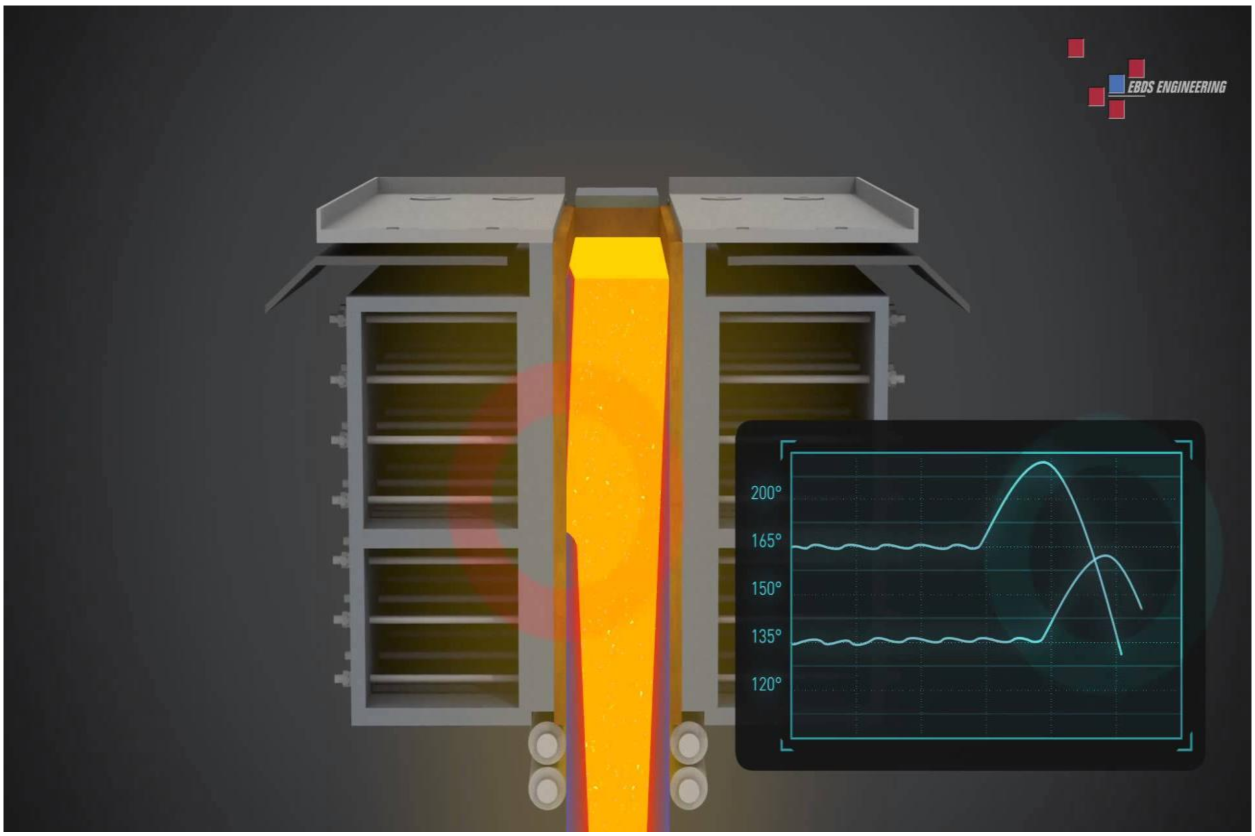
BREAKOUT DETECTION SYSTEM IN CASTER AND IMPROVING THE RELIABILITY OF THERMOCOUPLES



Prepared by:

PRITISH PRADHAN
Department of Instrumentation and Electronics Engineering
CET, Bhubaneswar

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ABSTRACT

During continuous casting of thin slab, breakout is the most catastrophic incident, which not only interrupts sequential production to attain high productivity and disturbs the production schedule, but also damages the devices of the caster, and results in huge economic cost. Most breakouts are of the sticking type and restrict high speed continuous casting.

In case of breakouts, the solid shell of the strand breaks and allows the still-molten metal inside it to spill out and damage the machine. To avoid this situation, Breakout Prediction System is widely used, which employs thermocouples. The temperature of liquid steel is measured using thermocouples inserted in Water Cooled Copper Plates of mould. The metal shell temperature at each instance of time is given by the reading of the thermocouple, as the metal slab moves down the caster. By using this technique, any breakout in the mould can be predicted and the required precautionary steps can be taken to avoid further damage.

The accuracy and reliability of temperature measurement are the precondition and guarantee for breakout prediction. This presentation deals with the possible ways of improving the reliability of thermocouples in moulds of slab caster. Special attention has been paid to the methods used to avoid frequent failure components, increase life of TCs and increase the accuracy of TCs.

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INTRODUCTION

Thin Slab Casting has proved to be a significant evolutionary step in casting methodology and has allowed much more efficiency and therefore cost effectiveness to be applied to the casting process.
With thick slab casting being used predominantly, the introduction of thin slab casting allowed for a range of process efficiencies including the reduction of total production line from 800m to 250m.

In the case of thin slab casting, the steel is cast directly to slabs with a thickness between 50 mm-70 mm instead of slabs with a thickness of 120 mm to 300 mm obtained in case of thick slab casting.

The casting process is comprised of the following sections:

- Molten steel is poured into the Tundish at the top of the slab caster, from a ladle.
- The Tundish, located above the mould feeds liquid steel to the mould at a regulated rate.
- A primary cooling zone or water-cooled copper mould is present through which the steel is fed from the Tundish, to generate a solidified outer shell sufficiently strong enough to maintain the strand shape as it passes into the secondary cooling zone.
- A secondary cooling zone is present in association with a containment section positioned below the mould, through which the still mostly-liquid strand passes and is sprayed with water or water and air to further solidify the strand.
- Except for the case of straight Vertical Casters, an Unbending & Straightening section is also present.
- A severing unit (cutting torch or mechanical shears) is present to cut the solidified strand into pieces for removal and further processing.

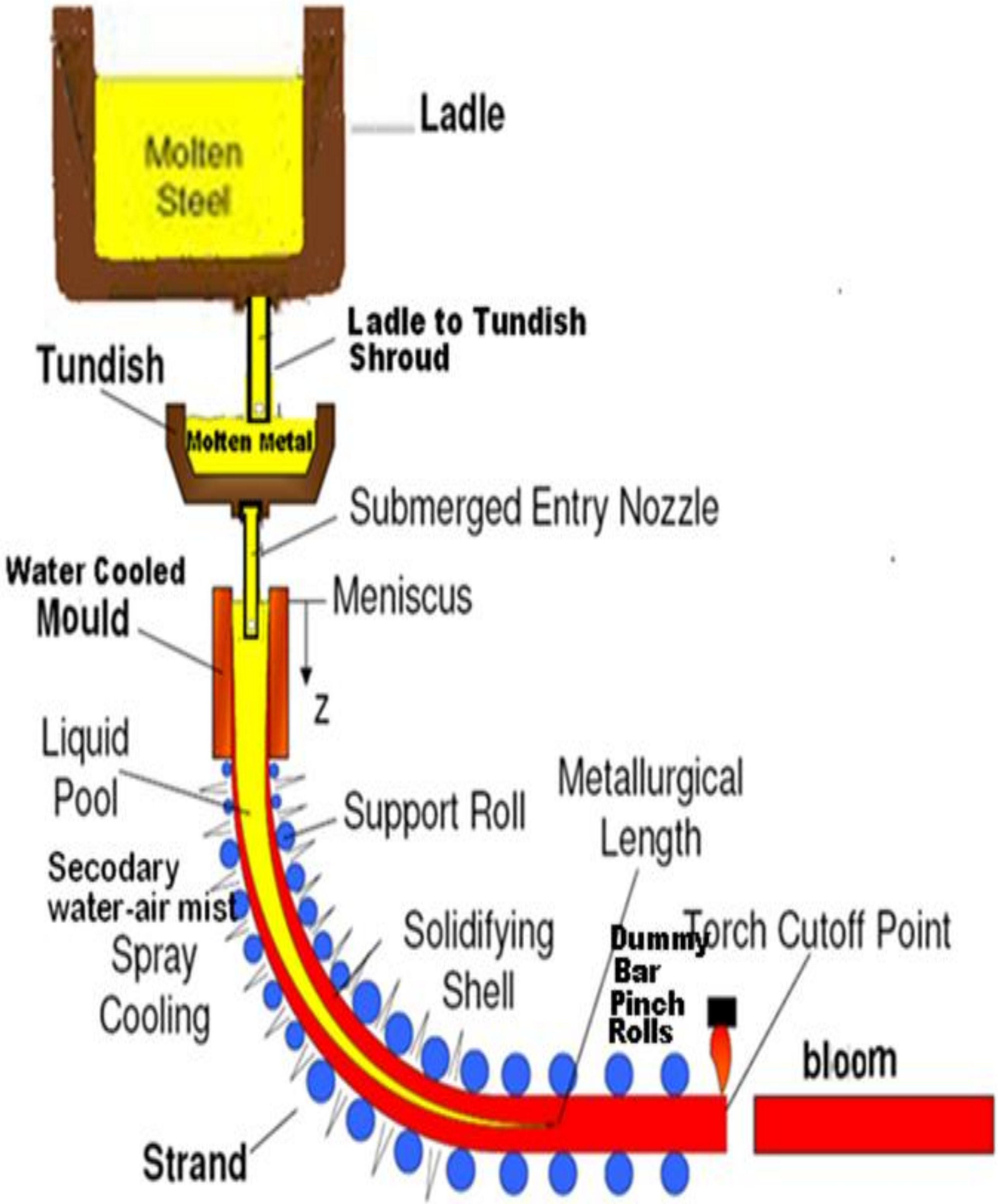


Figure 1: The process of continuous casting

STICKING & BREAKOUT

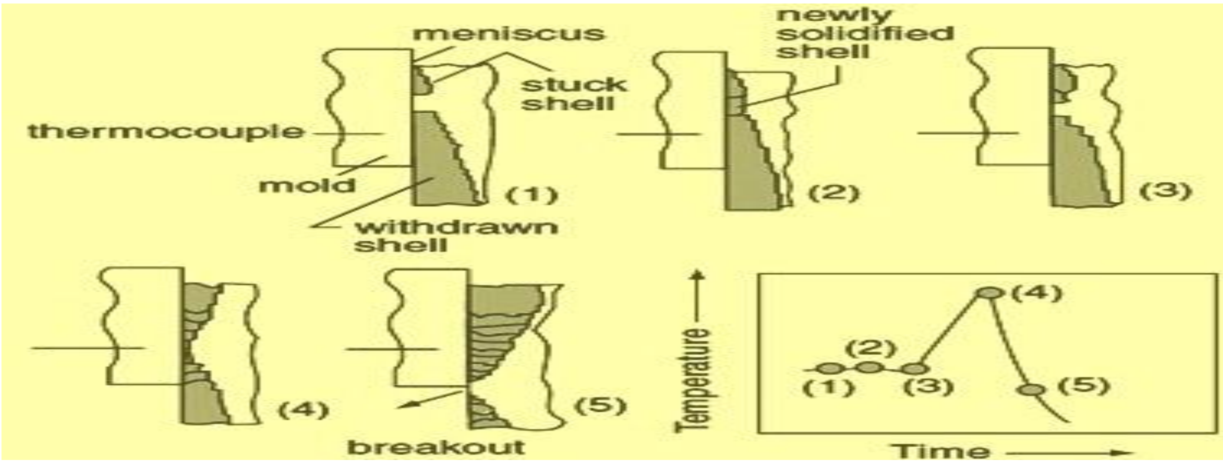


Fig 1.1

A lack of lubrication or mould surface problem can create a direct and very local contact of steel with the mould as shown in the fig 1.1. It has been noticed that: sticking generally occurs in the upper part of the mould teared area increases at about the same speed in the horizontal and vertical.

Breakout of the liquid metal is a major problem that may occur in the process of continuous casting. In this situation the solid shell of the strand breaks and allows the still-molten metal contained within to spill out and foul the machine. Generally, this event is very costly as it leads to a shutdown of the strand and mostly requires an extended turnaround involving removal of the spilled material from within the strand equipment and/or replacement of damaged machinery. The reasons may be one of the following:

- Due to the shell wall being too thin to support the liquid column above it, mostly because of improper heat management.
- Improper cooling water flow to the mould or the strand cooling sprays may lead to inadequate heat removal from the solidifying metal. This can cause the solid shell to thicken too slowly.
- If the metal withdrawal rate is too fast, the shell may not have time to solidify to the required thickness even with enhanced cooling sprays.
- The incoming liquid metal may be too hot and the final solidification may occur further down the strand at a later point than expected.
- But 70% of the breakouts occur due to the sticking of the solid metal the copper wall of the mould.

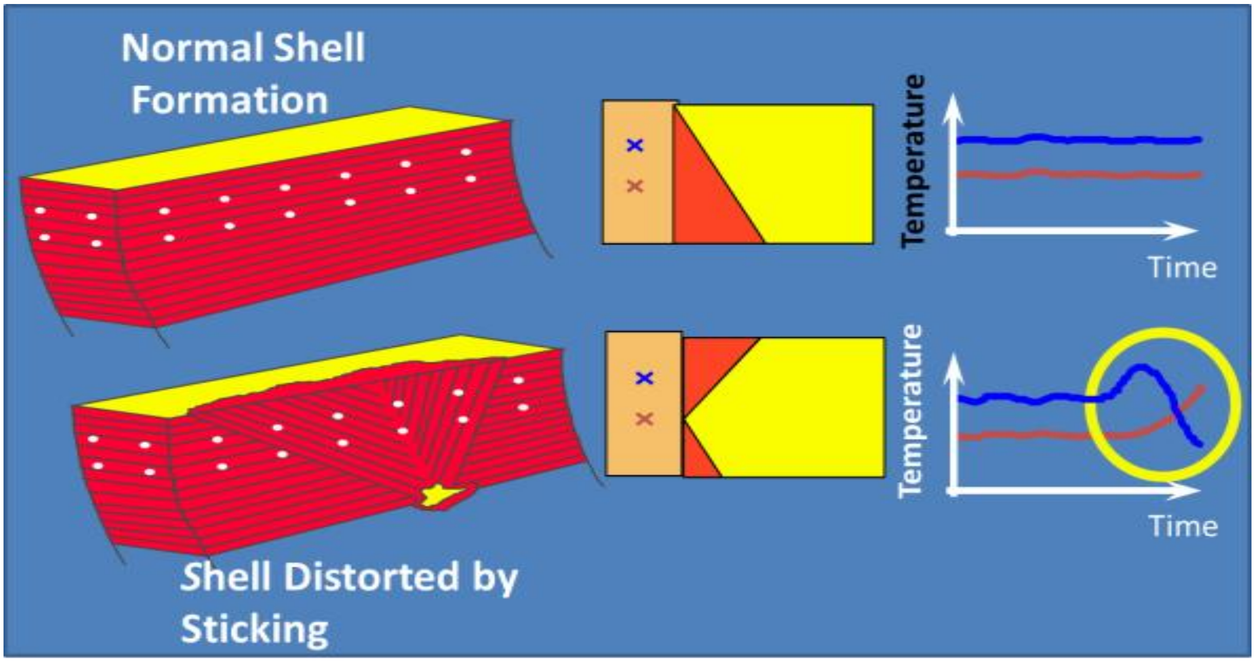


Figure 2: Comparison between normal shell and shell distorted by sticking

EFFECT OF BREAKOUTS:

Breakout in a slab caster has important financial effects:
• Loss of steel: 75% of steel in the mould lost.
Example: 75% of a 1500 x 350 x 800 mould at 8 tons/m3 = 2.5 t of steel lost
• Casting machine stop: loss of production
Example: 2 hours production loss = 240 t of steel less
• Casting machine damage:
-workforce to change the damaged parts and repair.
-equipment cost.
• Energy loss for ladle heating lost, standby of other ladles.

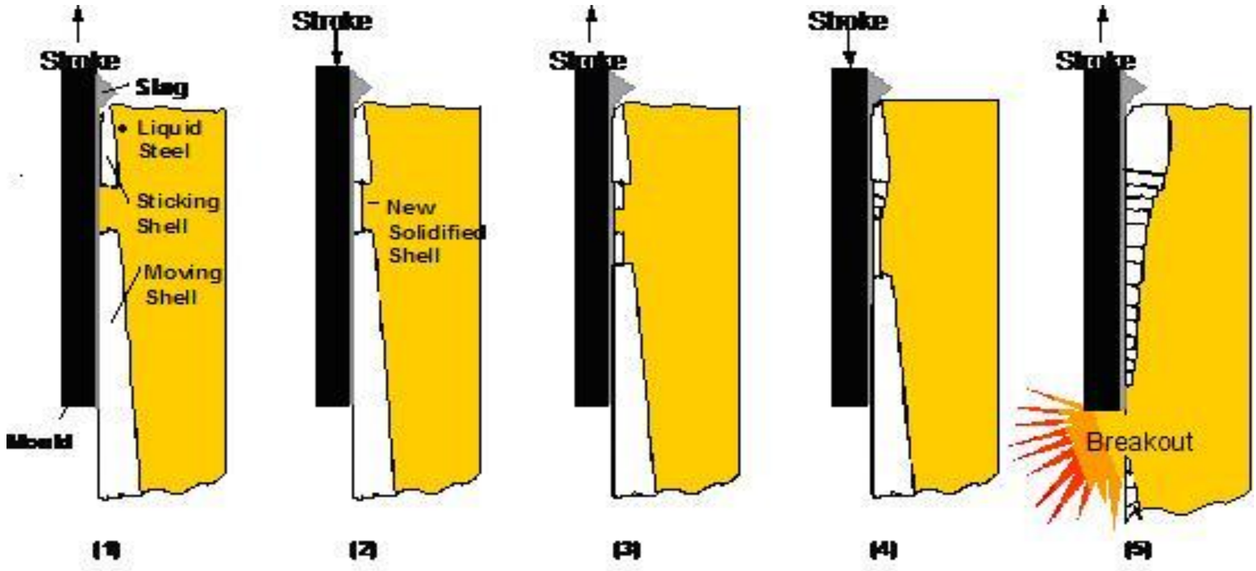


Figure 3: Breakout due to sticking

To avoid the sticking type breakout, many detection methods have been developed, such as measurement of heat flux, friction force and mould plate temperature. The measurement of temperature by means of thermocouples (TCs) embedded in mould copper plates has been proven to be the most suitable and most reliable method for detecting the sticker.

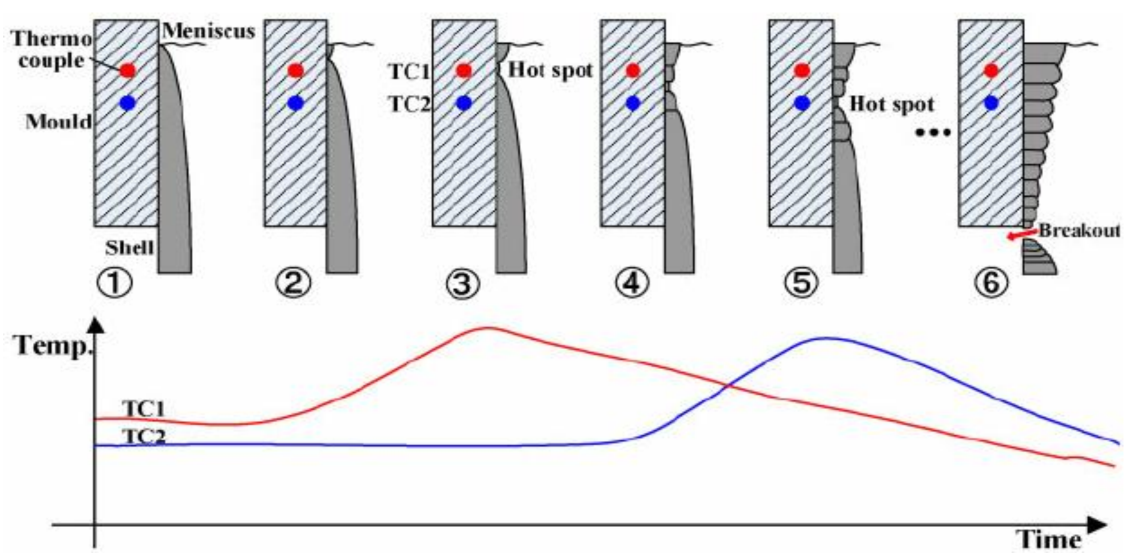


Figure 4: Breakout detection using thermocouple

When the shell is cracked in the mould, the mould and the molten iron are brought into direct contact with each other. As a consequence, at a site corresponding to the breakout (cracked portion), the temperature of the mould wall increases. After a certain delay from occurrence of the cracked portion, in the surrounding areas adjacent to the cracked portion of the shell, the temperature is increased through heat transmission from the cracked portion. Taking the above into consideration, a conventional breakout prediction system predicts the presence of breakouts by the use of a number of thermocouples located on the mould wall for monitoring a temperature variation pattern of the mould wall to detect presence of the cracked portion in the shell.

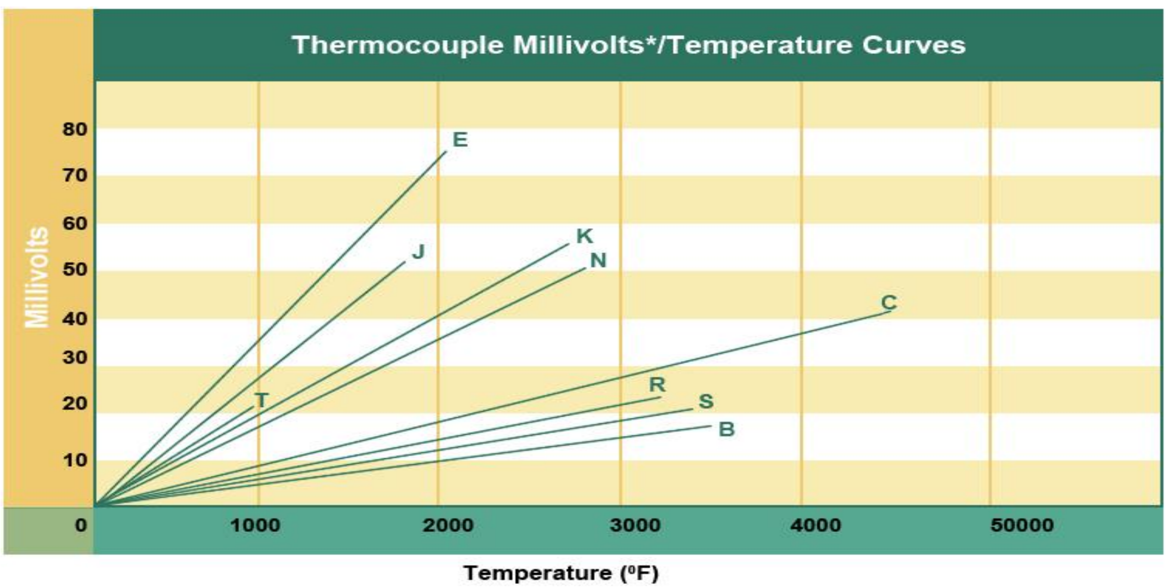


Figure 5: The thermocouple millivolts/temperature curves of different types of thermocouples available.

The suitable type of thermocouple must be chosen according to the function and temperature requirements.

There are 13 moulds in the Thin Slab caster and in each one of them, 60 thermocouples are inserted into the Water Jackets of copper plates. The metal shell temperature at each instance of time is given by the reading of the thermocouple, as the metal slab moves down the caster.

To avoid breakout due to sticker, reduction of casting speed has to be done. It heals the damage occurred due to sticking problem happening in the mould by providing more residence time for formation of stable skin.

The Breakout Prediction System includes an alarm generation based on signal (i.e. steep fluctuation of temperature) obtained from thermocouples fixed in the mould walls. Moreover, BPS also guides ramp of casting speed increment to reach its normal value after healing is done.

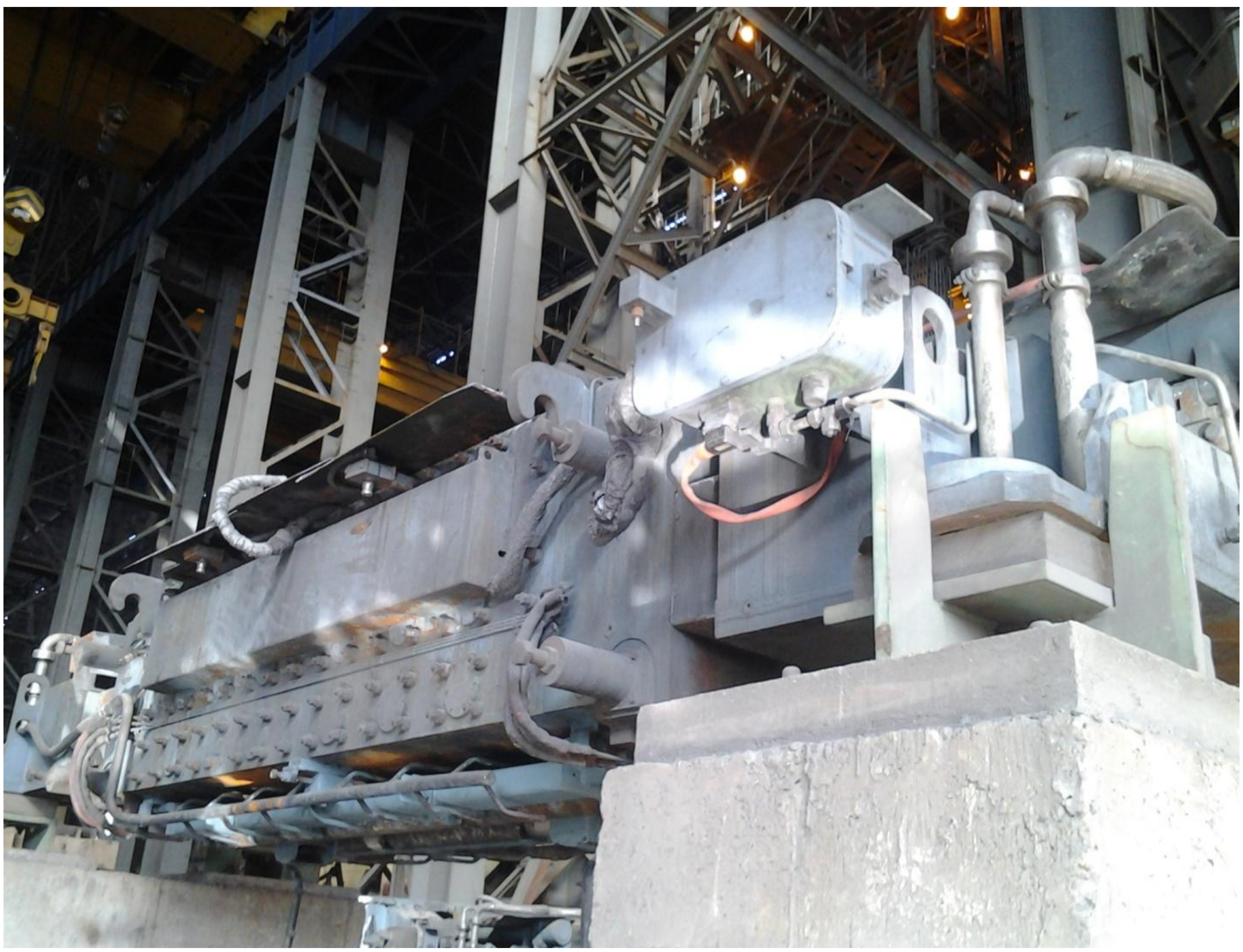


Figure 6.1: Typical instrumented mould

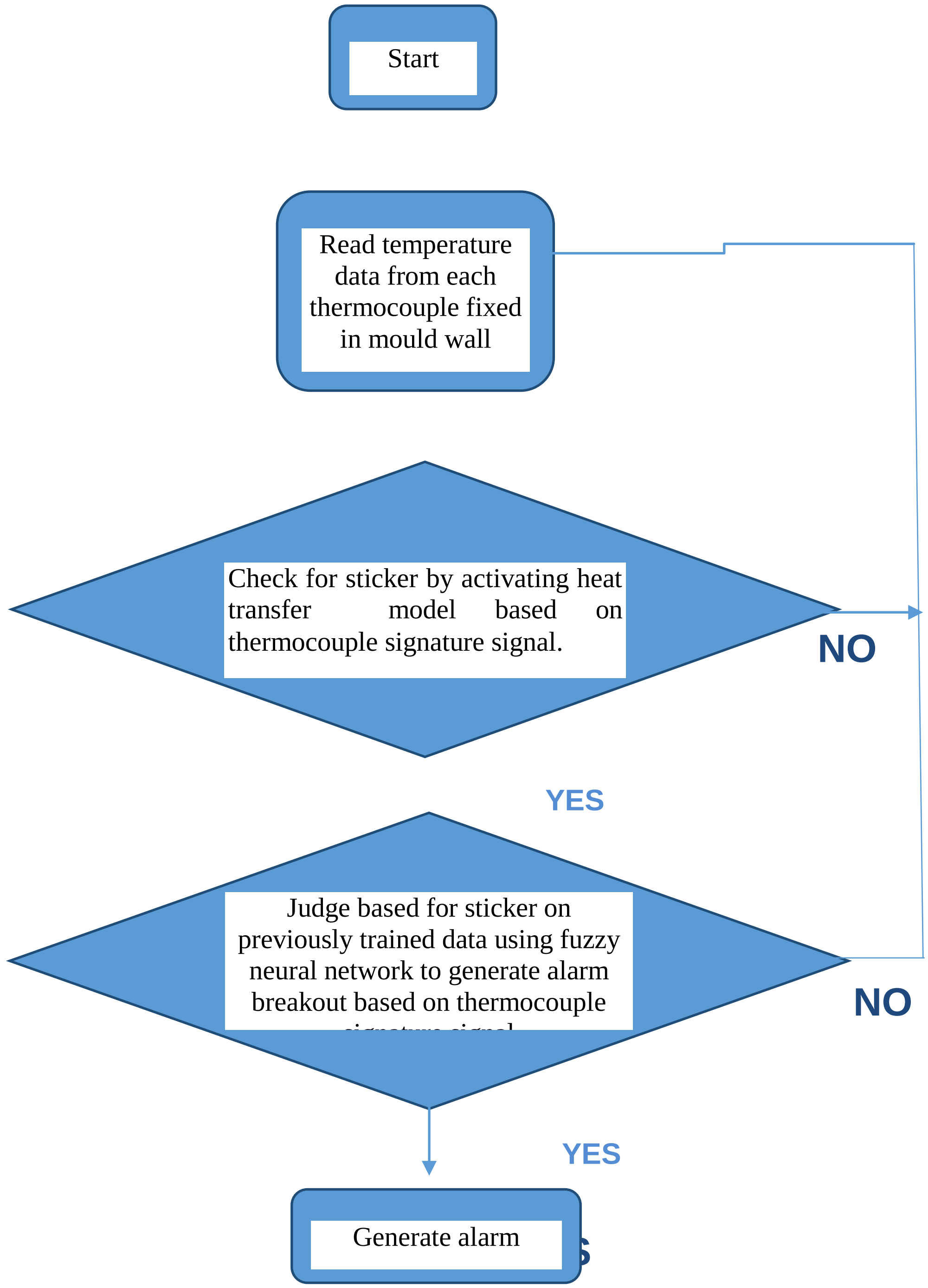
BREAKOUT DETECTION SYSTEM

- A system designed to predict and prevent sticking type breakout in CC process of steel is known as **breakout prediction system**.
- ***Sticker breakout-***
  1. Due to a disturbance in the lubricating conditions between the strand shell and mould wall, the molten steel "sticks" to one of the faces of mould during casting.
  2. If preventive action is not taken, sticking may lead to a rupture in the solid shell strand and the molten material is spilled out and hence a breakout occurs.

- ***Detection of sticking problems-***
  1. Sticker breakout in mould can be detected by monitoring characteristics pattern of temp profile of TCs placed in the mould.
  2. The temp profile from the TCs shows that in normal conditions, the highest heat flux point is found usually at the meniscus.
  3. But during a sticker breakout, this point moves down the mould wall.
  4. Then TCs in the mould wall will detect a temp inversion, where the lower TCs record higher temp than the upper ones for some time.

- ***Role of breakout prediction system(BPS)-***
  1. An alarm is triggered based on signal obtained from temp fluctuation i.e. when the lower TC is colder than the upper one for a specified time.
  2. Once the impending problem is identified, the casting speed is dropped for some time, allowing the sticker join the moving shell and hence avoiding a breakout

- ***Issues regarding performance of BPS-***
  1. Generation of false alarm due to faulty TCs .
  2. Missed sticker problem implying damage of some TCs while CC process.



(Flow chart for the breakout prediction system)

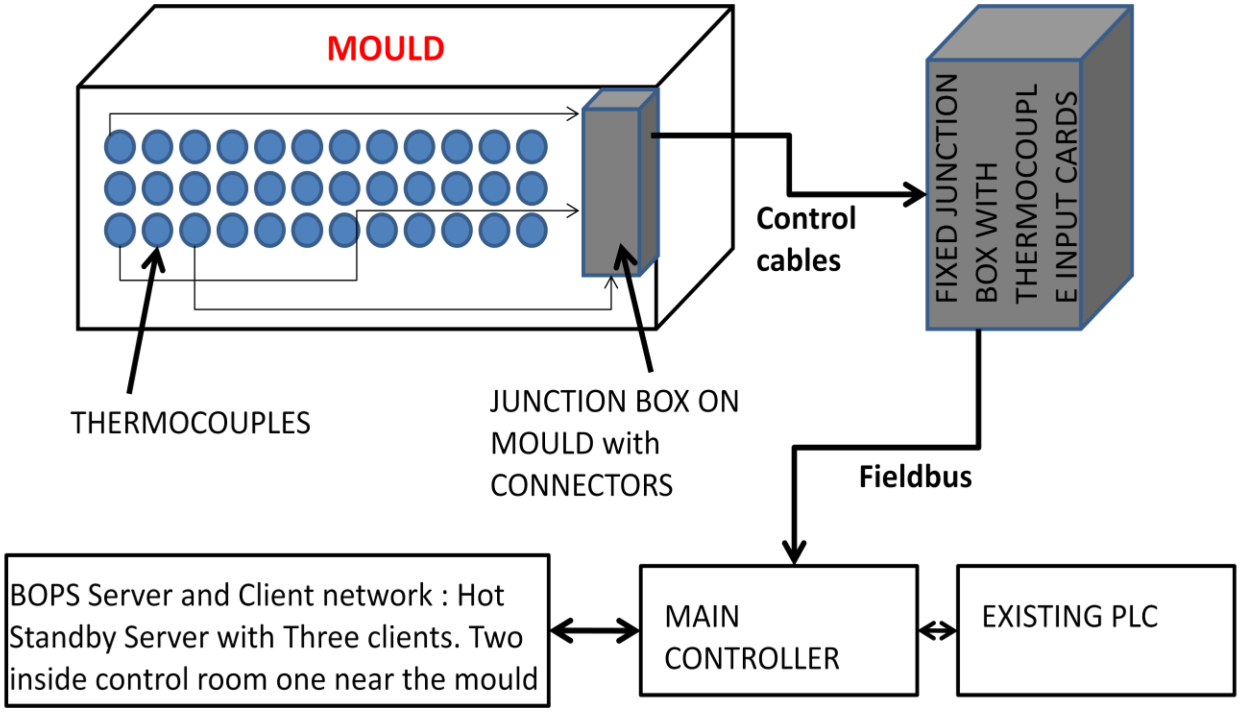


Fig. The overall Break Out Detection system

Fig 6.2: Thermocouples fitted in the mould

❖ **Overhauled moulds may have improver TC temperature variation in running caster, which can lead to breakout and slowing of cast speed. On an average one TC per mould shows temperature variation.**

To overcome this situation, we can implement
Integrated Breakout Prediction System (BPS) with heat transfer based solidification.

➢ ***Implimentation of heat transfer based solidification model of complete mould towards Breakout Prediction System (BPS)-***

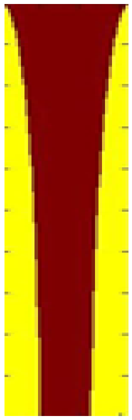
1. Heat transfer based solidification model of complete mould will predict the thickness of the shell inside the mould dynamically. Inside the mould at regular interval of time, the level sensors will detect the mould level and temperature at each step will be figured out.
2. By the application of this method, we can predict the temperatures of the one or two thermocouples if they stop functioning during the operation.

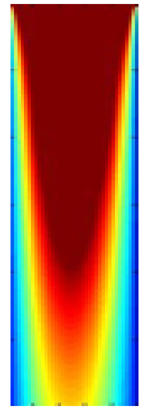
➢ ***Method for integrated BPS with heat transfer based solidification model-***

The proposed model needs casting speed, temp measured by TCs and material properties like density, thermal conductivity as input variables to determine the heat transfer rate from the molten metal at every node(i.e. grid of computational domain).

To get the temp change at each node, conductive and convective equations will be solved. Then it will predict the shell thickness and the characteristic pattern of a range of temp. This model will help to reduce the casting speed beforehand to omit breakout.

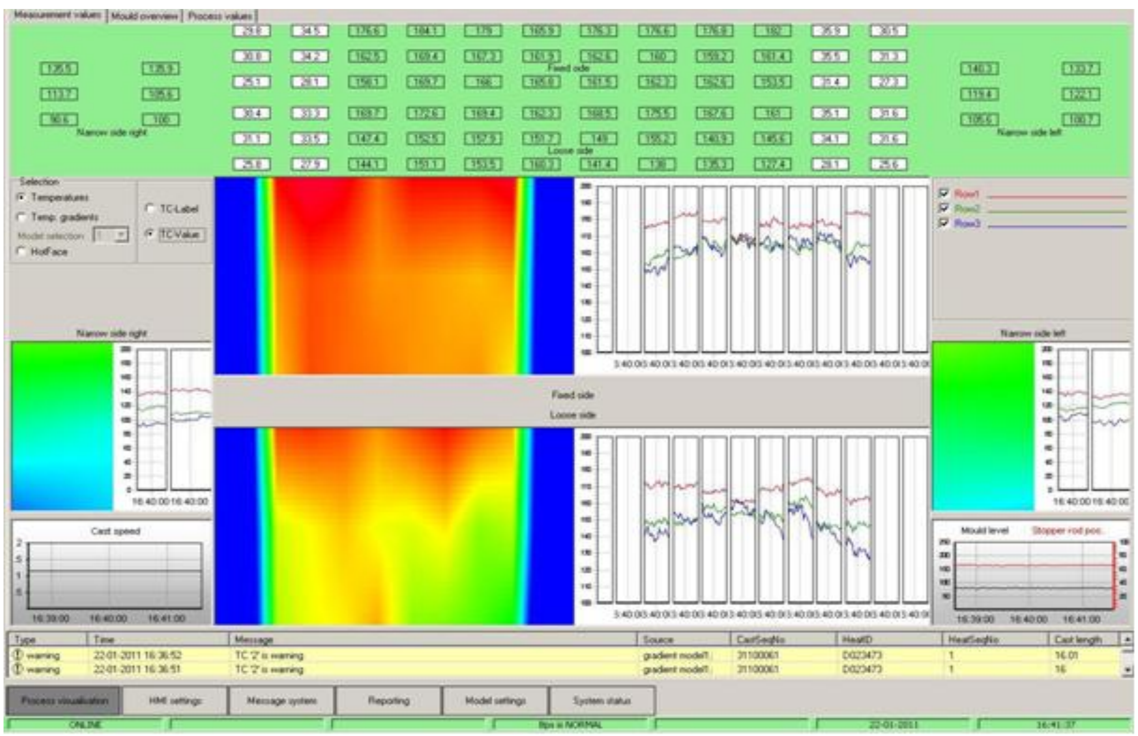
• To get rid of sticking type breakout, models can be prepared and communicate to and fro with actual BPS, which will help in the detection of sticker. A generalized model algorithm flow chart for developing BPS is given below. This flow chart shows that the temperature from the CC process is read from the TCs and patterns are noted. These thermal patterns are then compared with the simulated models to predict the breakouts. We can develop a heat transfer based dynamic model for the prediction of breakouts and the metallurgical length using MATLAB/Simulink.





a b

(Results of a model proposed to determine the metallurgical length and the temp profile using the same method;where (a) Solidified metal(yellow) and the molten metal(brown) & (b) Temperature profile from the model.)



Mould Thermal Image

TYPICAL HMI SCREEN

RESULTS

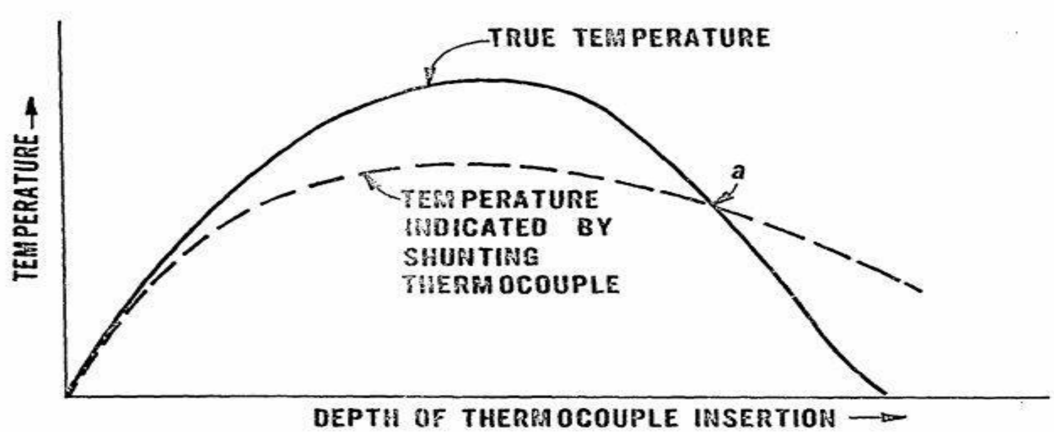
1) METHODS TO ENSURE OVERHAULED MOULD TO HAVE 100% ACCURACY OF TEMPERATURE MEASUREMENT:

To get 100% accuracy of temperature measurement, we must make sure that each of the 60 thermocouples in all 13 moulds are working efficiently without producing any error.

- For this we should carefully complete a thorough inspection of the thermocouple probe and wiring for pin holes, cracks and internal or external contamination issues which greatly reduce the accuracy of the temperature.
- *Leads reversion*-If the leads on the thermocouple are reversed, the temperature measured will be varying in opposite direction. Hence we can use the chart below to make sure +ve and –ve connections are in order.
- *Loop resistance*-Loop resistance of thermocouple circuit should be below 100 ohm. If resistance is high, then passing of a small current through the high resistance sensor to detect the break will generate voltage error.
- *Terminal connection*-Many times the readings are not correct or work at all, due to interference from crimp on connectors, wire insulation or incorrect materials being used for the connections.

So, the material selection for terminals should be done properly which can withstand the external conditions. Removing crimp from thermocouple wire when connected to cold junction yield a better result.

- *Thermal shunting*-The thermocouple should be positioned close to the Cu plate for maximum accuracy.



➢ Also we can follow the steps below during overhauling of the mould to ensure 100% accuracy-

1. A layer of conductive grease is applied on thermocouple tips to avoid direct contact with water.
2. Calibration of thermocouples should be done properly.
3. Checking and replacement of the defective seals of thermocouples.
4. Length of extension wires should be in accordance with temperature measurement range.
5. Proper isothermal balance should be maintained between the two terminals of thermocouple.
6. Same metals should be used in thermocouple(preferably close tolerance).
7. Multiple connections should be avoided.
8. Minimum number of joints in the wiring.

2) METHODS OF ELIMINATING FREQUENT FAILURE COMPONENTS:

- Abnormality in the shell growth can be detected by suitably mapping the mould. Characteristic signature pattern generated by the thermocouple coupled with the mathematical techniques can detect the impending breakouts.
- Ensure that thermocouple does not get any impurities inside during its manufacture or installation, or else the deterioration of the thermocouple will occur more rapidly.
- Because a change in temperature results in a slight variation in size over long periods of time, these constant cycles of expansion and contraction can cause "metal fatigue." In other words, the thermocouple becomes less and less resilient until it finally breaks. This process can be detected by monitoring the thermocouple for unusual readings, especially if it's in an environment where it is subject to repeated heat stress or extreme temperatures.

- **Sealed environment-** If the thermocouple is a sealed environment, any exposure to the atmosphere can exacerbate natural decay processes, leading to premature thermocouple failure. Oxygen in the environment reacts with the pure metal of the thermocouple, making the wires thinner and potentially more brittle: as the oxidation grows worse, it exposes more and more of the thermocouple to attack. Even a small amount of oxygen can cause problems, so a sealed thermocouple should have its environment checked regularly to make sure that it has not been compromised.

- **Proper Installation-** One of the leading causes of premature thermocouple failure is simply poor installation, which can make any other problems much worse. Thermocouples need to be precisely placed and protected. Otherwise, they may be subjected to stress beyond their design tolerances, or they may be brought into contact with chemicals that reduce the effectiveness or strength of their materials.

- **Proper selection of Thermocouple**- Thermocouples of noble metals are generally used for this purpose such as S, R , B type thermocouples which are made up of platinum and rohidium.

Thermocouple category	Graduation mark	Temp range	Specification		Thermal response time
			Dia mm	Protection tube	
Single Pt Rh 30-Pt Rh 6	B	0~1600	16	Corundum material	<150
			25		<360
Single Pt Rh 30-Pt Rh 6			16		<150
			25		<360
Single Pt Rh 10-Pt	S	0~1300	16	High-alumina material	<150
			25		<360
Double Pt Rh 10-Pt			16		<150
			25		<360
Single Ni Cr-Ni Si	K	0~1100	16	High-alumina material	<240
		0~1200	20		
Single Ni Cr-Ni Si		0~1100			

Table of different thermocouples and their temperature range.

3) METHODS OF ESTIMATING/INCREASING LIFE OF THERMOCOUPLE AND CABLE:

- Streaming water constantly tries to stream into the gap through which the TC has been punctured into the mould and may come into contact with the TC lead. To prevent this, pyrojacket can be used outside the divider.

Figure 7: Pyrojackets

- To prevent the staying of the copper plate with the steel shell, the mould keeps oscillating and as a result, the TC encounters a persistent jerk at a regular frequency. So proper shock retentive material must be used.

- Use thermowell to increase the life of thermocouple.

Figure 8: Various types of thermowells

- Do preventive maintenance- Thermocouples, protection tubes, and extension-wire circuits should be checked regularly. Experience largely determines the frequency of inspection, but once a month is usually sufficient.

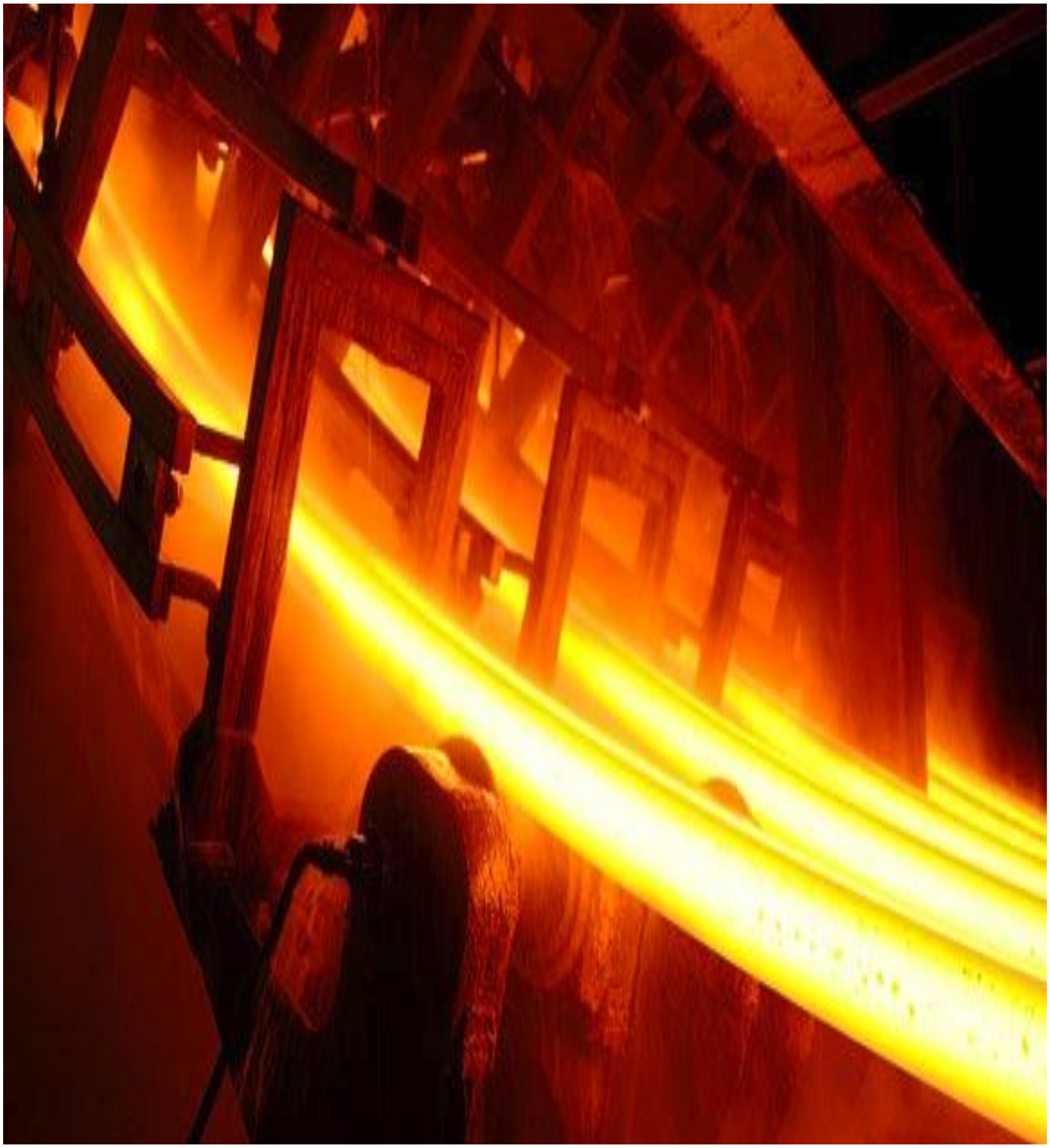
- Avoid Changing Depth of Immersion – Under certain conditions, inhomogeneities can gradually develop in a pair of thermocouple wires due to oxidation, corrosion, evaporation, contamination, and metallurgical changes. A change in depth of immersion, which shifts such inhomogeneous wire into a steep temperature gradient zone, can alter the thermocouple output and produce erroneous readings. Therefore, avoid changing the depth of immersion of a thermocouple after it has been in service. Thermocouples should be checked in place if possible. If it is necessary to remove the thermocouple, it should be reinserted to the same depth or deeper to avoid errors arising from placing an inhomogeneous segment of wire in a steep temperature gradient.

- Match Wire Type to the Thermocouple **–** The extension wire and connector wire are specific to the thermocouple type being used. Using the incorrect wiring components between control and process thermocouple can result in erroneous readings. Connectors and extension wire are often visually identified to thermocouple calibration type by color code.

4) WAYS OF IDENTIFYING IF LOW TEMPERATURE OF TC IS DUE TO PROCESS VARIATION?

- Check for cold junction compensation: Cold junction should be at a fixed value, if it is more than that fixed reference the reading will show lesser value.
- A library function can be created that stores all the possible values of temperatures for different processes. Whenever in doubt, the temperature detected can be compared to all the possible cases.
- Temperature can be compared with standard temperature transmitter and TC mV. If mismatch occurs there must be a problem in TC.
- Cable insulations must be checked.
- It must be checked whether the TC is immersed exactly or not. Due to vibration or any other reason it misaligns sometimes.

- It happens sometimes that TC card in data acquisition system malfunctions. It must be checked for that case.



Output - Casted Steel Slab from Continuous Casting Machine

CONCLUSION

I concluded that sticking of the solid metal shell to the copper mould is one of the major causes of breakout. To avoid any such situation, various methods can be implemented of which the use of thermocouples is the most reliable and accurate. The Breakout Prediction System uses multiple thermocouples punctured into the mould for monitoring a temperature variation pattern of the mould wall to detect presence of the cracked portion in the shell.

Once the presence of a sticker is confirmed by the model of BPS, an alarm is generated. Speed of casting is slowed down and healing time is provided for formation of stable skin. The speed is then increased back to normal and thus, a breakout gets prevented successfully.

I also concluded that various feasible ideas and methods can be implemented in the industries to increase the reliability of the thermocouples and maintain a high level of accuracy.
This will result in longetivity of the CCM (Continuous Casting Machine) and other equipments in its proximity. This will also help in achieving proper casting speed of Thin Slab and production without any major hindrances like that of Breakout.

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