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Main Processes in Steel Production with continuously cast Method

Continuous casting, initially introduced in 1840, is an attractive method in mass producing semi-finished metal shapes (slabs, blooms, and billets) from molten metal. More than 50% of current world's steel production is produced by continuous casting. Today, annually 750 million tons of steel in the steelmaking operation, 20 million tons of aluminum and many tons of other alloys are directly cast from molten metal by continuously casting method [1]. This paper presents a short review over the processes in continuously cast steel.

Introduction

Enhancing the quantity of the cast steel utilizes reducing the final cost of the cast steel products. Mass production of steel occurred only after the invention of the steam engine. The conventional casting of steel from iron ore is ingot casting. The continuing increase in the demand for steel around the world has been establishing the competition between countries and companies in producing larger mass of steel. This annual increase in demand for steel and competition to dominate over the market encouraged worldwide investment on research in increasing the speed of production and lowering the cost of the final steel products.

Continuous casting is an attractive method in making semi-finished metal shapes (slabs, blooms, and billets) from molten metal. The continuous casting method has many advantages such as increase in yield, better surface condition and internal quality of production, more uniform product, higher manpower productivity, easier integration into metal production systems and reducing metal production cost by saving time, energy, and capital. This is due to eliminating extra steps, such as ingot teeming, stripping, and transfers; soaking pits; and primary rolling [2, 3].

George Sella got a patent on continuous casting of metal for producing pipe in 1840 [4]. Henry Bessemer patented process for the manufacturing of continuous sheets of iron and steel in 1946 [5]. Thereafter, many inventions and modifications helped continuous casting process technology to grow to become the primary technique in producing ferrous and non-ferrous metals. The first vertical type large slab machine with bending of the strand to horizontal discharge was launched in 1961 [5].

Detailed historical aspects of continuous casting can be found in many papers [6, 7]. Today, annually 750 million tons of steel in the steelmaking operation, 20 million tons of aluminum and many tons of other alloys are directly cast from molten metal.

Process in continuous casting of steel

In continuously cast method a ladle filled with hot metal is rotated from the electric or basic oxygen furnace to a cast machine on top of the rectangular or delta and "T" shapes bath called a tundish. Molten metal is delivered from the ladle to the tundish after ladle treatment like alloying or degassing via a refractory shroud. Inserting argon gas causes a fully turbulent transient fluid motion in the tundish [4]. The main function of the tundish is to create a continuous, steady, and stable flow of liquid steel into the mold during draining of the ladle. The mold is tapered to compensate for metal shrinkage on solidification. It provides better heat transfer and, more importantly, fewer cracks. Sigfried Junghans introduced the oscillating mold system to the continuous casting [6]. Lubrication and oscillation of the mold decrease the friction to avoid sticking of the solidifying steel, shell tearing, and liquid steel breakouts [7]. Researchers found that the length of stroke and frequency of oscillation affect the quality of the steel and should be specified depending on the type of the steel [8].

The lubricant is the powder added to the molten metal [9]. Sintering and melting of mold powder added to the top of the steel surface protects the liquid flux layer. The powder flows over the liquid steel due to its low melting point and creates a lubricant between the shell and mold. This enhances the cleanliness of the steel by trapping the inclusions and other impurities and protects the metal from re-oxidation [3]. McPherson used the term "Mold Metallurgy" to emphasize the effect of the mold in steel cleanliness [10]. Furthermore, the powder has other functions like increasing oxide inclusion separation. The mold provides a solid shell with sufficient strength extended up to the entry of the secondary spray cooling zone (Figure 1).

Radioactive experiments and practical observations show that below the meniscus the molten metal starts lose its superheat and forms the initial shell [11]. Various hypotheses

were published to describe the mechanism of first shell formation [11, 12]. Controlling the reciprocation process and heal time by the casting speed put the skin under compression. This causes the confrontation between the pressure of the inner still liquid metal and contraction of the mold near the skin, which gives an odd shape to the solidification profile other than a simple square shape [13]. The nozzle clogging can create fluctuation level in the mold and can be reduced by improving the cleanliness of the steel and the casting treatment at the ladle furnace [14].

Solidification continues after the strand leaves the mold during secondary cooling stage. A number of experiments and theoretical models have been used to study steel solidification from the moment it leaves the tundish to the time it is quenched after it has cooled in the mold [15-32]. Other researchers target other areas in the steel making processes to lower the final cost of the steel. All these procedures are very complex and precise and a miscalculation can damage the machines or stop production, which increases cast steel's final cost. Cracks and other anomalies are created during the solidification process. Additive elements to molten steel during continuous casting may introduce inclusions to the microstructure of the strand, which affect the amount of anomalies during cooling after completion of solidification. Factors such as inadequate thickness of mould powder slag, large fluctuations in mold level and clogging of the submerged nozzle may cause the formation of the inclusions. The technical process reasons for increasing density of the inclusion in the steel matrix are low bath level in the tundish, poor mold and tundish level control and insufficient pouring tube depth [33]. Dissipation of superheat and temperature at the meniscus entrap the inclusion and gas bubbles, and turbulent flow and liquid-liquid and liquid-solid phases' interactions. Furthermore, thermal and solute buoyancies effect of surface tension take place during solidification of steel [3].

There are different types of casters. Steel production in the vertical bending (VB-type) caster contains a lower amount of inclusions distributed deeper compared to the curved caster (S-type) [36]. The driven force to move the strand forward is provided mainly by the rollers. However, gravity has an effect on the

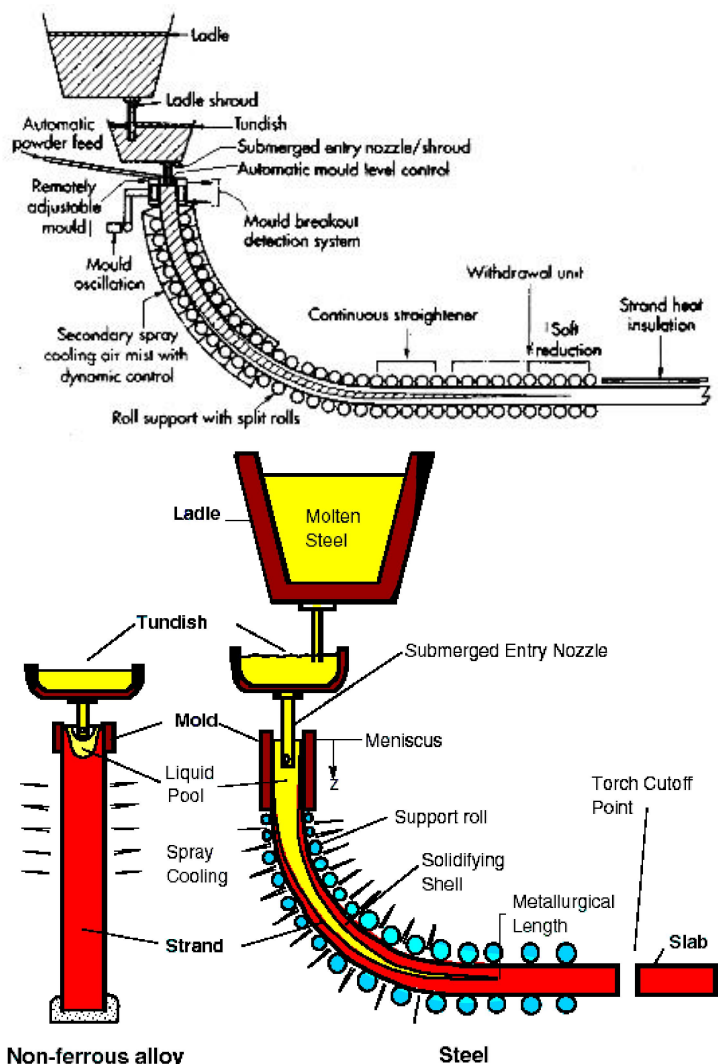


Figure 1: Process of continuous cast steel [34, 35]

speed of the strand in vertical casting. Applied forces during the solidification process affect the quality and soundness of steel. Some of these forces are external and residual stress generation, tension, oscillation and gravity-induced waves, residual distortion and wear along the mold, microscopic and macroscopic coupled segregation. Figure 2 illustrates some of factors and phenomena that occur during solidification inside the mold and during secondary cooling stage, which determines the microstructure of steel.

It is important to manage the proper progress in changes of the arc radius in bending and straightening process of VB-type continuous casting since it minimizes the occurrence of the crack and increasing the quality of the product. Implementation of the multi point unbending process can be seen in Figure 3 in which the radii gradually become into the horizontal plane as the strand passing the secondary cooling zone [37].

Solidification of the slab is completed over the formation of triple point and centerline within

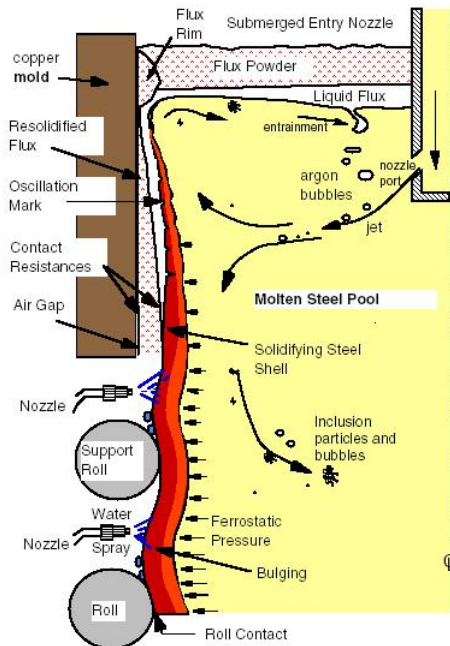


Figure 2: Phenomena during solidification upon to secondary cooling stage [3]



Figure 3: Strand unbending by straightener withdrawal units during secondary cooling zone of continuous casting process of steel [37]

the slab. The next step of the continuous casting process after completion of the solidification of the strand of the steel is to cut with a torch, shear of solidified continuous cast strand of steel into desired lengths of slabs, bloom, or billet. However, the cooling process of the slab may continue until its temperature is lowered enough prior to cutting. The solid phase through the entire thickness of the strand introduces new thermal properties to it. There is extensive research concerning the cooling of the hot charges under the meniscus up to completion of solidification in the secondary stage to find the critical cooling rate, which provides a certain degree of cleanliness.

Secondary cooling

Secondary cooling is started after the steel leaves the mold (Figure 4). At secondary cooling molten steel is encapsulated by a solidified skin and water spray causes the release of superheat from the inner section of the steel. Poor thermal conductivity of steel

limits the effectiveness of spray cooling and, in return, results in reheating the surface [13]. The quality of the secondary cooling process was the subject of many investigations in the laboratory experiments [38-40]. Higher cooling rate increases exogenous inclusions by increasing the possibility of entrapment [41]. Different methods such as dynamic control of continuous casters and dynamic spray cooling model are used to control the temperature of the strand in continuous casting. Thermal tracking of the slab cooling history is accomplished by dynamic control of continuous casters suggested in the literature [42]. Dynamic spray cooling includes techniques such as control points along the caster length [43], through slab slices [44], combined feedback with feed-forward [45] and curve fitting [46].



Figure 4: Secondary cooling stage in continuous casting steel

During the secondary stage, liquid steel is solidified to semis. Three important factors determine the type of the microstructure develops during the solidification of a casting. These factors are:

The temperature gradient in the liquid ahead of the liquid–solid interface (G)

The velocity of the liquid–solid interface (V)

The alloy composition (C_0).

Depending on the G/V ratio, the microstructure is planar at first to cellular and then to dendritic, as G/V gets smaller. Hence, usually three zones in the macrostructure of a

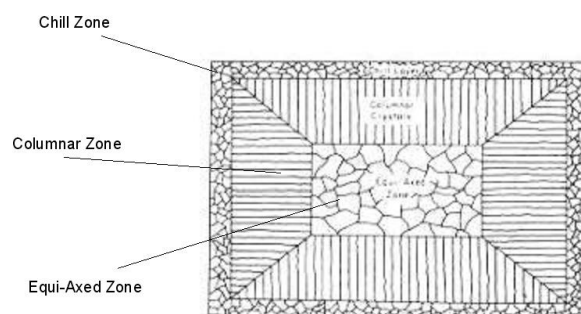


Figure 5 Three zones in microstructure in semis

continuously cast steel semi can be recognized. These zones from the surface towards the centre, as it can be seen in Figure 5, are chilled crystal zone, columnar zone and equiaxed zone, respectively [47].

Increasing efficiency of continuously cast method

Increasing application of continuous cast steel is essential to the rapid return on investment, especially because of large flow from large capacity blast furnace, makes research on increasing productivity very attractive to steelmaking companies. Different techniques were suggested to improve the productivity of ready to deliver process for slab, billet and bloom steel. These techniques include increasing the average sequence length, increasing the casting speed, increasing the averages section size cast, improving equipment utilization, ladle returns, decreasing maintenance time and increasing the strand width [33]. There are a number of other methods such as compression casting, which increases the productivity. However, all of these techniques may have a negative impact on the life of equipment used in the

that, the large surface exposure of the billet to the air increases the oxidation on surfaces during solidification.

After the solidification through its thickness is completed, the strand is cut off by torch into predefined dimensions of slabs blooms, billets or bars depending on the customer demands. Then it may be heat treated or imposed to cold and hot working to introduce proposed special properties into the cast steel product.

Summary

This paper presented a short review on processes of the continuously cast steel production. There are many developments with the sole purpose of maintaining and/or increasing the production rate of cast steel. These developments led to the huge current steel industry built on the basis of enormous amount of research in different stages and procedures of steel manufacturing. Applying continuously cast method in steel production facilitates high production of cast steel in revolutionary manner. Despite all, the consciously cast steel processes introduce different types of the defects listed in the previous publication of the author [48]. These

defects should be addressed by the researchers in this field to upgrade the quality of the continuously cast steel products. Therefore, the research works will continue toward increasing the efficiency and productivity of the steel making process by enhancing both quality and quantity of casting processes. Most of these developments, supported by extensive research, have been aimed at increasing the sophistication of the caster machine design and casting process in order to decrease the casting time and cost. Results from experimental tests, analytical computation and numerical simulation utilized the

promotion of steel manufactured techniques around the world and lowered the cost of the steel making process in which causes its own impact in technology and engineering world.

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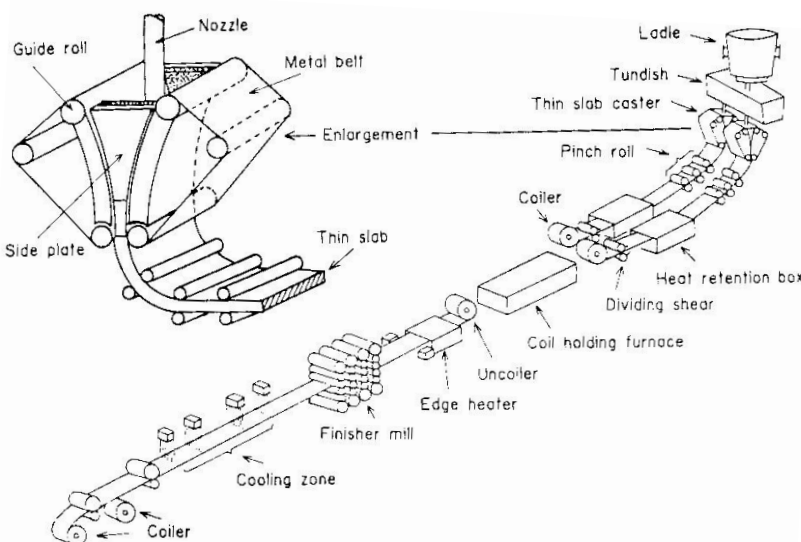


Figure 6: Schematic diagram of a Kawasaki steel twin belt caster

process, product final cost or desirable properties of the steel. An example of this aspect can be offline slitting of the wide slab or increasing the width of the strand. This method is an effective way to get higher productivity, although, slitting is a cold work process and not suitable for hot charging. It also needs good internal soundness of the slab. Temperature loss is a consequence of implementation with hot charges. Therefore, this method is replaced with another method called twin casting [33]. A typical schematic diagram of twin casting is shown in Figure 6. Nevertheless, a disadvantage of this method is

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