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Development of Mist Cooling Process for Spring Steel Wire

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The Stelmor forced air-cooling process has been widely used as a cooling method for hot rolled high carbon steel wire coils. However, there are inevitable temperature differences between the edge and center part of the wire coils because of the differences of mass density. A mist cooling process integrated with the Stelmor forced air-cooling process was developed to overcome these disadvantages. The temperature difference between the edge and center part of wire coils can be reduced to less than 30°C. Uniformity of the tensile strength of spring steel wires was achieved by applying this mist cooling process.

Keywords: Stelmor, Mist Cooling, Wire Rods, Cooling Rate, Tensile Strength

1. INTRODUCTION

The control of the cooling rate following the hot rolling of steel rod is important for the microstructural evolution and will strongly affects the final mechanical properties of the rod(1). The cooling rate during these transformations will determine the final grain size of the microstructure. Figure 1 shows the Stelmor conveyor in the Rod Mill of China Steel Corporation (CSC). The total length of the conveyor is 102m, which can be divided into ten forced air-cooling zones. The wire coils are arranged to pass over several zones in order to obtain the desired microstructure and corresponding material properties. However, there are inevitable temperature differences between the edge and center part of wire coils as shown in Fig.2. The reasons to cause the difference of temperature are differences of mass density and cooling rate between coil edge and center. Hence, the traditional cooling mechanism of the Stelmor forced air-cooling process is inadequate for high carbon steel wire rods which need a more uniform cooling rate.

Fig.1. The Stelmor conveyor in the Rod Mill of CSC.

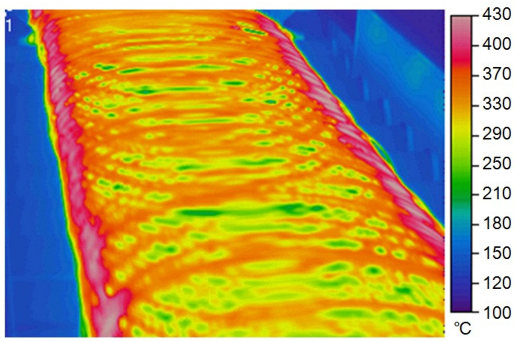

Fig.2. The temperature differences between the edge and center part of wire coils.

A continuous cooling transformation (CCT) phase diagram is often used in heat treating of steel. These diagrams are used to represent which types of phase changes will occur in a steel as it is cooled at different rates. Figure 3 shows the different cooling paths of edge (red line) and center (blue line) part of spring steel wire coils. Due to the different cooling rate of the wire coils on the conveyor, the variation in tensile strength of spring steel wire coils was up to 23%.

In this study, a novel mist cooling system is developed to cool wire rod material that has been coiled at a specified temperature. This system was installed above

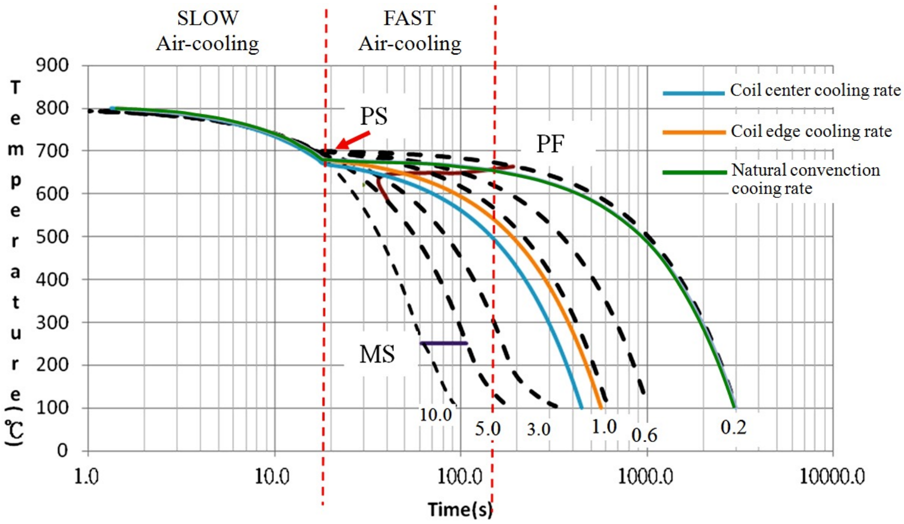

Fig.3. CCT diagram for edge and center parts of spring steel wires in an air-cooling process.

the conveyor in the first cooling zone of the forced air-cooling process, which is located adjacent to the coiling equipment. The mist cooling rate is controlled corresponding to the diameter of the wire rod material and steel grade while the material online temperature measured with a thermometer. Mist cooling has the following advantages in comparison with the air-cooling method [2].

(1) Mist cooling has a higher heat transfer coefficient.
(2) Mist cooling can achieve a more uniform cooling effect.
(3) Mist cooling has the wide range of cooling capacity.

2. RESEARCH METHOD

Recently, more commonly used instruments for wire rods temperature measurement on the Stelmor conveyor is the infrared pyrometer[3]. In this study, the wire rods temperature measuring system was designed for the mist cooling process. The temperatures tolerance within ±5% is allowable for all experimental data[4]. The experimental temperature database of wire rods under different mixed ratios of water to air flow rate can be established by this system.

In order to optimize the mist cooling process, it is necessary to obtain an accurate cooling rate for coils cooling upon the conveyor deck. Commercial software FLUENT was used for simulations in the current work, in which the SIMPLE (Semi-Implicit Method for Pressure Linked Equation) algorithm and κ-ε turbulent model were applied[5]. It provides an accurate and successful approach for predictions of the heat flow within the spraying nozzle and mist distribution upon the Stelmor cooling bed. The computing grids were mapped within the computational domain and a grid independent analysis was applied to ensure both computational accuracy and efficiency. A convergence criterion for the residuals of variables being less than 10^{-6} was adopted in the numerical computations.

Figure 4 shows the temperature simulation preliminary results of spring steel wire coil with different air flow rates: 100L/min and 250L/min, while the water flow rate was fixed to 5L/min. It reveals that the mixing ratio of water and air flow rate affects the temperature

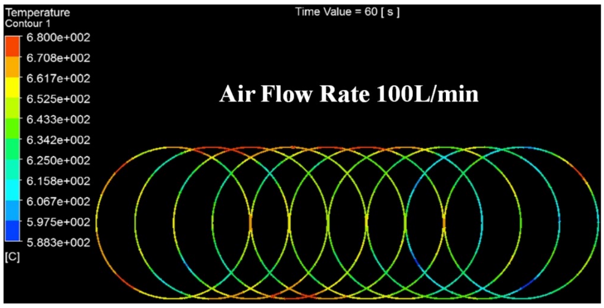

Fig.4(a) Surface temperature distribution of wire coil at an air flow rate of 100L/min.

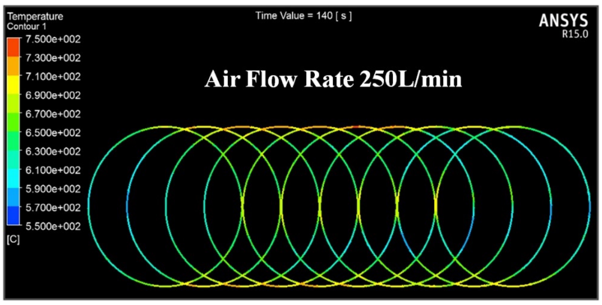

Fig.4(b) Surface temperature distribution of wire coil at an air flow rate of 250L/min difference between the edge and center part of wire coils. As air flow rate was increased, the temperature difference was reduced. This numerical model was used to predict the effect of individual process parameters on wire coil temperature distribution, forming the basis for developing the most efficient controlled cooling ranges.

3. RESULTS AND DISCUSSION

A series of experiments have been conducted to investigate the relationship between the cooling rate and the mechanical properties of spring steel wire rods. Since as a key factor to affect the grain size of the microstructure, an appropriate cooling rate of wire coils was determined by optimizing the mixing ratio of water and air flow in the mist cooling system.

Hence, a calibration curve for cooling rate should be established. Based on these conditions, a variety of mist cooling rates (3.2~10.3°C /s) along stock can be obtained as shown in Fig.5. The air flow rate and water flow rate were controlled in the range of 50~300L/min and 1.5~5L/min, respectively. Based on these relationships between the mist cooling rate and the mixing ratio of water and air flow rate, the wire coils temperature on the conveyor was accurately controlled. Therefore, the critical cooling rate of each zone on the Stelmor conveyor are determined to meet the requirements of product quality.

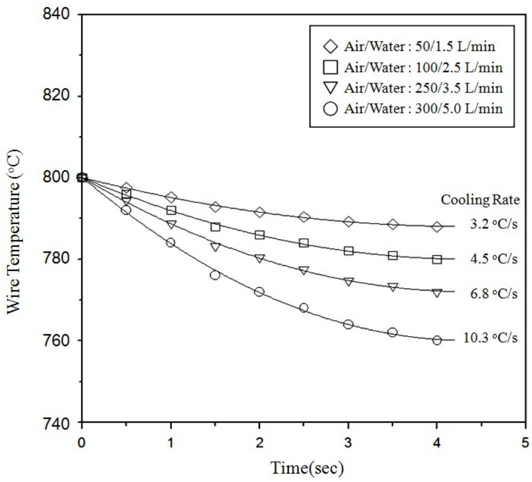

Fig.5. Mist cooling rate under different percentages of water mixed with air flow.

Figure 6 shows the uniform surface temperature of the spring steel wires could be controlled at about 340°C and the homogeneous cooling of the wire coils over the width of the conveyor were obtained. Results showed that the temperature difference(ΔT) over the width of the wire coils on the conveyor was reduced from 80°C to less than 30°C. Figure 7 shows measured results of the two dimensional temperature distribution for the entire conveyor area by means of infrared thermography. Results showed that the temperature difference between the edge and center part of wire coils on the conveyor can be reduced to less than 30°C.There are no martensite be found on the surface and core of wire rods. The original tensile strength of wire rods obtained by the Stelmor air-cooling process is 122 kg/mm^2. A higher and more uniform tensile strength of up to 130 kg/mm^2 for wire rods was obtained by the mist cooling process. It was shown that the mist cooling process can be an effective tool to overcome the inherent temperature difference over the width of the wire coils on the conveyor. It also can be expected that various kinds of products with high added value can be produced by this equipments.

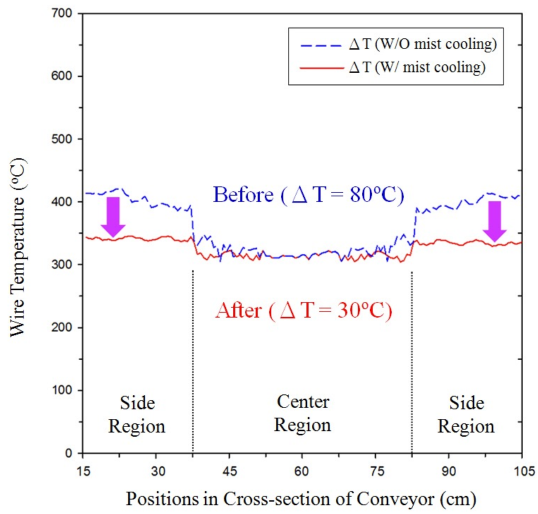

Fig.6. Surface temperature distribution in a cross-section of the conveyor.

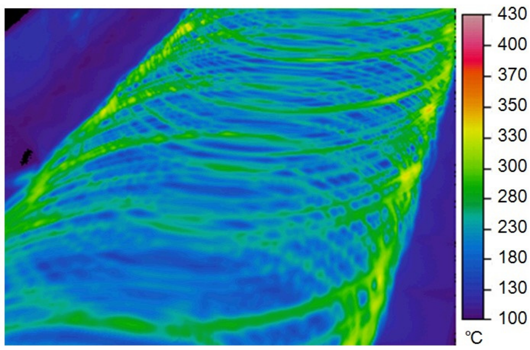

Fig.7. Infrared image of the wire loops on the conveyor with mist cooling.

Figure 8 shows that the new system was installed in the CSC No.2 Rod Mill from May 2017. The application result shows that the variation in tensile strength of spring steel wire coils was reduced significantly from 23% to 10%, as shown in Fig.9. Hence, the material qualities of the spring steel wire rods have been obviously improved.

Fig.8. The developed mist cooling system was installed on the Stelmor cooling bed.

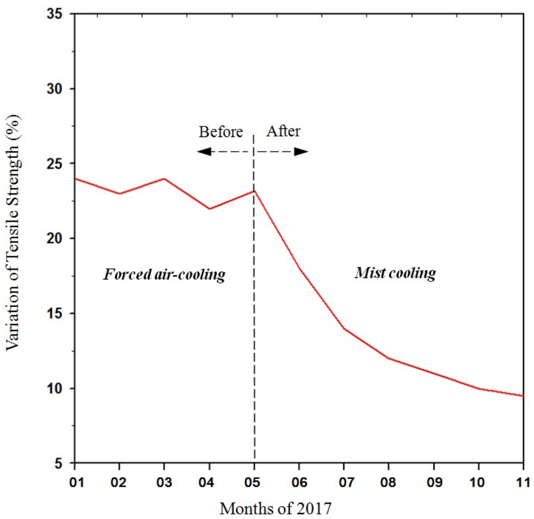

Fig.9. The variation in tensile strength of spring steel wires with mist cooling.

4. CONCLUSIONS

Finally, conclusions can be drawn as follows:

(1) A new control function of mist cooling for the Stelmor system has been developed to ensure the formation of the required microstructure of wire rods.

(2) The uniform surface temperature of the spring steel wires can be controlled at about 340°C and the homogeneous cooling of the wire coils over the width of the conveyor was obtained.

(3) The cooling range for mist cooling is from 3.2 to 10.3°C /s along stock can be achieved by different mixing ratios of water and air flow rate. The mist cooling rate increases with increasing the air and water flow rate.

(4) The temperature difference over the width of the wire rods loop on the conveyor can be reduced form 80°C to less than 30°C by using the developed mist cooling system.

(5) The average tensile strength of wire rods increased to 130 kg/mm^2 which is higher than the original strength of 122 kg/mm^2 obtained by the Stelmor air-cooling process. The variations in tensile strength within spring steel wire coil loops was reduced from 23% to 10% and no martensite be found in the core of wire rods.

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