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A Novel Temperature Diagnostic System for Stelmor Air-Cooling of Wire Rods

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A novel online and movable temperature diagnostic system was designed to capture the surface temperature profile of wire rods during the Stelmor air-cooling process. It consisted of an infrared pyrometer, a data logger, a cooling system, 3-axis steering gear, and a movable mechanical platform. A series of experiments had been conducted to investigate the relationship between the cooling rate and the mechanical properties of NLP(Non-Lead Patenting) wire rods. The temperature of the wire rods during the Stelmor air-cooling process was more accurately controlled through the use of this novel system and the variation in the tensile strength of NLP wires was reduced from 40% to 16%.

Keywords: Stelmor, NLP (Non-Lead Patenting) Wire Rods, Temperature Diagnostic

1. INTRODUCTION

Forced air-cooling processes such as the “Stelmor” cooling conveyor are generally used as cooling methods in a hot rolled wire rod mill. The strength and ductility of NLP(Non-Lead Patenting) wire rods can be controlled in the rolling line with these processes. However, because forced cooling is performed with an air blast, the cooling capacity of the forced air-cooling process is often inadequate. Generally speaking, the air flow from the plenum chamber cannot be accurately controlled for the required cooling rate of wire rods because of the lack of a temperature measurement system in the air-cooling process for processes such as the Stelmor in the Rod Mill at China Steel (CSC).

Fig.1. The Stelmor conveyor in the rod mill at China Steel.

Figure 1 shows the Stelmor conveyor in the rod mill of CSC. The total length of the Stelmor conveyor in the rod mill is 100 m, and it can be divided into ten cooling zones. Zone Nos. #1 to 5 are the fast air-cooling areas, which are used to cool the high carbon steel wire rods rapidly. The zone Nos. #6 to 10 are the slow air-cooling areas used for alloy steel wire rods cooling. The wire rod coils are arranged to pass over several zones in order to obtain the desired microstructure and corresponding material properties. Each zone is equipped with fans to provide the forced air for cooling, and each fan is connected via a plenum chamber to the bottom of the conveyor deck as shown in Fig.2. Air flows through a series of nozzles on the deck and up through the coils to complete the air-cooling process.

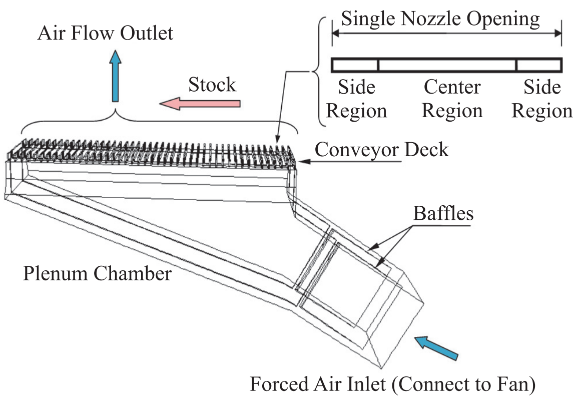

Fig.2. Assembly of a single plenum Stelmor air conveyor system.

Hence, variable-speed fans provide the flexibility for controlling the air flow rate. Meanwhile, two baffles are installed within the plenum and provide the function to direct the air flow to the side or center regions of the conveyor deck through adjusting the baffle angles.

From Fig.1, it is clear that the wire rod coils pass over the cooling nozzles on the Stelmor conveyor and are not in a static state, but always move forward with the rotation of the cooling conveyor equipment. Accordingly, a surface temperature profile of the wire rods measured with a contact thermocouple is not suitable for Stelmor air-cooling process. Kawasaki Steel Corporation[1] has been using the wire rod coils attached to a pre-welded thermocouple to assess the Stelmor conveyor cooling performance, but this measurement method can only be applied to offline experimental equipment, and cannot be applied to the temperature measurements of an actual on-line Stelmor air-cooling production process. When Maanshan Iron & Steel Company[2] were revamping their Stelmor conveyor equipment, they tried to add a series of infrared temperature measurement systems above the Stelmor conveyor and connect these to the process computer in order to more precisely control the cooling rate of the wire rods. Baosteel Corporation[3] also developed an online cooling control system through the use of improved Stelmor equipment. From the existing literature survey, although there have been many recent studies of the Stelmor air-cooling process, almost all the studies have focused on air-cooling control. No novel temperature diagnostic system or equipment can be found in the existing literature.

In this study, we developed a wire rods temperature diagnostic system for the Stelmor process in the rod mill. The system combined an infrared pyrometer with a mechanical platform capturing the surface temperature of wire rods immediately for the various districts and gathered the temperature information for feedback to the process computer in order to adjust the air flow in the Stelmor air-cooling process.

2. EXPERIMENTAL METHOD

Recently, the more commonly used instruments for wire rods temperature measurement on the Stelmor conveyor is the infrared pyrometer.

In order to capture the surface temperature profile of wire rods during the Stelmor air-cooling process, the present investigation utilized both a single color and a dual-color pyrometer to test which type is better for wire rods temperature measurement. The size of the area (spot size) to be measured determines the distance between the pyrometer sensor and the wire rods. The spot size must not be larger than the wire rods coil. The pyrometer sensor should be mounted so that the measured spot size is smaller than wire rods coil. The positions for the temperature measurement of the wire rod coils during the Stelmor process are shown in Fig.3. There are three major positions (P1, P2 and P3) for taking temperature measurements. Both side positions (P1, P3) and the center position (P2) for the temperature measurement of the coils are 15cm and 60cm from the conveyor wall, respectively.

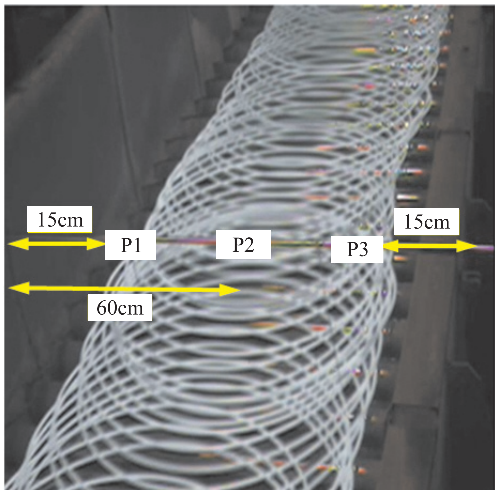

Fig.3. The positions (P1, P2 and P3) taken for temperature measurement.

Figure 4 shows the temperature measurement results using the dual-color pyrometer. The center position for the temperature measurement of the coils had more gaps between the wire rods, so the diagnostic signal from wire rod coils was unstable and fluctuant. However, at both the side positions for temperature measurement the coils were more compact and the diagnostic signal was more stable and repeatable.

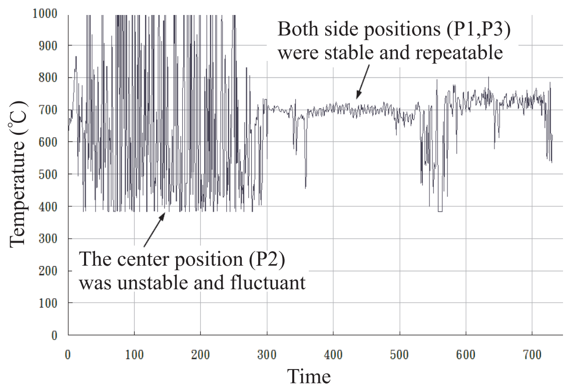

Fig.4. Both side positions were stable and repeatable.

The dual-color pyrometer[4] utilizes two wave lengths in the continuous spectrum to measure the intensity of radiation from the wire rods and deduces the temperature from the intensity ratio. This led to some measurement variations from the gaps between the wire rod coils during the switching of the two wave lengths, as shown in Fig.4.

Figure 5 shows the temperature measurement results of a single color pyrometer, clearly demonstrating that the temperature data for the center position (P2) of the coils was more stable than the data measured from dual-color pyrometer, and showing a similar temperature trend for both the side positions (P1, P3). Therefore, in this study the single color pyrometer was used for the setup and installation of the wire rods temperature diagnostic system in the Stelmor air-cooling process.

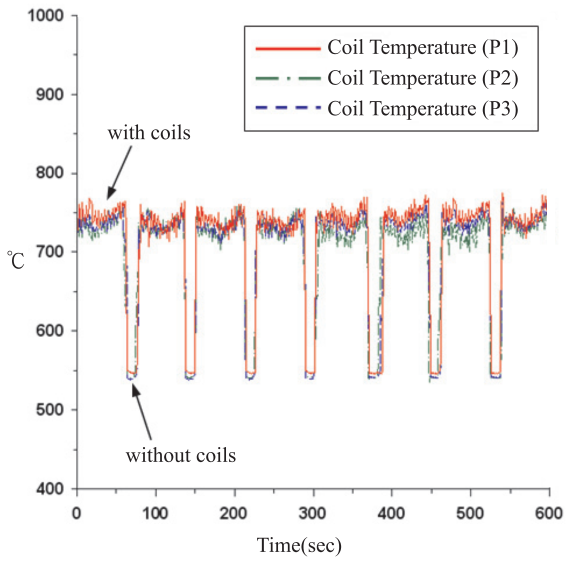

Fig.5. The temperature measurement results of the single color pyrometer.

Besides, there are also other mechanical equipments and electrical systems that need to be developed and designed for the novel online and movable temperature diagnostic system in the Stelmor air-cooling process. There are eight major components of the temperature diagnostic system designed for wire rods temperature measurement in Stelmor as follows, and as shown in Fig.6: (1) Single Color Pyrometer; (2) Movable Mechanical Platform; (3) 3-Axis Steering Gear; (4) The Encode; (5) Data Logger; (6) Water Cooling System; (7) Air Cooling System; and (8) The Extended Line. The temperature diagnostic system can be used for wire rods temperature measurement in different manufacturing processes including fast and slow air-cooling processes even for the case of within the encopanels on the Stelmor conveyor as shown in Fig.7.

Figures 7(a) and 7(b) show the situations of wire rod temperature measurement for fast and slow air-cooling process in Stelmor, respectively.

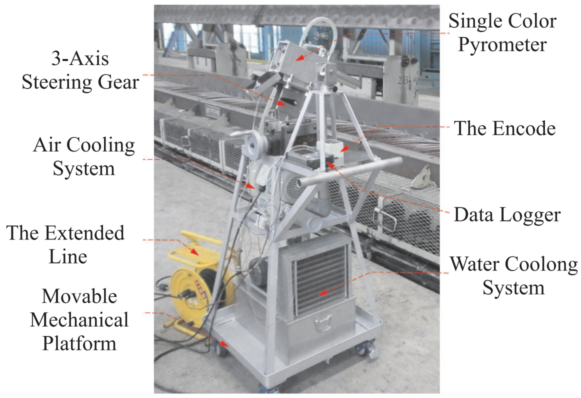

Fig.6. The novel online and movable temperature diagnostic system for Stelmor.

Fig.7(a). The wire rod temperature measurement for a fast air-cooling process (W/O Encopanels).

Fig.7(b). The wire rod temperature measurement for a slow air-cooling process (W/ Encopanels).

3. RESULTS AND DISCUSSION

3.1 Wire Rods Surface Temperature Distributions

Figure 8 presents the surface temperature distributions in cross-section of NLP coils at different locations

(Zone No.#1, Zone No.#2, Zone No.#6 and Zone No.#10) along stock. The wire rod surface temperature distributions measured in terms of the self- developed novel online and movable temperature diagnostic system reveals that the surface temperature distributions in the cross-section of NLP coils are not uniform, so the variation in tensile strength of NLP wires are about 40% before improving. Besides, the surface temperature distributions are symmetrical within the center region (P2) of the coils and show a similar temperature trend with the both side regions of the coils (P1, P3), this phenomenon also can be found at different locations. Because, the center region (P2) of the coils has more gaps between wire rods, the surface temperatures are about 60~90℃ lower than at both the side regions of coils (P1, P3).

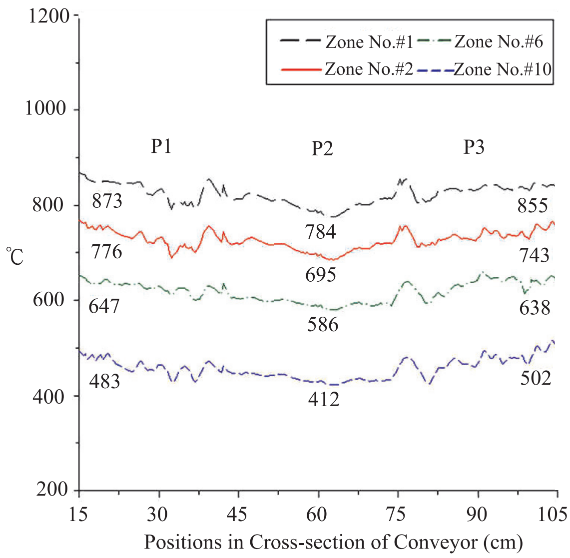

Fig.8. Surface temperature distributions in a cross-section of the conveyor at different zones.

Moreover, according to the continuous cooling transformation (CCT) diagram(5) of NLP wires, the optimum phase transformation temperature is between 500 ~ 550℃. Because, a reheating effect occurs when the wire rods enter the slow cooling zone (Zone No.#6), the surface temperature of NLP wires rose to about 630℃. Therefore, in order to capture the surface temperature of NLP wires, a novel online and movable temperature diagnostic system was designed for Stelmor air-cooling process in this study. Then, the temperature decay, i.e. the air cooling rate from Zone No.#1 to Zone No.#5, can be calculated, and the air cooling rate could be controlled by the fan-loadings and baffle angles.

3.2 Local Air Flow Rate Distributions

In order to obtain NLP wires with uniform strength, it is necessary to optimize the air flow distribution for the Stelmor air-cooling conveyor control. Figure 9 shows the local air flow rate distributions in a cross-section of conveyor at different locations (Zone No.#1, Zone No.#2, Zone No.#4 and Zone No.#6) along stock and with different fan-loadings (100%, 85%, 80% and 75%, respectively). The results reveal that the center region (P2) of coils having a similar air flow rate with the both side regions of coils (P1, P3). The same phenomenon also can be found at different locations. Actually, the total heat capacities in the both side regions of coils are more than the center region, so the cooling capacities of the forced air-cooling process for the both side regions are insufficiently.

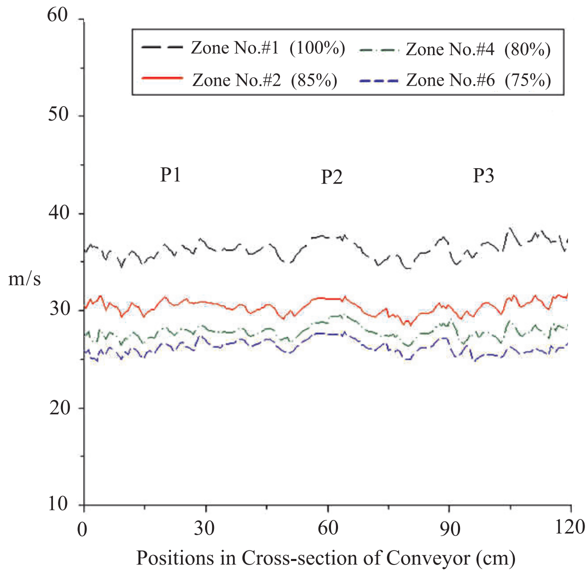

Fig.9. Local air flow rate distributions in a cross-section of the conveyor at different zones.

In the air-cooling process occurring on the Stelmor conveyor, the wire rod experiences convective heat transfer by forced air flow through the array of coil loops. The temperature distribution across the coil array can then be evaluated using an equivalent coil section. Figure 10 presents the typical laying array of wire rod coil loops, and it can be observed that the overlapping of coil loops is more dense in the side regions than in the center region of the wire rod coil array. Hence, it is necessary to optimize the air distribution in order to ensure a uniform cooling effect on the wire rod coils. A simple algorithm was originally designed to evaluate the required air distributions across the conveyor stock array, allowing the optimum control for the wire rod coil cooling to be determined by adjusting the operating baffle angles.

As illustrated in Fig.10, P denotes the pitch relevant to different intersections. D is the coil loop diameter. Meanwhile, N is defined as the distances of overlapping intersections from center of one coil loop, D/P.

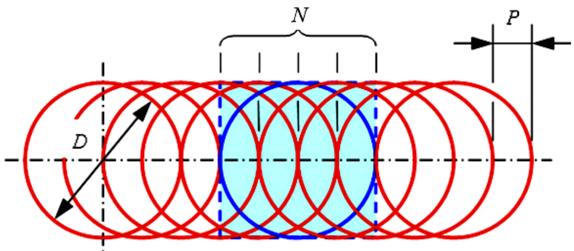

Fig.10. Typical laying array of wire rod coil.

The presented simple geometrical model was then applied to produce NLP wires in the rod mill of CSC. The values of *P, D* and *N* could be determined by the coil diameter and the conveyor roller speed. In this study, the coil loop diameter (D) is about 900mm and the number of overlapping intersections of wire rod coil (N) is about 20.

Therefore, in this case, the areas of the overlapping wire rod coils at the side and center regions can be divided into four kinds of symmetrical parts as shown in Fig.11. Each of the four symmetrical parts,1 to 4, in the areas of overlapping wire rod coils has their own circumferential angle of about 75°, 13°, 20°, 16°, respectively. Hence, the areas of each part can be calculated with a simple mathematical formula as follows:

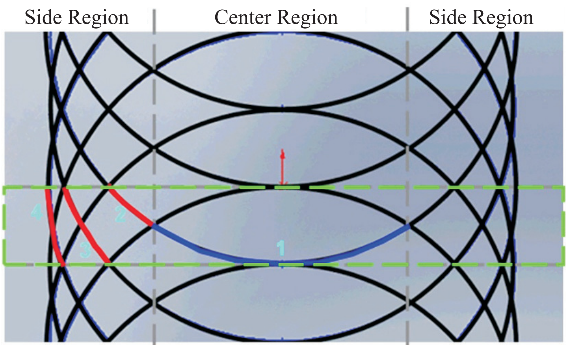

Fig.11. Four kinds of symmetrical parts for overlapping coils at side and center regions.

The length of wire rod coils at center region (part no.#1):

$$(1)\ 900\text{mm} \times 3.14 \times \left(\frac{75}{360}\right) \times 2\text{pieces} = 1178\text{mm}$$

The length of wire rod coils at side regions: (part no.#2 to 4)

$$(2)\ 900\text{mm} \times 3.14 \times \left(\frac{13}{360}\right) \times 4\text{pieces} = 408\text{mm}$$

$$(3)\ 900\text{mm} \times 3.14 \times \left(\frac{20}{360}\right) \times 4\text{pieces} = 628\text{mm}$$

$$(4)\ 900\text{mm} \times 3.14 \times \left(\frac{16}{360}\right) \times 4\text{pieces} = 502\text{mm}$$

The ratio of side regions to center region

$$= \left(\frac{408+628+502}{1178}\right) \times 100\% = 130\%$$

So, the length (heat capacity) of the wire rod coils at the side regions exceed that of the center region by about 30%. Accordingly, the required air flow rate to compensate for higher heat capacity at the side regions can be obtained.

3.3 Improving the Quality of NLP Wires

A series of experiments have been conducted to investigate the relationship between the cooling rate and the mechanical property of NLP wire rods. Since the cooling rate during phase transformations determines the scale of microstructure obtained, the cooling rate of wire rod coils were accurately controlled via the optimum settings of operating fan-loading and baffle angle in each plenum. In this study, the wire rod surface temperature distribution was measured and checked by means of the self-developed novel online and movable temperature diagnostic system. In the rod mill of CSC, since the measurements were repeated to confirm the optimum values of fan-loadings and baffle angles to obtain the desired air distribution and the required cooling effect under the conveyor deck, the material qualities of the NLP wires have been markedly improved.

A new controlled cooling process function for the Stelmor system could be established to ensure the formation of the required microstructure of wire rods. From the results, shown in Fig.12, when the wire rods entered the slow cooling zone (Zone No.#6), the surface temperature of the NLP wires could be controlled at about 500 ^{o}C and meet the optimum phase transformation temperature requirement at 500~550^{o}C. Besides, there are no martensite texture be found in the core of the wire rods.

Figure 13 presents measured results of NLP wires surface temperature distributed in different locations along stock. A series of experiments had been conducted to investigate the relationship between the cooling rate and the mechanical property of NLP wire rods. From the established operating database, it has become possible to qualify the cooling effects of NLP Wires along stock of Stelmor conveyor, and therefore, the air-cooling process parameters could be optimized. Results showed that the both side and center region temperature difference of the ring-shaped pile of wire rods on the conveyor reduced to less than 20~40^{o}C. Besides, there are no martensite texture be found in the core of wire rods and the average tensile strength of wire rods up to 126 kg/mm^2 high than the normal cooling process 122 kg/mm^2.

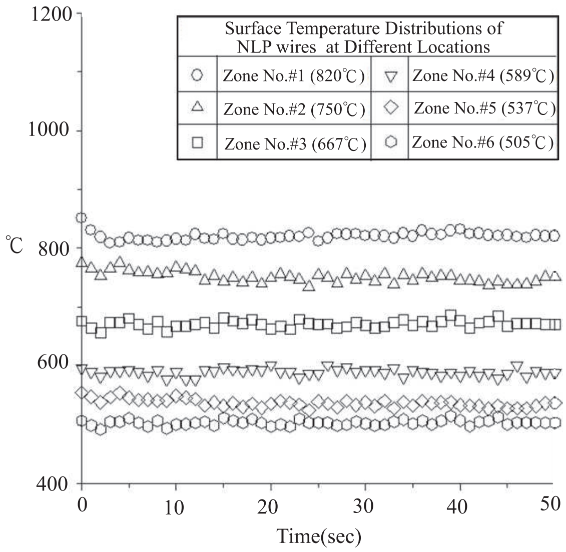

Fig.12. Surface temperature distributions of NLP wires at different locations.

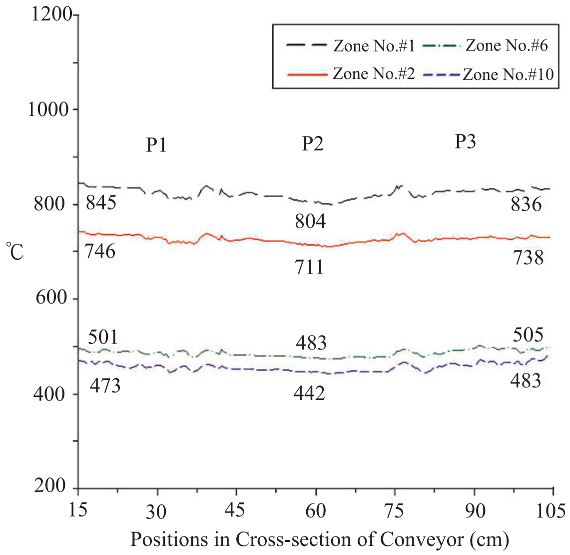

Fig.13. NLP wires surface temperature distributions with the optimized cooling process parameters in different locations.

Finally, the Stelmor air-cooling process control mode established in current work was applied to improve the quality of NLP wires with uniform strength. Measurements for coil surface temperature distributions were performed to check the cooling effect along stock of Stelmor conveyor using the developed novel online and movable temperature diagnostic system. These coil surface temperature measurements were repeated to confirm the optimum process parameters used for each plenum and the established operating database was utilized to adjust these process parameters for desired air distribution on deck corresponding to the required cooling effect of Stelmor conveyor.

Figure 14 shows the overall surface temperature distributions of NLP wires during the Stelmor air-cooling process. The air cooling rate from Zone No.#1 to Zone No.#10 could be calculated and controlled by the developed novel online and movable temperature diagnostic system. The temperature of the wire rods during the Stelmor air-cooling process was more accurately controlled through the use of this novel system and the variation in tensile strength of NLP wires was reduced from 40% to 16%. Hence, the material qualities of the NLP wires have been obviously improved in the CSC No.#2 Rod Mill.

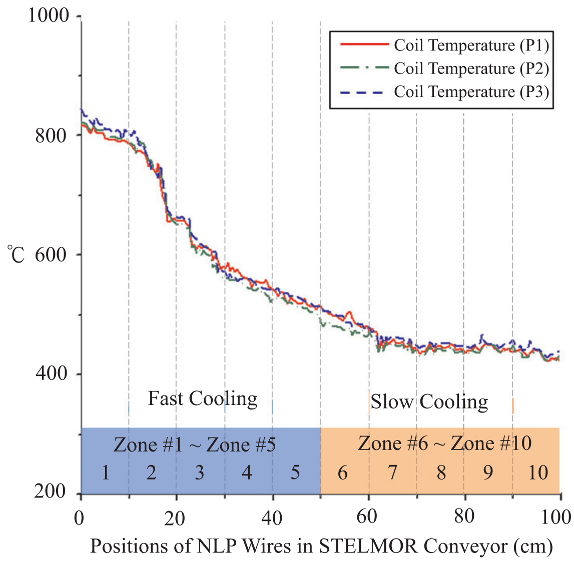

Fig.14. Overall surface temperature distributions of NLP wires during the Stelmor air-cooling process

4. CONCLUSIONS

The conclusions drawn from the results and discussion are presented below:

(1)The single color pyrometer is more stable for wire rod temperature measurement than the dual-color pyrometer.

(2)The surface temperature distributions are symmetrical in the center region (P2) of the coils and there is a similar temperature trend in the both the side regions of the coils (P1 and P3) ; moreover this phenomenon also can be found at different locations.

(3)In order to obtain NLP wires with uniform strength, the required air flow rate to compensate for the side regions was about 30%.

(4)When a new controlled cooling process function for the Stelmor system can be established, the surface temperature of NLP wires at Zone No.#6 could be controlled at about 500℃ and meet the optimum phase transformation temperature requirement at 500~550℃.

(5)The two sides and center temperature difference of the ring-shaped pile of wire rods on the conveyor was reduced to less than 20~40℃. Besides, there was no martensite texture to be found in the core of the wire rods. The average tensile strength of the wire rods was increased to126 kg/mm^2, higher than the 122 kg/mm^2 achieved by the normal cooling process.

(6)A series of experiments had been conducted to investigate the relationship between the cooling rate and the mechanical properties of the NLP (Non-Lead Patenting) wire rods. The temperature of the wire rods during the Stelmor air-cooling process was more accurately controlled through the use of this novel temperature diagnostic system and the variation in the tensile strength of the NLP wires was reduced from 40% to 16%.

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