Break Outs in Continuous Casting of Steel

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Introduction

Continuous Casting is a term applied to casting processes involving in continuous, high volume production of solid metal sections with a constant cross section from the liquid metal. The quality, grade and shape of the cast product influence the product end use for subsequently rolling in the finishing mills. It accounts for 90.5% of the global crude steel output & finds extensive use for improving the yield, quality, productivity and economics of steel production in the world. Depending on the desired annual tonnage, liquid steel availability and the anticipated operating hours, the continuous casting machine is designed for the number of strands & casting speeds to match the liquid steel supply from the melting shop.

Temperature and chemical composition homogeneity are the primary requirements of steel for continuous casting. The molten steel from the furnace is tapped in the ladle and is subjected to various ladle treatments involving alloying and degassing. After this, the ladle is transferred to the casting shop where argon rinsing is done to get the requisite cast flow temperature and placed on a rotating turret. The slide gate of the ladle is opened and oxygen lancing done to allow liquid steel flow via a refractory shroud into a tundish that allows a reservoir of the metal to feed the casting machine. The tundish possess various flow control devices such as dam, weir, baffles and impact strike pads that enhance inclusion separation & assure stable stream pattern to the mould. The liquid steel from the tundish is drained into the mould through orifices controlled by stopper rods and metering nozzles. Submerged entry nozzle present between the tundish and the mould in bloom/slab casters help in avoiding re-oxidation of the liquid steel during its flow in the mould.

The process of continuous casting is shown schematically in Fig.1.To start the continuous casting machine, the mould bottom is sealed by a dummy bar that is placed hydraulically through the spray chamber by the straightener withdrawal unit that prevents liquid steel from flowing out of the mould. The steel that

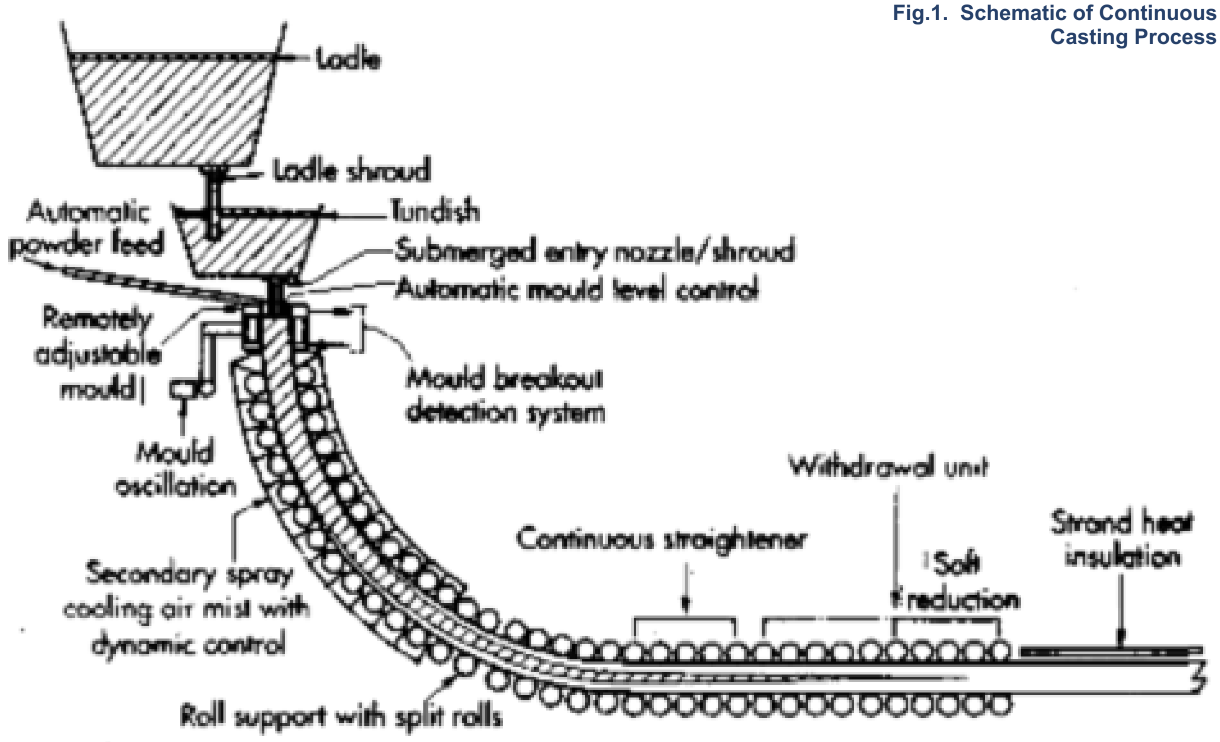

Fig.1. Schematic of Continuous Casting Process

is poured into the mould gets partially solidified with a solid outer shell and liquid core. To suppress the turbulence created by the liquid steel and control the fluctuations in the metal level, Automatic Mould Level Controller with either radioactive source or floater system are installed in the modern casters. The mould is equipped with oscillator to prevent sticking of the cast strand to the mould with mould oscillating cycles varying in frequency, stroke and pattern. A stroke pattern called negative strip is employed where in the downward stroke of the cycle enables the mould to move faster than the section withdrawal speed enhancing the shell strength. The friction between the shell and the mould is reduced through use of mould lubricants like oils or powdered fluxes. Once the steel shell has sufficient thickness, the straighter withdrawal unit gets started and proceeds to withdraw the partially solidified strand out of the mould with the dummy bar with liquid steel continuing to fall into the mould. The withdrawal rate is dependant on the cross section, grade and quality of the steel. After exiting the mould, the strand with the solid shell enters the roller containment section and the secondary cooling chamber. The support rolls below the mould are of high rigidity and the roll interval is short to minimize bulging caused by ferro-static pressure thus preventing subsequent cracking and segregation due to bulging. Here, the solidifying strand is sprayed with water or water & air mixture (air-mist) for promoting solidification thus preserving the cast shape integrity and the product quality. The roller containment area is based on the cross section of the product to be cast and higher the section, the longer the roller containment area. After the strand is completely solidified, it passes through the straighter withdrawal unit and the dummy bar is disconnected. After this, the strand is cut to required lengths either by oxy-acetylene cutting machine or flying shears.

The reliability of the continuous casting machine with regard to its availability and utilization is the key towards improved yield and increased productivity. Any operation irregularity during continuous casting can lead to the downtime of the caster affecting its availability. Hence, it is necessary to take care of the operational irregularities to enhance the caster availability.

Break Out – Affecting Caster Availability

One of the major operational irregularities encountered in continuous casting is “Break Out”. This is when the thin shell of the strand breaks, allowing the still-molten metal inside the strand to spill out and foul the machine, requiring an expensive shutdown. The downtime of the machine due to the strand break out is further prolonged for withdrawal of the break out strand as it may get jammed either with the guide rollers or foot rollers necessitating cleaning of the jam by gas cutting for withdrawing the strand. As the break out strand becomes relatively cold, it needs to be cut into small pieces for taking out from the machine with the straightening machine designed to straighten the curved cold strand in steps during the stationary stages and the upper rolls provided with adequate lifting weight for easy passage of the curved strand in smaller lengths. Hence, break out has a profound influence on the caster availability affecting the productivity and the cost of production.

Factors Influencing Break Out

The factors that influence break out occurrence are

✦Inconsistent Temperature & Casting Speed

Higher the superheat of the liquid steel, lower is the thickness of the shell formed. Due to the ferro-static pressure exerted by the flowing metal in the mould, bulging takes place and as the shell does not possess sufficient strength, break out occurs. Inconsistent and inhomogeneous temperature has a big influence on cause of break out. As casting speed increases, the occurrence of break out increases since mould lubrication becomes insufficient due to the lack of mould flux flow from meniscus into the solid shell/mould boundary. Also, increasing casting speed results in decrease of the total heat removal. Often, breakout is due to too high a withdrawal rate, as the shell has not had the time to solidify to the required thickness, or the metal is too hot, which means that final solidification takes place well below the straightening rolls and the strand breaks due to stresses applied during straightening. For a fixed carbon content of the steel, higher temperature and higher speed combination influences break out occurrence.

Any change in the oscillation setting for reducing the oscillation mark severity through increasing the oscillation frequency that increases the speed of the mould thus increasing the friction at the interface risks break out occurrence.

✦Improper Lubrication between the Mould & the Strand

Poor quality of casting powder if used gets entrapped in the molten steel below the meniscus resulting in improper lubrication between the mould & the strand causing sticking of the strand which poses difficulties in withdrawing the strand from the mould resulting in discontinuity in the strand leading to hanging break out. In case of billet casting, the shell sticks to the mould due to inadequate or uneven lubrication affecting the heat transfer causing sticker break out.

✦Ineffective Water Flow in the Mould

Any decrease in water flow to the mould leads to lowering of heat extraction leading to formation of very thin shell ultimately resulting in break out. The difference in inlet and outlet water temperature, pressure and flow rate has a bearing on the mould cooling. Choking in the mould cooling system leads to increase in pressure and reduction in flow rate affecting heat extraction and break out occurrence. Also, the large difference in inlet and outlet water temperature (high T) results in sticking of the strand in the mould leading to break out.

✦Improper Mould Geometry

Moulds are provided with a taper to accommodate the shrinkage of the steel on solidification for increasing the metal-mould contact area and thereby increasing the heat extraction from the mould. Increasing heat extraction increases the shell thickness. In case of a conventional mould with linear taper for high speed billet casters, the heat transfer at the meniscus level rapidly produces a solid shell with shrinkage of the shell pulling the corners off the mould stopping heat transfer and at the bottom portion of the mould, shell growth continues except at corners where re-melting takes place. When the shell leaves the mould, the shell temperature shows considerable variation and application of increased casting speed during this time can result in a break out. If the taper provided does not match the requirements, an air gap is introduced between the mould and the metal shell. As air has the highest resistance to heat in the mould heat transfer system, it greatly hampers the formation of the shell of required thickness eventually leading to break out.

The loss in taper of the mould caused by wear and distortion leads to a marked increase in the occurrence of longitudinal corner cracks as a result of reheating of the corner. As far as the distortion of the mould is concerned, it can take place due to the lower thickness of the copper plate and insufficient support of the copper plates to take care of the thermal expansion of the copper. Distortion of the mould can also take place due to damage of the lower part of the mould

during dummy bar insertion. An excessive taper of the mould increases the resistance to withdrawal that results in increased mould wear. The combination of reverse taper and thermal shrinkage causes air gap thickness to increase that results in increased wear of the corner thereby lowering the heat extraction which makes the surface temperature to increase. This phenomena coupled with the ferro-static pressure induces a tensile strain at the surface in the corner causing cracks to occur. This crack effectively reduces the thickness of the shell in a highly localized manner, which may eventually lead to a break out.

Higher the corner radius of the mould, higher would be the air gap. This air gap resists heat transfer leading to formation of thin shell and facilitate break out occurrence. In slab/bloom casters, four separate copper plates are fixed to form cavity encircled between them. If there is a gap along the junction between the two copper plates, the initial metal penetrates into the gap and gets solidified causing hanging at a later stage to result in formation of a break out. Also, improper alignment of the mould has an impact on heat transfer mechanism influencing occurrence of break out.

✦Improper Level of Metal in the Mould

During casting, metal level in the mould needs to be maintained at 70%-80% of the mould height. If the molten metal level drops below the submerged entry nozzle, then the skin formed on the subsequently added metal will be less and break out takes place. This drop in metal level can take place during nozzle change, tundish change or tundish nozzle choking. Break out can occur if the casting speed is not regulated when there is restriction of metal flow from tundish to the mould. Also, if there is any mould overflow caused by improper control of stopper rod leading to running, the over flown metal sticks to the mould top causing hanging causing difficulty in withdrawal of the strand which after some time results in a break out.

The lowering of the metal level in the mould also causes slag entrapment. If the submerged entry nozzle is closed using the stopper rod for sufficient period of time, the molten metal level in the mould gets lowered below the allowable limit and if pouring starts again, the liquid metal suppresses the mould slag resulting in slag entrapment. Also, during the change of ladle for sequence casting, the tundish metal level gets down and if proper care is not taken, the slag from the tundish can enter the metal inside the mould through the submerged entry nozzle. Re-oxidation caused by flaring open stream, improper de-oxidation, high slag viscosity envisaged by incorrect aluminium wire injection in the billet mould to result in making slag highly viscous due to high Al_2O_3 can infiltrate in the strand forming slag spots locally inhibiting the shell formation. This slag entrapment paves way towards improper lubrication between the strand and mould causing sticking of strand to the mould resulting in strand discontinuity and leads towards break out.

✦Off-Center of the Metal Stream from Tundish to the Mould

Off-center of the casting stream from the tundish leads to improper heat dissipation causing uneven shell in the mould. Due to the lower strength of the thin shell, break out occurs as the metal coming into the mould induces ferro-static pressure.

✦Choking Of the Spray Cooling Nozzles

The foot roll section is present just below the mould where in the water is directly sprayed on the strand by means of nozzles. The strand is supported from all sides by the rollers making the passage of the strand smoother. Here, maximum amount of heat is extracted facilitating formation of thicker skin of the shell. If the nozzles in this section get choked, the skin thickness of the shell will be comparatively low causing break out. In case the foot rollers get jammed, the strand will not pass easily requiring extra pull by the withdrawal rolls which if crosses a limit causes rupture of the strand surface leading to break out.

✦Dummy Bar Irregularities

Once the molten metal solidifies in the mould above the dummy bar and a shell of sufficient thickness is formed, the dummy bar is gradually withdrawn. If the dummy bar is withdrawn erratically, break out occurs. Also, loose packing of the dummy bar leads to molten metal flow out of the mould resulting in break out. If the dummy bar separates from the strand prior to the lifting of the dummy bar head, premature separation occurs which can lead to break out occurrence.

Types of Break Out

Based on the appearance of the break out shell, break outs are broadly classified into various categories.

✦ Hanging or Sticking Induced Break Out

Here, molten metal sticks to the mould and hence, the name sticking or hanging. This may be caused by either improper lubrication between mould & strand caused by poor quality of casting powder, slag entrapment in the mould, mould overflow, presence of mould corner gaps, inadequate/uneven oil lubrication in case of billet caster or improper alignment of the mould.

✦Crack Induced Break Out

Longitudinal corner crack and broad face longitudinal cracks in the strand influences the break out occurrence. In case of longitudinal crack induced break out, the uneven flow of casting powder and uneven heat removal from the mould results in non-uniform shell growth and the thin shell ruptures during cooling caused by improper selection of casting powder & non-uniformly cooled mould. For longitudinal corner crack induced break out, the shell insufficiently solidified along the narrow face of the mould gets broken by tensile stresses during contraction caused by reduced mould narrow face taper and improper heat removal from the narrow faces.

✦Entrapped Slag Break Out

The entrapment of casting powder or large sized inclusions in the shell results in reduced heat transfer leading to thin shell causing break out. In case of billet casting, re-oxidation, improper de-oxidation of low carbon steels with highly viscous slag, incorrect aluminium wire addition in the mould increasing alumina content cause slag spots which inhibit the shell formation to form slag break outs.

✦Thin Shell Break Out

This type of break out is observed in billet casters caused by uneven shell formation in the mould due to either off centering of the casting stream in the mould or highly deformed mould tube.

✦ Teeming Arrest Induced Break Out

Failure to disconnect a teeming arrest for interruption in casting while sequencing the heat results in a break out if the joint cannot withstand the withdrawal force on restarting the casting.

Measures to Control Break Out

Considering the impact of break out on caster utilization and availability, necessary measures are to be taken to control the occurrence of it.

✦Ensuring uniformity of the temperature by taking temperature only after argon rinsing at the casting platform. Based on the steel chemistry, cast flow temperature has to be fixed at a super heat of around 60C before placing the ladle on the turret to assure superheat of 25C-35C in the tundish.

✦Control the casting speed based on the temperature monitored in the ladle. For a fixed carbon content of the steel, ensure higher the temperature with lower the casting speed & higher the casting speed with lower the temperature. Hence, properly adjust the casting speed depending on the temperature and carbon content of the steel. Increase the casting speed in steps and maintain steady state casting by casting at a particular speed. For any interruption in casting during sequencing, reduce the casting speed.

✦Any casting powder has a self-life period and hence should not be used after that period. Casting powder should be opened only during casting and can be dried by placing a high wattage bulb. Never use the opened bags of casting powder for another casting. Select the appropriate casting powder for a given steel chemistry. During start up of casting, use start up casting powder of low viscosity and low melting point. In case of billet casters, ensure uniform distribution of the linseed oil in the mould.

For slab/bloom casters, measure the molten slag pool thickness to assess that the slag pool thickness is in excess of 10 mm and sufficiently more than the stroke by using apparatus consisting of steel, copper & aluminium wires attached to a plate. This can help in avoiding slag entrapment and uniform lubrication of the strand.

✦Use of multi-tapered moulds in place of conventional linear tapered moulds for high speed billet casters.

✦Check the moulds for distortion if any. Select the appropriate mould taper and adjust it for the narrow face based on the steel grade and the solidification mode in bloom/slab casters.

✦Check the water flow in the mould and identify choking if any by measuring the increase in the water pressure before the start of casting. Overall, check the difference in inlet and outlet water temperature, pressure and flow coupled with inspection of the flow equipment. Also, check the quality of water. Adjust the mould cooling pattern i.e. water flow in lit/min. for various faces of the mould based on the steel grade and solidification mode for such grades. To take care of sticking, detect the mould wall temperature changes using thermocouples and decrease the casting speed so as to allow the shell to re-grow uniformly. For a given caster, ensure that the difference between the inlet and outlet water temperature does not exceed the specific value during casting.

- Ensure corner radius along the copper plates to be 0.2 mm max. If corner gaps exist along the junction of the copper plates, fill the corner gaps with gypsum or lime before start of the caster.
- Install Automatic Mould Level Controller in the casters for maintaining the metal level in the mould. For differentiating the metal and the slag in the mould and take caring of slag entrapment, electromagnetic sensors can be installed in the mould.
- Adjust the tundish nozzles and center the tundish before casting. Take care of tundish nozzle choking by assuring Ca-Si cored wire injection before placement of ladle on the turret for high aluminium steels to form low melting calcium aluminates. Stopper running can be avoided by use of freezer.
- Assure proper de-oxidation, prevent re-oxidation by using tundish metal covering flux & use of shroud between ladle and the tundish and maintain Mn/Si > 3 for billet casters.
- Seal the dummy bar head with asbestos rope, use chiller box and ensure proper distribution of chillers before casting
- Inspect the spray cooling nozzles and water flow through the nozzles for identifying choking if any.

Conclusions

A thorough understanding of the reasons for break out on the appearance of the break out shell and the experience behind its occurrence can help in controlling break outs during continuous casting and pave towards increased caster availability to meet the targeted productivity and improved yield.