Control Of Centerline Cracking in Continuous Cast Corten Steel Slabs

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Introduction

Continuous Casting has evolved as an important production process leading to improvement in the yield, quality, productivity and economics of steel production in the world. Today, it accounts for 90.5% of the global crude steel output. A good quality product with high productivity is an essential requirement of a modern continuous caster that necessitates identifying the critical factors responsible for defects and ensuring implementation of possible remedial measures for production of defect free casting.

Centerline cracks as shown in fig.1 are one of the major internal defects observed in Corten steel slabs that appear near the centerline of the cast slabs and are caused by shrinkage of the liquid at the center on the account of liquid to solid transformation and deformation of the strand. These cracks can occur as a result of thermal strains whenever a region of the slab is subjected to a sudden temperature change of 100°C to 150°C relative to the neighboring regions, as the ductility of the steel at this temperature (>1300°C) is only 0.2% to 0.3% (ref.1).

Cracks and heavy segregation along the centerline of the as cast slabs are principally formed as a result of fluctuations in slab geometry at the point in the strand where final solidification occurs due to misalignment and/or bending of the support rolls (ref.2). Due to these cracks, the centerline is open and oxidized during the cooling process and as a result do not close on subsequent rolling.

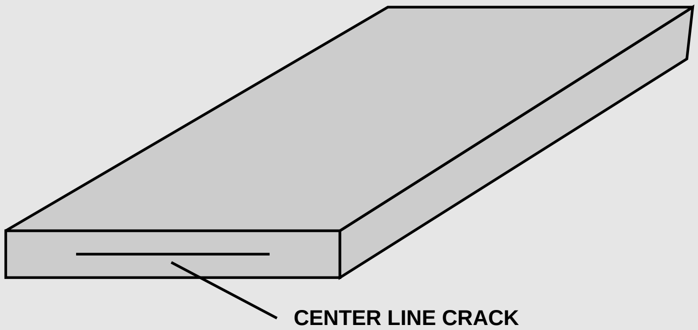


Fig.1. Centerline Crack in Continuous Cast Steel Slab

Literature Survey

Corten steel belongs to the category of structural steels called ‘Weathering Grades” in which the resistance to atmospheric corrosion is improved by addition of small amounts of Cu, P, Ni & Cr. This steel rusts at a lower rate than plain carbon steels and under favorable climatic conditions can develop a stable hydrated iron oxide layer that retards further attack and hence finds suitable to Indian climatic conditions. It finds extensive use for railway coaches and containers to handle waste. This steel grade is highly prone to centerline cracks in the continuous cast slabs.

The factors influencing centerline crack occurrence in Corten steel slabs are

(a) Segregation (b) Cooling Condition (c) Machine Condition

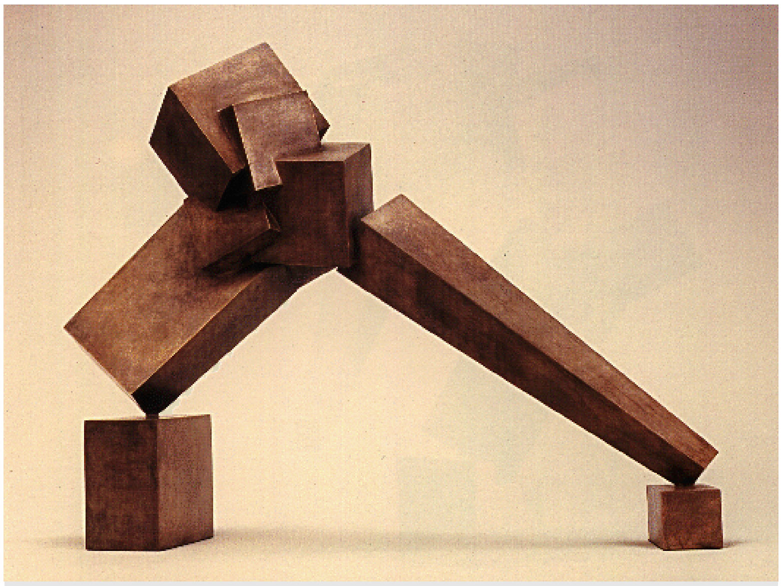
(d) Casting Speed

(a) Segregation

Segregation refers to the non-uniformity of chemical composition caused by rejection of solute by the liquid during freezing as the solid has less solubility for them compared to the liquid and the increasing content of the common elements such as C, Mn, P & S ameliorate segregation tendency in steels. While micro-segregation is caused by difference in composition between the dendrites and the inert-dendritic liquid, macro-segregation refers to non-uniformity of the chemical composition in the cast section on a large scale.

Corten steel grade possess carbon content of around 0.10% accompanied with phosphorus level of 0.085% and hence, solidifies first directly to δ which later transforms to γ by a peritectic transformation causing shrinkage that is compensated by flow of the remaining melt i.e. macro-segregation owing to high diffusivity of P in δ (ref.3). It could also be a consequence of the physical movement of the micro-segregated spots due to motion of the fluid & free crystals. The fluid motion is due to the density difference because of temperature & composition gradient in the melt that leads to free convection, forced convection due to stirring by gas evolution & pouring of the liquid stream, surface tension driven flow near the surface of the mould and suction of liquid from the inter-dendritic region due to the shrinkage of metal during solidification which is often aggravated by bulging of the metal surface due to presence of withdrawal rolls or differential stresses in the solidified shell as a consequence of the thermal gradient (ref.4).

To reduce segregation & thus inner crack formation, an equi-axed zone is recommended. There are innumerable tiny crystals



floating in the melt. When the superheat is dissipated, these start growing thus forming equi-axed zone. Therefore, superheat should be as low as possible so as to lower the macro-segregation in the central region. This clearly indicates the influence of superheat on centerline segregation and cracking.

Centerline segregation deteriorates due to roll bending. Because, the bent roll rotates eccentrically due to thermal deflection of the roll, the slab is greatly reduced in thickness by the bent roll when the convex side of the roll reaches the slab surface, causing the flow of the residual molten steel that may induce enrichment of the solute elements. Also, the center segregation at the position where the slab is frequently subjected to reduction due to the attachment of the convex side of the roll might be locally improved because of the flow out of the enriched molten steel, while at the position where the slab is frequently subjected to lighter reduction due to the attachment of the concave side of the roll, the segregation may greatly deteriorate because of the inflow of the enriched molten steel and succession of the squeezing of the molten steel at the roll position, thus causing the variation of the center segregation in the casting direction (ref.2).

(b) Cooling Condition

Surface reheating is a phenomena defined as the difference between the surface temperature of the casting at the bottom of the spray zone and the relatively constant temperature of the cast product about 2 m below the mould (ref.1). The size and the number of cracks are reduced with less surface reheating. If the spray cooling water is applied uniformly over a much shorter length, it results in considerable reheating and the occurrence of cracks is significantly increased. It is due to the sudden loss in heat extraction rate from the surface as the slab moves from sprays into radiation cooling zone. The centerline temperature suddenly decreases once all the latent heat has been removed. The centerline contracts and is placed in tension while it cools through the zone of low ductility resulting in centerline cracking.

The formation of centerline cracks can be suppressed by increasing the spray cooling rate to the surface of the strand at the point of complete solidification (ref.5). Increased spray cooling has a beneficial effect because it results in a cool shell that can more effectively withstand the ferro-static pressure. Strong spray cooling can produce fine dendrites and thus reduce the micro segregation & inner crack formation (ref.6).

(c) Machine Condition

This is an important factor that strongly influences the formation of centerline cracks. Improper roll gap might result in bulging of the solid shell that aggravates centerline segregation. If the shell bulges outwards, cavity is created in the central liquid region thus enhancing suction of the impure inter-dendritic liquid from the surrounding mushy zone into the central region. Re-gapping the rolls in the continuous casting machine reduces centerline cracking in the slabs. The strain responsible for crack formation is generated by bulging of the wide face owing to inadequate containment and it is normal to the bulging force acting on the regions of low ductility near the solidus at the central zone (ref.7).

In general, the support rolls for the slab caster are designed for cooling by means of single central hole for the cooling water and these rolls are popularly termed as Hot Rolls. This results in the roll surface being hot during casting making the hot trolls more susceptible to bending. Also, the bending tendency is proportional to the cube of the length of the roll.

When the hot slab enters the roll gap, a deflection occurs as the ferro-static pressure is applied to the roll. This deflection is within 1 mm and remains almost constant. How ever, when a short interruption (about 1 minute) to casting occurs and the slab is stopped (which may be due to bumping caused by improper machine alignment), the roll bends appreciably towards the slab due the thermal reasons. On recommencing withdrawal, the roll rotates eccentrically for a period of time until temperature equilibrium is achieved, after which the roll returns to the constant deflection situation. Hot rolls bend greater amount at the stoppage and takes a longer time to recover. Total recovery might not even occur in hot rolls. Machine alignment is also affected by roll wear particularly for small diameter rolls with wear caused by a combination of stress and corrosion (ref.8).

Optimum roll lay out needs to be determined by considering the effect of strains due to inter roll bulging and roll misalignment. Also, optimum roll pitch is necessary as tight roll pitches reduce roll bulging and increase roll misalignment. As bulging occurs at every roll pitch and misalignment inevitably variable (in fact, it can obviously be zero at some rolls), the greater weightage should be given to bulging (ref.9).

(d) Casting Speed

Higher is the casting speed, lesser is the time for heat extraction. Hence, longer would be the length of the liquid core as well as the mushy zone and lesser would be the thickness of the shell upon emergence from the mould that leads to slab bulging and macro-segregation at the center of the slab. Lower casting speed produces stronger shell that could withstand ferro-static pressure and reduce segregation. Optimization of the casting speed is necessary as it cannot be lowered beyond a certain limit since, this could seriously cut down the production

Experience at Alloy Steels Plant

Alloy Steels Plant, Durgapur possess a unique slab cum bloom curved caster with capability to produce slabs in single strand and twin strand for blooms for a variety of alloy steels. During the period 1996-97, the plant witnessed problems of centerline cracking in cast slabs of the Corten variety steels. This led to in depth study of various casting and machine parameters in about 105 heats that constitutes of heats both with and without centerline cracking in slabs for assessing the responsible parameters for cracking in this steel grade (ref.10).

It was observed that instances of centerline cracking increased with super heat exceeding 40°C, application of the combination of Hard Mould Cooling (HMC) having water flow rate > 5900 lit/min. or Normal Mould cooling (NMC) having water flow rate 5250 lit/min. – 5900 lit/min. with Soft Spray Cooling (SSC) having specific water consumption of 0.66 lit/kg, hydraulic pressure of 70-75 bar at withdrawal and higher roll gap in the segments 3 to 7. Casting speed was found to have no influence on cracking as it was averaging 0.80 m/min. in both good and centerline crack cases.

- One of the prime factors responsible for centerline cracking was higher roll gap in the segments 3 to 7. In the caster, there are 5 rolls each in these segments having roll diameter of 310 mm with barrel length of 1350 mm. The rolls in these segments are of center bore design with cooling provision for the roll through the center bore. The roll gap is 175.5 mm for segments 3 & 4, 175 mm for segments 5 & 6 and 174.5 mm for segment 7. In all the rolls, the bottom roll tolerance with template is 0.9 mm min. and 1.1 mm max. The maximum bending permissible is 2 mm for individual roll and 3 mm combined. After casting of centerline crack heats, the rolls in these segments was observed which revealed roll bending and higher roll gap. It was revealed that roll bending occurred due to stoppages during casting (failure of slide gate, bumping etc.) that heated up the roll, improper supply of water for cooling inside the rolls due to leakages along the rotary joints and finally, the rolls were not allowed to run for a specific period of time after casting. Along with the above, non-removal of the worn out rolls, non-regular roll gap checking and improper cleaning of the machine aggravated increase in roll gap. Regular monitoring of the roll gap, avoiding leakages along the rotary joints complimented with continuous cooling of the rolls till steaming stops after casting for ensuring roll stability and periodic checking of the machine for removing the worn out rolls & replacing them could greatly contribute in production of centerline crack free slabs.
- Increase in spray cooling intensity from specific water consumption of 0.66 lit/kg to 0.80 kg/lit also helped in drastic decrease in centerline cracking of slabs. The combination of Soft Mould cooling (SMS) with water flow rate of below 5250 lit/min. that facilitated increased shell strength and hard Spray Cooling (HSC) of 0.88 lit/kg minimized the cracking incidences in the Corten steel slabs. Along with the above, maintaining super heat below 40°C reduced cracking tendency in the cast slabs.
- Application of higher hydraulic pressure at withdrawal (70-75 bar) in combination with Soft Spray Cooling (SSC) was found to have a combined effect on centerline crack formation in the slabs. It was also observed that the hydraulic pressure fluctuations were 15 bar - 25 bar on the dummy bar. Reducing the hydraulic pressure at withdrawal to 60- 65 bar and assuring Hard Spray cooling (HSC) decreased the instances of centerline cracking.

At Alloy Steels Plant, centerline cracking in the slabs could be totally eliminated through control of the casting and machine parameters.

Conclusion

The casting and machine parameters play a pivotal role in occurrence of centerline cracks in continuous cast steel slabs of Corten type steel grade. These defects can be eliminated in the cast product by monitoring the roll gap & bending, application of soft mould cooling followed by hard spray cooling, maintaining superheat below 40°C and appropriate selection of casting speed & hydraulic pressure at withdrawal.

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