Influence of Temperature Uniformity of Billet before Rolling on Microstructure and Properties of Hot Rolled Rebar

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Abstract. Through calculating the temperature field of billet in the process of reheating furnace, direct rolling and direct rolling with insulating cover, the temperature uniformity of billet obtained by different processes before starting rolling had been analysed. And then the mechanical properties and microstructure of hot rolled rebars in different positions of each process had been examined. The conclusions are as follows: The temperature uniformity of billet before rough rolling can be effectively increased by adding insulation covers in the conveying process of billet. With the decrease of temperature difference between the head and tail of billet, the fluctuation range of mechanical properties of production is narrowed. The process can obviously reduce the difference of grain size between the head and the tail of billet.

1. Introduction
The technical level of sheet and strip production not only is an important symbol of the development level of iron and steel industry, but also reflects the level of industrial technology development of a country. As the most important part of sheet and strip, hot strip rolling technology continues to develop in the direction of compact process, energy saving and high efficiency. The technology has been developing from the earliest hot charging to CSP, then to ESP, ISP, etc[1-2].
The hot rolling technology of bar and wire has also been used for reference in the development of hot-rolled sheet and strip. The development process is from the earliest hot charging and hot feeding to the direct rolling process and towards the direction of continuous casting and rolling of long profiles. The world's first attempt at continuous casting and rolling of bar and wire rods occurred in China, mainly for the production of threaded bars. In June 2018, Shanxi Jianbang Group Co., Ltd. and Italy Danieli Group Co., Ltd. cooperated to build the world's first long profile continuous casting and rolling production line. In the same year, Guilin Pinggang Iron and Steel Co., Ltd. and Italy Danieli Group Co., Ltd. signed a high-speed endless continuous casting and rolling bar and wire rod production line project cooperation agreement[3-4].
The first unit in the world to study the direct rolling process of rod and wire is Japan Kobe Iron Making Co., Ltd[6]. Next is the Feng Guanghong team of Beijing Iron and Steel Research Institute and the Liu Xianghua team at Northeastern University in China[6-12]. Then some of China's steel enterprises are also following the study, such as Nanjing Jinghuan Thermal Metallurgical Engineering Co., Ltd. and Shaanxi Iron and Steel Group Co., Ltd[13-15].
At present, there are few detailed studies on the process of continuous casting and rolling process for rod and wire production. This paper focuses on the differences between the common ways of casting and rolling in bar and wire production. In order to optimize the direct rolling technology of rod and wire rod, the temperature characteristics of different continuous casting billets and the differences of
mechanical properties and microstructure are deepened.

2. Experimental

2.1. Raw material

The raw material was 6m long continuous casting billet with size 150m square, which was produced by EAF-LF-CC short flow process. These billets were rolled into HRB400 rebar with different production processes. The chemical composition of the material is shown in Table 1.

| C   | Si  | Mn  | P   | S   | Ni  | Cr  | Cu  |
|-----|-----|-----|-----|-----|-----|-----|-----|
| 0.22| 0.31| 0.59| 0.017| 0.015| 0.059| 0.095| 0.05 |

In this experiment, the rebar produced with different processes need to be sampled on the cooling bed. Ten billets were selected for each process and three groups of 1.5m rebar were taken at different positions of the head, middle and tail of the same billet. In addition, the rebar within the 3m on the edge of cooling bed should not be taken during sampling. The specific sampling location of the same billet is shown in Figure 1.

2.2. Experimental process

In this paper, three different casting-rolling processes for bar and wire rod production had been compared and analyzed. And then numerical calculation and industrial test were carried out for three different processes. The three casting-rolling linking processes were heating furnace hot charging (process A), direct rolling (process B) and direct rolling with insulation covers (process C).

The casting parameters of three processes were the same. First, they were all produced by six-strand billet. Second, the casting speed of the continuous casting machine was 2.3-2.4 m/min. Third, the water flow of the mold was 173.6 m³/h and the water temperature difference of the mold was 4.5℃. The main difference between the three processes was the transportation process from the continuous casting machine to the rolling mill, with different temperature processes.

The temperature field before rolling was calculated by numerical simulation. Then the temperature difference between head and tail of billets and the temperature difference between center and surface were analyzed. Raytek infrared thermometer was used to measure the temperature of slab conveying process and the simulation results were verified.

Then mechanical properties and microstructure of the rebar corresponding to the different positions of billets were tested and the differences in microstructure and properties of rebars produced by different processes were analyzed. The following is explained in detail.
3. Results and Discussion

3.1. Temperature uniformity of billet
The curves of the center and surface temperature of billets with time in the whole process A are shown in Figure 1. After the uniform temperature of the furnace, the temperature difference between the core and the surface of the billet is 90°C before rough rolling. The curves of the center and surface temperature of billets with time in the whole process B and process C are shown in Figure 2. The temperature difference between the core and the surface of the billet of process B is 160°C before rough rolling and the temperature difference of process C is 120°C. The temperature difference between the head and tail and the temperature difference between center and surface of the three processes before rough rolling are shown in Figure 8. The temperature difference between head and tail of billet before rough rolling in process A is 30, and process B is 80, and process C is reduced to 50. Therefore, the temperature uniformity of billet before rough rolling can be effectively increased by adding insulating covers during the conveying process, which is beneficial to the stability of final product quality.

In order to ensure the accuracy of calculation results, the surface temperature of billet in process B had been measured by infrared thermometer. The relative error is less than 1% compared with the measured value, as shown in Figure 8. Therefore, the above calculation results are accurate and effective.
3.2. Difference in stability of mechanical properties
The scatter plot of yield strength and tensile strength of three kinds of process steel is shown in Figure 7 - 9. The fluctuation range of yield strength and tensile strength of rebar of process A is 50MPa. The fluctuation range of yield strength and tensile strength of rebar of process B is about 100MPa. The fluctuation range of yield strength and tensile strength of rebar of process C is reduced to 70MPa. There is no significant difference in elongation between the three processes in Figure 10.

Although the direct rolling process of bar and wire rod greatly reduces the energy consumption in the production process, the mechanical property stability of the product is greatly reduced, from 50 MPa to 100 MPa. However, the fluctuation of mechanical properties of rebar can be significantly reduced by using the heat preservation cover between continuous casting and rolling processes, but the yield strength and tensile strength are decrease slightly.
3.3. Microstructure characteristics of different processes

In order to compare the characteristics of the three processes, the microstructure of the rebar in the head, middle and tail of the casting billet produced by the three processes had been examined. The results are shown in Figure 11. There is little difference in the structure of the rebar corresponding to the head, middle and tail of the casting billet of process A and process B, but there is great difference in the structure of the rebar corresponding to the head, middle and tail of the casting billet of process C. The grain size and ferrite ratio at the 1/2 radius of the cross-section rebar produced by the three processes are shown in Table 2.

| Process | Production process                        | Initial rolling temperature (℃) | Average grain size (μm) | Ferrite ratio (%) |
|---------|------------------------------------------|--------------------------------|-------------------------|------------------|
| A       | heating furnace hot charging             | 1050                           | 11                      | 75.5             |
| B       | direct rolling                           | 950                            | 6~8                     | 62.9             |
| C       | direct rolling with insulation covers    | 980                            | 8                       | 63.6             |

Because the start-up temperature of direct rolling process is lower than that of heating process, and there is obvious temperature difference between head and tail of billet. Therefore, the grain size of process B is obviously smaller than that of process A, and the microstructure of the rebar corresponding to the head and tail of the billet is not uniform. Because the initial temperature of direct rolling process is lower than that of heating process, and there is obvious temperature difference between head and tail of billet. Therefore, the grain size of process B is obviously smaller than that of process A, and the microstructure of the rebar corresponding to the head and tail of the billet is not uniform. The average grain size of the rebar of process A is 11 micron, and there is no obvious difference in the microstructure of the rebar corresponding to the casting head, middle and tail. The average grain size of rebar produced of process B is 6-8 micron, the grain size of corresponding rebar at the head of billet is the smallest, and the grain size of corresponding rebar at the tail of billet is the largest. The uniformity of microstructure can be effectively increased by using process C.
4. Conclusion

(1) For 6m long billet, the temperature difference between center and surface of billet by heating furnace before rolling is 100℃, and the temperature difference between head and tail is 30℃. Then the temperature difference between center and surface of billet is reduced from 160℃ to 110℃, and the temperature difference between head and tail of billet is reduced from 80℃ to 50℃ when the insulating covers are used in the billet conveying process of direct rolling. Therefore the temperature uniformity of billet before roughing can be effectively increased by adding insulating covers in the conveying process of billet.

(2) The temperature uniformity of billet has a significant effect on the mechanical properties of the product. With the decrease of temperature difference between head and tail of billet, the fluctuation range of mechanical properties of rebar is narrowed. And then the yield strength and tensile strength of billet to the rebar show the phenomenon of "high at both ends and low in the middle" along the length direction of billet.

(3) The average grain size of the products produced by heating furnace process is 11 micron, while that by direct rolling process is reduced to 6-8 micron. The average grain size of the product becomes 8 micron when the insulating covers are used in the billet conveying process of direct rolling. The process can obviously reduce the difference of grain size between the head and the tail of billet.

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