The cooling techniques on the continuous casting process

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Abstract. In the process of blast furnace ironmaking, in order to facilitate the transportation and storage of the molten iron, the liquid molten iron is continuously cast into iron block by using cast iron machine. In the process of continuous casting, adopting safe and efficient cooling method can shorten the cooling time of cast iron block, increase the cooling rate of molten iron in cast iron mold, and improve the productivity of cast iron machine. In this paper, the development of cooling technology in continuous cast iron process is reviewed, and the technical characteristics and application evolution of spray water cooling and dry cooling are introduced.

1. Introduction

Large amount of energy and water are consumed in the process of iron and steel production, and it also produces a lot of pollutant discharge [1-3]. The iron melted from the furnace is gradually cooled in a continuous casting machine and converted into a solid semi-finished product, known as a crude iron block. The iron block and its cooling and solidification process are carried out by means of technical control, because the mechanical and material properties, the occurrence of defects and the overall quality of the final iron block products depend largely on the cooling technique applied on the iron block. The continuous cast iron machine has a upward inclined circulating chain belt with many iron molds and chain plates. As shown in Figure 1[4], it runs around the star gears at both ends of the upper and lower ends. The upper chain belt is driven by the motor and the lower end star gear is the guide wheel. Its bearing position can be moved to adjust the tightness of the chain belt. According to the fixed situation of roller, cast iron machine is divided into roller fixed cast iron machine and roller mobile cast iron machine.

Continuous iron casting process requires molten iron to solidify in a certain time, so the cooling technology of the molten iron and iron mould is particularly important for continuous iron casting process. For security, it is forbidden to spray water directly to the molten iron liquid, because the high temperature molten iron liquid and water will explode. On the other hand, the premature cooling of water spray will affect the mechanical performance of the castings, so the cooling rate should be controlled to ensure safe production and qualified castings[5-6]. To consider the distance between the
molten iron filling and the water cooling equipment, in this period, the molten iron has not solidified, cast iron mould under the heating of iron liquid with higher than 1000 °C, so high temperature is very easy to deform and damage the moulds. Further, in the molten iron casting process, due to molten iron spatter, there will be some molten iron splashing to the connection between the roller and the sliding sleeve, so that they are welding together, and roller can not roll on the track, accelerated the wear of the roller and track. In addition, the bottom thickness of cast iron mould is different and the heat conduction is uneven, which can easily cause local internal stress and lead to the damage of cast iron mould[7]. This problem can be solved by set air cooling devices between iron liquid flow tank and water spray cooling device. The cooling air duct can be arranged above and below the cast iron mould running track respectively. The combined cooling of air and water spray can effectively reduce the temperature of iron mould, prolong its life, improve the structure of cast iron mould to make the bottom wall thickness consistent, and eliminate the local internal stress caused by uneven heating of cast iron mould.

Figure 1. Scheme of continuous casting model[4]

This paper introduces the development of cooling technology used in continuous cast iron machine, compares the technical characteristics of spray water cooling and dry cooling, and its influence on the life of iron mould and the operation of cast iron machine are also been discussed.

2. Water spray cooling

In the process of continuous cast iron, speeding up the cooling rate of molten iron liquid in cast iron mould and shortening the cooling time of cast iron block can improve the productivity of cast iron machine and reduce the weight of equipment, and improve the life cast iron machine equipment. However, in order to prevent the explosion reaction, the cooling water must spray in the case that the molten iron has been crusted on the surface. Figure 2 shows the infrared imaging of the water spray cooling process and the falling crude iron block in the continuous cast iron workshop. The length of the cast iron machine track is about 40 m, water spray device is installed 12m from the end of the track. It can be seen from Figure 2, at the beginning of the water spray, the hot iron liquid surface still has a high temperature of nearly 1000 °C, while the temperature of the crude cast iron block dropped from the track is as high as 1080 °C, which is due to a large amount of latent heat released during the solidification of the melted iron liquid. The cooling water of direct spray cooling is sprayed in the middle of the cast iron track, and the water spraying on the cast iron track are too frequent, it will cause the thermal fatigue damage of the cast iron mould. The reflective spray cooling device is rather adopted: that is, the water hits the arc plate upward, and after reflection, it flows down into a waterfall
in both directions. The water is sprinkled evenly on the surface of the iron block, and the cooling area is increased, then the cast iron mould and iron block are cooled evenly [7].

The cooling technology and the cooling device design of iron casting needs to be based on certain theory or numerical study, and the heat transfer of continuous iron casting process is very complicated. Pedduri Jayakrishna [8] developed a three-dimensional numerical model for the study of molten steel turbulence, and the continuous casting process of steel billet solidified in iron casting mould is established. The results obtained from their simulation show that one of the main reasons for the high thickness of the solidified shell is the nature of recirculation flow. A comparative study on the solidification of a part cast from three different alloys was conducted by Crisan et al. [9]. The analysed cases were of castings from 0.1% C steel, 0.5%C steel and eutectic spheroidal graphite cast iron, respectively. Samir et al.[10] presented a more computationally and efficient approach. They developed a one dimensional transient heat transfer model of casting to determine the temperature distribution as a function of time. Casting is considered to be semi-infinite. The solidification time and length of metal solidified at different times have also been determined.

For a long time, steel has been an important building material[11]. With the materials development, cast iron is no longer a mainstream construction material, and there is a lack of extensive research on this type of construction. C. Maraveas et al. [12] presented the results of an extensive experimental investigation of the mechanical properties of structural cast iron at elevated temperatures and after cooling down to room temperature, including tensile and compressive tests, under both steady-state and transient heating conditions, and cooling from high temperatures. The cooling conditions greatly affect the structure of the cast iron[13]. M.M.Jabbari [14] experimental study of gray cast iron found that both Dendrite Arm Spacing (DAS) and ferrite-cementite layer
greatly depend on the cooling rate. Joel Hemanth [15] presents the results obtained and the deductions made from a series of microstructural studies, ultimate tensile strength (UTS) and fracture toughness tests involving hypoeutectic gray cast iron which was sand cast using sub-zero and water-cooled end chills. It was found that the UTS and fracture toughness is highly dependent on the rate of cooling, which determines the ECC, DAS and grain size of the material. T. Borsato et al.[16] characterize the static and fatigue strength of a heavy section solution strengthened ferritic ductile iron casting. Static mechanical properties were found to decrease slightly with the increase of the solidification time. The first developments in magnetic molding made by Wittmoser and Hofmann [17] over 70 years showed that the increase in the thermal conductivity of magnetic mold compared to sand mold leads to an increased rate of cooling and significant grain refinement of steel and grey cast iron.

3. Dry cooling
As mentioned above, in the process of continuous cast iron, spraying water on the surface of molten iron that has been crusted can achieve the purpose of rapid cooling and solidification, and increase the output of cast iron. However, spraying water in cast iron with high temperature workshop has some adverse effects: firstly, it is to waste a lot of water resources. Chinese iron and steel industry accounts for nearly 50% of the total production of crude steel (crude steel) in the world. Compared with developed countries, the average consumption per ton of steel is 7-8 m³ of water [18]. This because the research in China focuses more on iron casting process equipment and treatment technology than on water-saving optimization research [18]. on the other hand, most large and medium-sized steel mills in China were established in the 1980s, so their cooling water use efficiency is very high, and water cooling technology is relatively backward[19]. A portion of water spray cooling with dry cooling can replace 48% of one time cooling water, which represents a reduction in water consumption of about 1.5 m³/min[2]. Another hazard of water-cooled solidification in cast iron process is environmental pollution. Water pollution caused by iron and steel industry is mainly related to cooling water containing ammonia and cyanide, gasification products such as benzene or naphthalene, discharge of chloride and pH change of treatment wastewater compared with fresh water [3]. Lastly, the impact of water-cooled solidification on production safety in the cast iron process is well known that explode reactions occur in contact with water at high temperatures and affect production safety. Although the current water spray are located in the bottom of the cast iron track, while the water mist may also rises in the workshop, and if the mist in contact with high temperature iron liquid, it will cause serious safety accidents and affect the continuous production of cast iron. Therefore, the new production standards in China gradually prohibit water spray cooling in continious iron casting.

The idea of dry cooling is based on the use of internal water cooling rollers. A closed-loop water system is used in dry cooling, which means that water is preserved and reused. Dry cooling can significantly reduce the amount of water used in the cast iron process. It is obviously different from water spray cooling. Water spray cooling nozzle is the main way to drain heat in the secondary cooling zone of continuous iron castings, which the disposable water is used. For water spray cooling, the one-time passing water means that the water will not be reused because it is atomized into small water droplets in the nozzle, which will be heated and evaporated when hitting the hot surface of the steel chain. Klime [2] assessed the applicability and feasibility of dry cooling compared to spray cooling using the original numerical model of continuous steel casting. The authors developed and validated the model, and the numerical model have been applied to casting control and optimization of steel structures.
4. Conclusion

High efficiency cooling technology makes melted iron liquid solidify into crude iron blocks quickly, which is very important for continuous production of cast iron. Water spray cooling can quickly remove heat from the surface of molten iron that has been crusted, promoting the solidification of molten iron. However, for large-scale cast iron production, water spray causes waste of water resources and environmental pollution, and also poses a threat to production safety. The dry cooling technology with internal circulating water cooling can solve this problem very well, but its devices structure is relatively complex, and the circulating water also needs to be cooled again. If this dry cooling technology with closed circulation of circulating water can be combined with air cooling, it will provide more efficient, environmentally friendly and energy-saving cast iron cooling technology, which is expected to become a trend of the cooling technology of continuous iron casting development.

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