pin hole porosity

Fig 17: Pin hole porosity

- Crack

Fig 18: Crack

Ultrasonic Testing: Ultrasonic testing (UT) is a widely used non-destructive testing (NDT) technique that utilizes high-frequency sound waves to evaluate the properties of a material. UT works by introducing sound waves into the material and analyzing the reflected waves to detect internal flaws, measure thickness, and assess the material's overall integrity. Prior to testing, the billet surface was prepared by grinding any irregularities exceeding 0.5 mm depth to ensure optimal sound wave transmission. A couplant, in this case a low viscosity oil, was applied to the prepared surface to minimize air gaps that could hinder signal transmission. The UT inspection utilized a pulse-echo technique with a 45 MHz longitudinal wave transducer. The transducer was systematically scanned across the entire billet surface in a raster pattern, ensuring complete coverage. The UT flaw detector was calibrated with a reference block of known dimensions and material properties to ensure accurate positioning and sizing of any potential defects. During testing, the A-scan presentation on the UT display was continuously monitored for sudden signal amplitude changes or additional echoes indicative of internal discontinuities. All detected anomalies were documented, including their location, size, and character based on the reference standards. The figure below shows the ultrasonic flow detector.

Fig 19: Ultrasonic Flow Detector

Using ultrasonic inspection, a defect of cavity (Blow hole) is found in the steel billet.

ULTRASONIC INSPECTION REPORT					
Customer: Mr RINL, Mr ADWAITH A, Mr MIJUWAD P.P & MR ANAJ T Group-1			Report No : CIS-UT/TP/001/24 Date of Inspection : 27.03.2024		
Material : CS Identification : Steel Billet			Surface condition : Smooth Thickness : 35,40 & 48mm		
Inspection Technique : Pulse echo					
Acceptance Standard : AWS D1.1			Reporting Level(%) : 20% of DAC		
Flaw Detector : MODSONIC Arjun30 plus			Couplant : Water Paste		
Probe Type	0 deg	45 deg	60 deg	70 deg	DAC Established With 3mm Notch of 38mm Reference Block
Frequency	4MHz TR		4MHz	4MHz	
Primary Reference Responsed(dB)(%)	40	N/A	N/A	N/A	
Scanning Sensitivity (dB)	40+6	N/A	N/A	N/A	
Range Calibration (mm)	100	N/A	N/A	N/A	
INSPECTION REPORT:					
1. Steel Billet Sample-1 (depth-12mm, cavity size-15mm)					
2. Steel Billet Sample-2					
3. Steel Billet Sample-4 (depth- 15mm, cavity size-15mm)					

Fig 20: Ultrasonic Inspection Report

Magnetic Particle Inspection: Magnetic Particle Examination (MPE) serves as a Non-Destructive Testing (NDT) technique aimed at detecting flaws such as cracks in ferromagnetic materials like steel. This method involves magnetizing the material, disturbing the field around defects. Subsequently, iron particles are attracted to these areas of magnetic flux leakage, allowing for the visual identification of defects. While MPE is efficient and cost-effective, it is specifically applicable to ferromagnetic substances. To investigate any surface or subsurface cracks, the steel billet underwent magnetic particle examination (MPE). Before conducting the examination, the billet underwent a thorough cleaning process to eliminate any potential contaminants that could affect particle adhesion. Furthermore, a white background paint was applied to enhance the visibility of crack indications. Employing the yoke method for magnetization involved placing a hand-held electromagnet across specific regions of the billet to induce a strong magnetic field longitudinally. Wet magnetic particles, a suspension of finely divided ferromagnetic particles in a carrier liquid, were subsequently administered onto the painted surface of the billet. The continuous steel matrix directed the magnetic field lines, but imperfections like cracks led to a disruption in this flow, attracting the wet magnetic particles and creating visible accumulations along the crack path. Systematic scanning of the entire billet surface was carried out using the yoke in various orientations to ensure complete coverage. After examination, residual magnetization was eliminated using a demagnetizing coil, and the wet magnetic particles were meticulously cleaned from the billet's surface. This MPE procedure facilitated a prompt and reliable assessment of surface crack defects on the steel billet.

Fig 21: MPI ink and White Contrast Paint

Fig 22: Magnetic Particle Inspection

Crack defect identified by magnetic particle inspection.

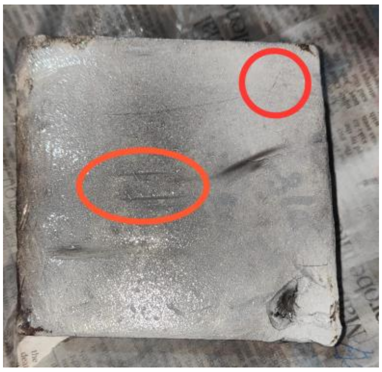

Fig 23: Crack defect in MPI

MAGNETIC PARTICLE TEST REPORT

Report No: TP/MPT-001		Date: 28.03.2024
Customer: Mr RINIL, Mr ADWAITH A, Mr MIJUWAD P.P & Mr ANAJ T (Group 1)		
Job Description: STEEL BILLET		
Precleaning: Buffing	Testing Equipment: Yoke	Date of Test : 27.03.2024
Magnetic Particle: Magnaflux Wet	WCP-2 & 7-HF	
Magnetic Process: Continuous	Current: HWDC	
PROCEDURE & ACCEPTANCE Standard : ASME Sec V & AWSD1.1		

Identification	Qty	Observation	Remarks
STEEL BILLET SAMPLE-2	01No	CRACK	Reject

Fig 24: Magnetic Particle Test Report

Radiographic Testing: Radiographic Testing, also known as RT in the field of Non-Destructive Testing (NDT), utilizes X-rays or gamma rays to penetrate materials and identify internal flaws. Different densities within the material absorb radiation differently, resulting in darker areas on the film or digital detector. Skilled inspectors carefully analyze these images to pinpoint cracks, voids, or other imperfections. RT offers versatility, deep inspection capabilities, and the advantage of producing permanent records. However, its operation necessitates stringent safety measures and specialized training due to the involvement of radiation. In an assessment of the internal structure of a continuously cast steel billet, radiographic testing played a crucial role. Prior to the testing phase, the surface of the billet was meticulously cleaned to eliminate any substances that could impede the passage of radiation. To ensure accurate alignment and minimize dispersed radiation, the billet was precisely positioned between the X-ray source and the radiographic film cassette. The distance between the X-ray source and the billet, determined by its thickness and the desired image quality, was meticulously set. Exposure parameters such as kilovoltage (kV) and milliamperage-seconds (mA·s) were thoughtfully adjusted to achieve optimal penetration and image contrast. After the irradiation process, the radiographic film underwent strict processing in a darkened environment using established chemical techniques to create a permanent record of the billet's internal configuration. The resulting radiograph was scrutinized in detail by a qualified inspector using a calibrated light box to identify any discontinuities like cracks, porosity, or shrinkage cavities within the billet. This systematic approach employed in specimen preparation, radiographic exposure, and film processing guaranteed the attainment of top-quality radiographs for the meticulous evaluation of the steel billet's integrity. Pin hole and crack defects were successfully detected through the comprehensive radiographic inspection technique used.

Pin hole and crack defect are identified using radiographic inspection technique.

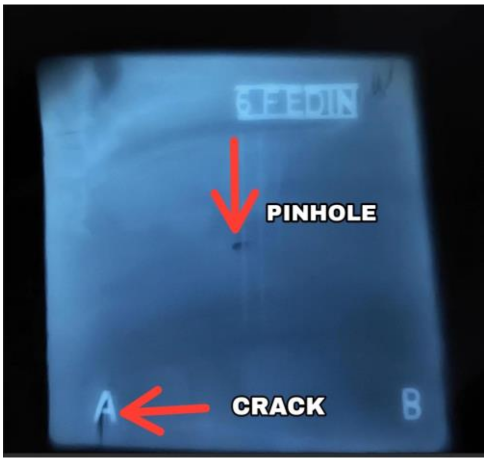

Fig 25: Radiographic Test Result

Defect identified in cast billet

Sl No	Non-Destructive Testing	Defect Found
1	Visual Inspection	Piping Corner Crack Transverse Crack Longitudinal Crack Slag Inclusion Shrinkage Cavity Bending Rhomboidity
2	Liquid Penetrant Test	Pinhole porosity Crack
3	Ultrasonic Testing	Cavity (Blow hole)
4	Magnetic Particle Inspection	Crack
5	Radiography Testing	Pin hole porosity Crack

Table 2: Defect Identified in Cast Billet

Microscopic Examination of a Billet

A section of the steel billet was meticulously prepared for microstructural investigation through the utilization of a Scanning Electron Microscope (SEM). The sample was subjected to grinding, polishing, and etching to achieve a sleek, reflective surface that accentuates the microstructure of the material. Subsequently, the SEM analysis employed secondary electron imaging to unveil details regarding the dimensions, shapes, and distribution of the various phases present within the steel billet. A visual depiction of the test piece extracted from the SEM examination is included below.

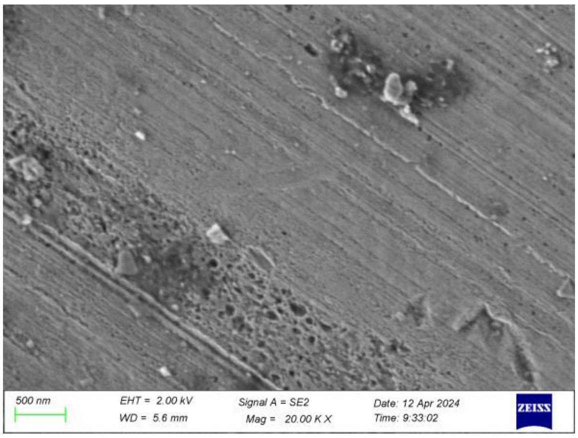

Fig 26: Microscopic Picture of Billet

- ***Cause and Effect Diagram***

Quality control tools encompass various methods and techniques utilized to guarantee that a product or service aligns with the desired quality standards. These tools are applicable at any phase of the production process, ranging from initial development to ultimate delivery.

The seven basic quality control tools are:

1. Cause-and-effect diagram (Ishikawa diagram)

2. Check sheet

3. Control chart

4. Histogram

5. Pareto chart

6. Scatter diagram

7. Stratification (or flowchart)

A cause-and-effect diagram, commonly referred to as an Ishikawa or "fishbone" diagram, serves as a visual instrument used to investigate and present the potential causes of a specific outcome.

Root cause analysis of defects

Cause and effect analysis showing major causes of the continuous casting billet defects.

Piping

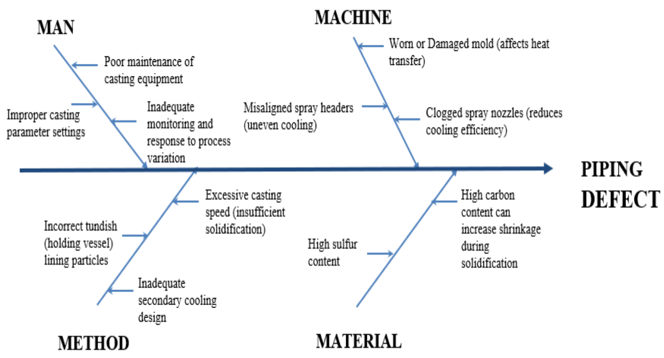

Fig 27: Cause and effect diagram for Piping

Crack

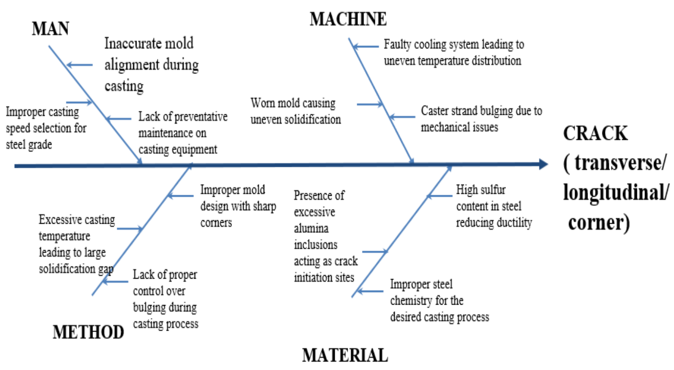

Fig 28: Cause and effect diagram for Crack

Slag inclusion

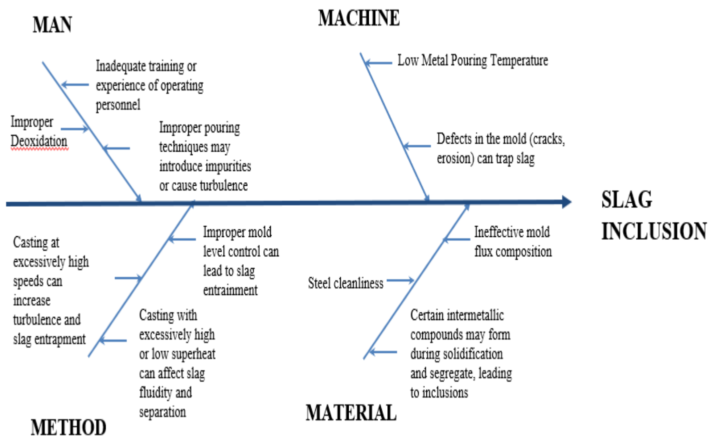

Fig 29: Cause and effect diagram for Slag inclusion

Bending (Deformation)

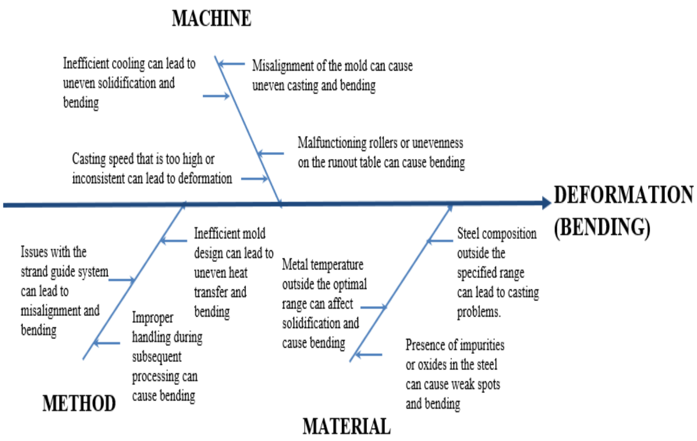

Fig 30: Cause and effect diagram for Bending

Shrinkage Cavity

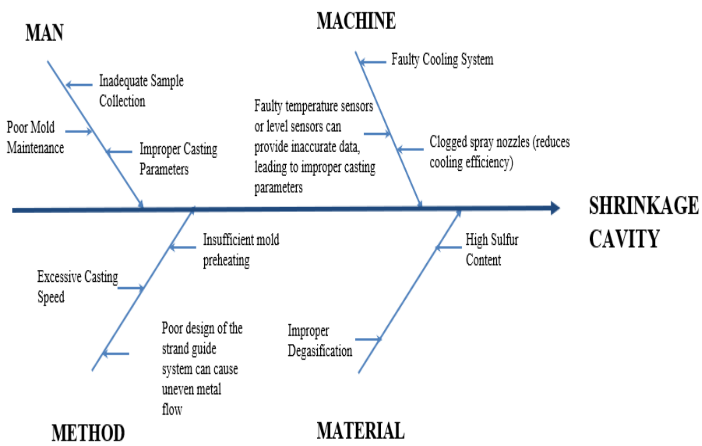

Fig 31: Cause and Effect Diagram for Shrinkage Cavity

Pin Hole

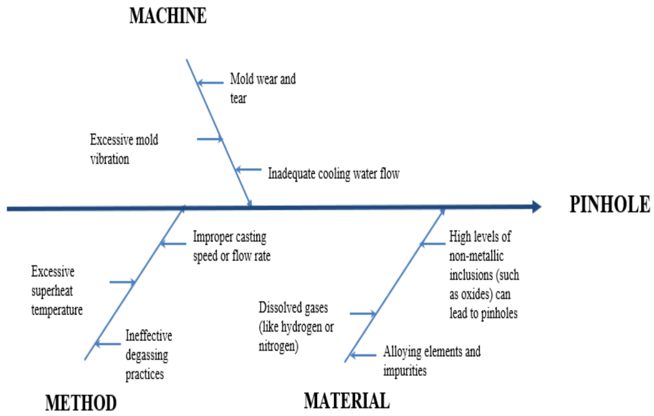

Fig 32: Cause and effect diagram for Pin hole

Blow Hole

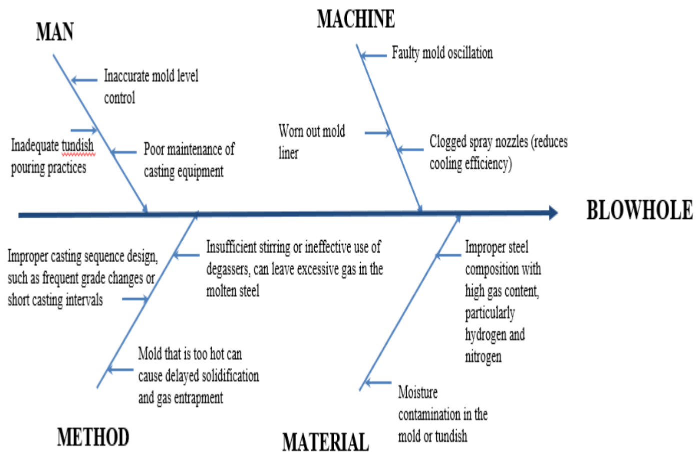

Fig 33: Cause and effect diagram for Blow Hole

Rhomboidity

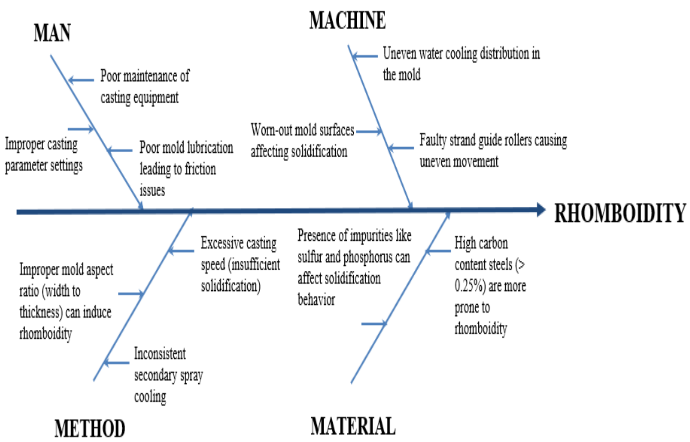

Fig 34: Cause and effect diagram for Rhomboidity

6. CONCLUSION

Industrial case study of continuous casting defects is discussed in this paper by using cause and effect diagram. Various defects are found out using nondestructive testing. By using cause and effect diagram various causes and remedial measures are discussed. This investigation will be highly useful in reducing casting defect in industries and inproving the quality of casting with less rejections.

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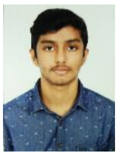

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