INCREASING OF ALUMINUM CONTINUOUS CASTING LINE PRODUCTION QUALITY VIA IMPROVEMENT OF THE CONTROL OF TECHNOLOGICAL PARAMETERS

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ABSTRACT

The report presents research, analysis and subsequent improvement of the control of the temperature of the water, cooling the casting rolls. The necessity to investigate the influence of the temperature of the cooling water on the casting process required the purchase and introduction of high-tech equipment to measure the thickness of the strip. It allowed us to trace the influence of the change of temperature of the cooling water. The initial adjustment was based on the ON / OFF approach to manage the fan of the cooling tower, but that did not guarantee a constant temperature of the cooling water.

A considerable improvement of the variation in water temperature, and thus - improvement of the quality of production was achieved by implementation of an automated control system.

Keywords: Twin Roll Casting, Dierect Chill CAsting, PID, SCADA, PLC, cooling, temperature.

INTRODUCTION

Twin Roll Casting (TRC) of aluminium strip has important advantages over the rival Direct Chill Casting (DC) process. TRC requires a much lower investment cost and reduced space for equipment, energy and production costs are much lower which makes the product highly competitive. TRC process has successfully been used for many years for the production of alloys with narrow solidification range, while research on developing techniques for the wide solidification range alloys is continuing.

TRC Casting is highly sensitive to process parameters such as melt temperature, head box height, cooling rate as well as the cleanliness of the melt, degassing, tip design etc. These parameters have to be controlled accurately and maintained in a narrow range in order to achieve a sustainable and consistent quality of uninterrupted production. The description of these parameters and their influence on the quality of the cast strip is discussed in various articles in literature [1, 2]. A schematic of TRC process is shown in Fig. 1 where the liquid metal is fed into twin rolls. While it solidifies, it is also deformed by the force on the rolls, to produce cast strip of required thickness. Casting speed is adjusted so that sufficient amount of heat for solidification is removed by the rolls and that the rolling force is sufficient to overcome the tensile strength of the solidified metal and reduce the gauge to the required magnitude. Heat is extracted by the water cooled rolls through the contact area between the cast strip and the rolls.

One problem that can occur during the TRC process is the ripple effect which is caused by changes in heat transfer rate; If the contact area between the roll and the strip changes or the roll temperature changes, heat extraction rate is changed. This results in transverse regions of strip with different microstructure or thickness variations. The ripple causes problems during the subsequent rolling operations and eventually results in a strip of poor quality. In the literature, there are mathematical models, recommended for the investigation of the thermal effects [3 - 6].

TRC rolls are cooled by continuously circulating water, the temperature of which is maintained by passing part of the flow through a cooling tower. A dedicated control system monitors the water temperature and mixes cooling tower water, which is at a lower temperature, with the circulating water. Since the water quantity in circulation is limited, any mixing of cold water from the cooling tower results in a temperature fluctuation. The response of the control system must be good enough to keep the circulating water temperature accurately fixed and maintained with minimum fluctuations.

In this paper we describe the experimental work, carried out in Alcomet to improve the temperature control system for the cooling water and the analysis of the obtained results.

EXPERIMENTAL

The work has been carried out on Fata Hunter TRC Strip Casting Line Number 4 in Alcomet, with roll diameters of 600 mm. The alloy cast was AA8011, casting width 1350 mm, thickness 6.37 mm, casting speed 0.9 m/min.

This line is also equipped with a Seltek CC-CXT scanning x-ray thickness gauge, presented in Table 1. The scanning x-ray gauge continuously scans the cast strip as it progresses from the casting stand to the rewinder across its width. The thickness measurements are +/-0.1 micron in accuracy and can detect thickness variations and periodic thickness oscillations easily. Care is taken to make sure that the detected oscillation in thickness is not coming from eccentricity of rolls or of bearings.

The software program **Supervisory control and data acquisition** (SCADA) provides overall monitoring of the features of the manufactured production, starting from the beginning of the coil to the end. Parameters such as coil number, alloy and casting dimensions are entered once, but the remaining process parameters - casting speed, liquid metal temperature, strip thickness, cooling water temperature etc., are monitored and recorded continuously. This information can be statistically analyzed online or offline to reveal any changing trends which are highly useful to control that the process is stable. Some of these changes may be difficult to identify by a naked eye or other measurement techniques.

RESULTS AND DISCUSSION

We have analyzed the thickness ripple in the coils before and after the introduction of the new cooling water temperature control system. The periodic thickness variation measured is about +/- 20 microns of a strip with thickness of 6350 microns. As mentioned earlier, there are other factors that can create periodic thickness variations, but these can be easily eliminated by the period of the variation. For instance, any defect caused by the roll has a period of one roll revolution. A typical surface topography of the cast strip is shown in Fig. 1.

Initially, the temperature of the close circuit cooling water of the casting rolls had been controlled by an on/off system. When the temperature of cooling water reached a predetermined high level, the fan starts rotating and this leads to a drop of the water temperature in the tower. When water temperature falls below the limit, the fan stops and ends further cooling. This operation created a +/- 8 degree oscillation in water temperature with a period of approximately 30 minutes, as shown in Fig. 2.

This periodic variation in temperature, in turn resulted in thickness variation of the cast strip, as shown in Fig. 3. The edges of the cast strip are thinner than the centre and the magnitude of the difference depends on the alloy. Hence, scanning of the strip from one edge to the other goes through a minimum at edge, to a maximum in centre, then again to minimum at the other edge. When the average thickness of strip is calculated from measured data we observe the variation depicted in Fig. 4.

Table 1. Seltek CC-CXT Scanning X-ray Gauge.

Measurement Range : 3500-8000 microns	
Source : 65 keV, 1 mA	Sampling time : 1 ms
Sensitivity : 0.1 %	Resolution : 0.1 micron

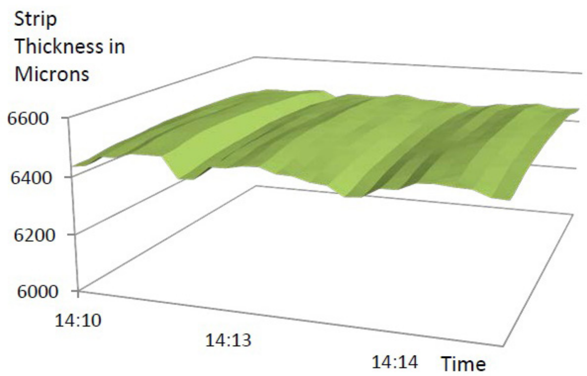

Fig. 1. Variation of the thickness in one revolution of the casting roll.

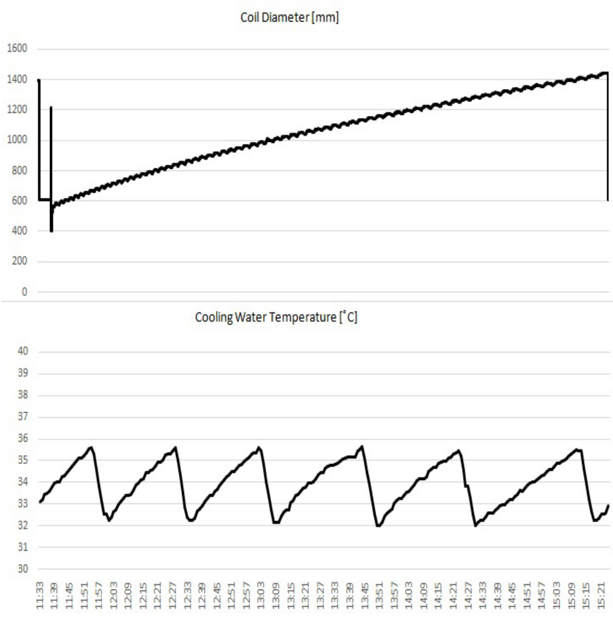

Fig. 2. Variation of water temperature with on/off system.

When an object is heated or cooled, its length changes by an amount proportional to the original length and the change in temperature. The linear thermal expansion of an object can be expressed as:

$$\Delta l = L_o \alpha (t_1 - t_0)$$

where:

Δl= change in object length (m, inches);
L_0 = initial length of object (m, inches);
α = linear expansion coefficient (m/m°C, in/in°F);
t_0 = initial temperature (°C, °F);
t_1 = final temperature (°C, °F).

For the change of length, when we need to introduce the coefficient of thermal expansion of the rolls; in our case it is $\alpha = 12{,}6.10^{-6} m/mK$ for roll diameter of 600 mm. Then we have:

$$\Delta l = 600000.12{,}6.10^{-6}.5 = 37{,}8 \mu m$$

Analysis of the manufactured products, measured by means of X-Ray

In order to show in detail what is the influence of the cooling water, we have taken random sample coils. Part of them have been produced *before* the water hysteresis change (coil No. 415567) and another part – *after* implementing the automated control system (coil No. 4160813).

The cooling water temperature has a strong impact on the coil characteristics, causing wavy shape of the strip, as evidenced by the data of coil No.415567, dated 29 April 2015 (see Fig. 5). This impact is clearly pronounced for the coils according to the X-Ray data and

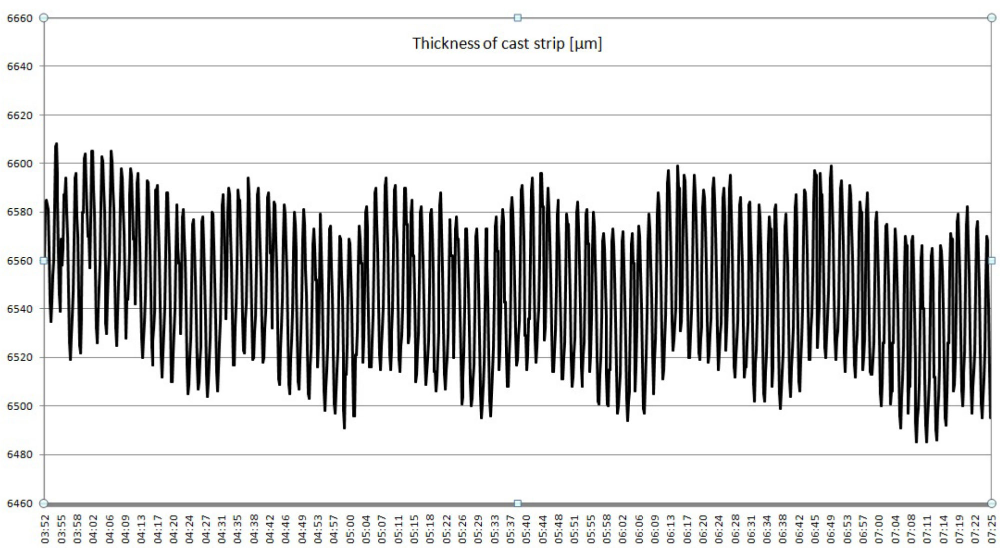

Fig. 3. Measured thickness of cast strip.

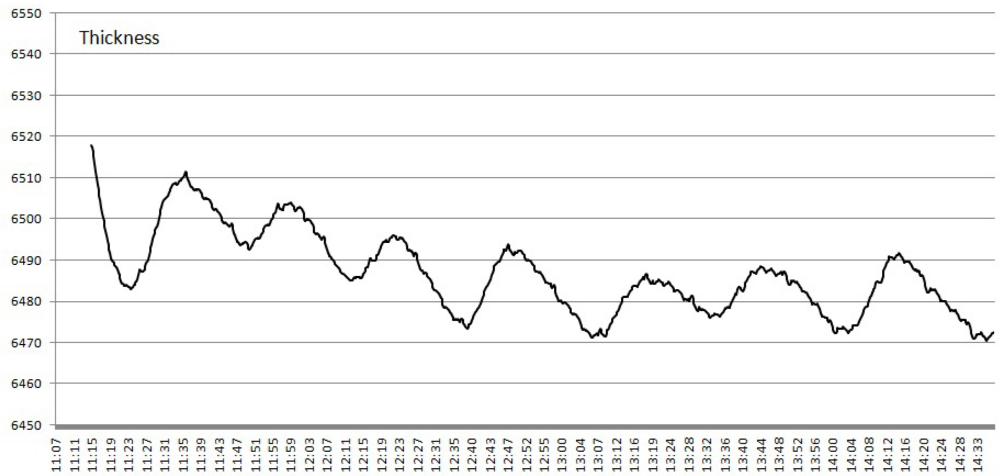

Fig. 4. Variation of average thickness of strip.

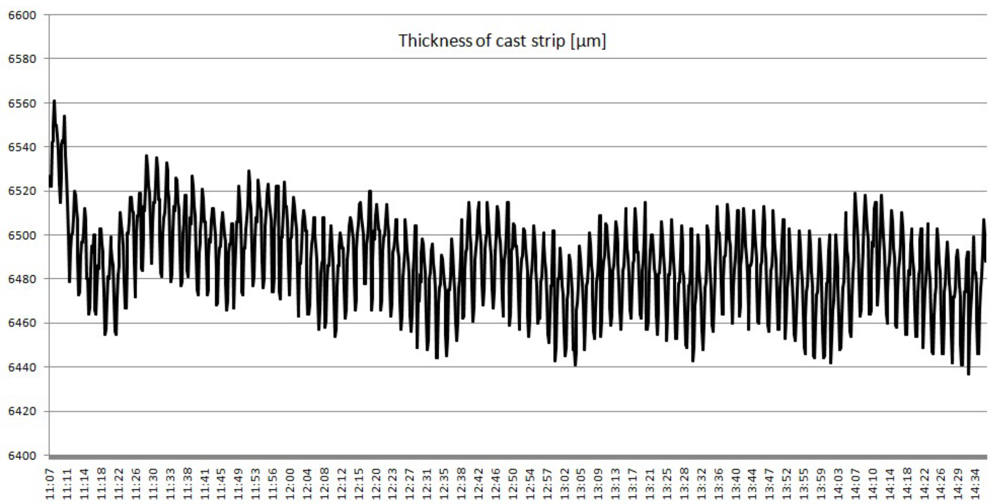

Fig. 5. Thickness profile of the 6.5 mm thick cast strip - coil No.415567.

the data from the SCADAPLC Alcomet, for the water temperature deviation (see Fig. 7).

For this coil (No.415567), the maximum temperature of inlet water has been t_{max} = 35.73°C, and the minimum temperature, t_{min} = 31.00°C. The difference between the maximum and minimum temperature of inlet water is 4.73°C - see Table 2. The measured difference of 4.73°C is for the considered coil, but for the other coils, as evidenced by the SCADA archives, the values are nearly the same.

For the time of casting of one coil, the water reaches the maximum values 7 times. This leads to expansion of both the upper and the bottom roll, because of the temperature expansion of the metal due to heating. This in turn leads to shrinkage of the gap between the rolls and strip thinning. The minimum values of the water are also seven and they lead to cooling of the rolls, their contraction and, respectively to increases of the gap between the rolls and strip thickening at these locations.

Hysteresis of the water

The deviations of cooling water temperature occurred due to the fact that the water hysteresis was ±2°C. Here, we have to note that it is not possible to detect

Table 2. Difference between the maximum and minimum temperature of inlet water.

Water temperature	Maximum (t_{max})	Minimum (t_{min})	Difference
Inlet	35.73°C	31.00°C	4.73°C

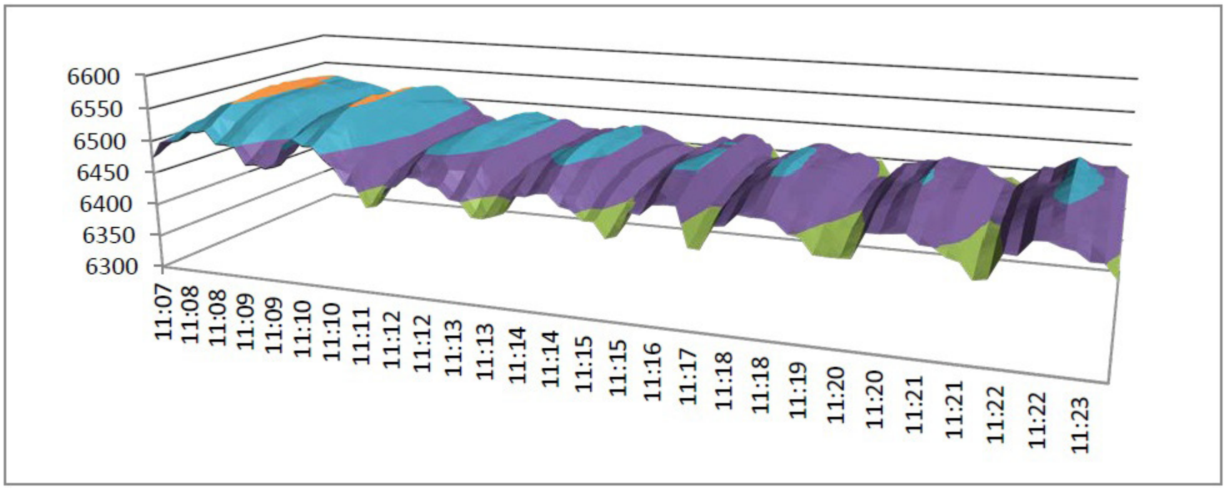

Fig. 6. Variation of cast strip thickness (microns) with on/off control of the cooling water temperature - coil No.415567.

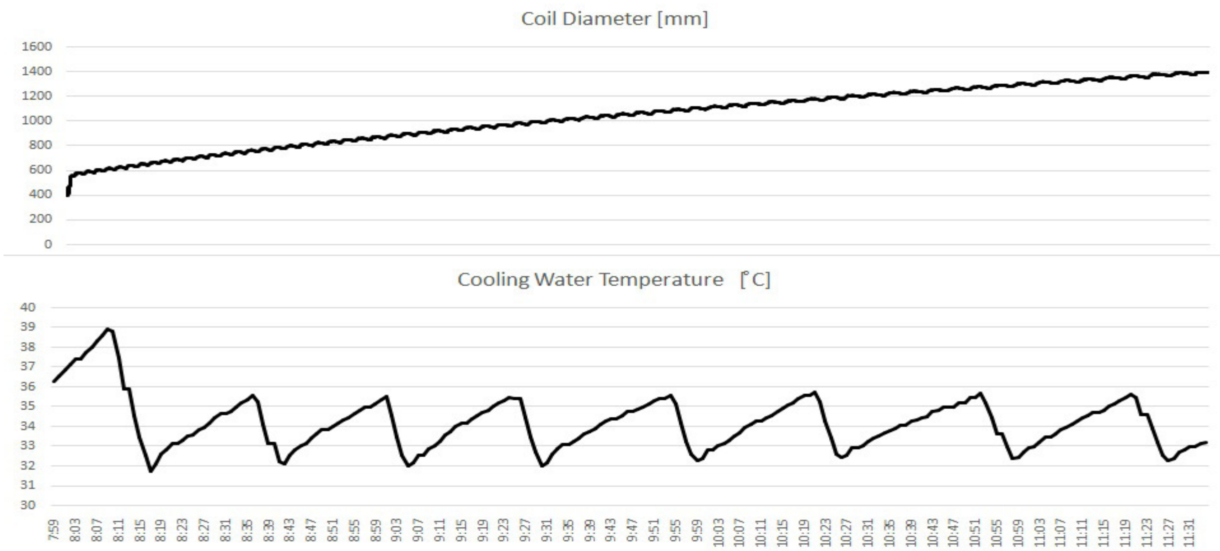

Fig. 7. Temperature fluctuations of the water through the rolls - coil No. 415567.

these effects with a naked eye. The analysis of the data from X-Ray showed that there was a need to reduce this hysteresis value in the management of the water temperature, so that it should give a minimum impact on the quality of the cast roll.

Introducing of a system for precise control of the water tower temperatures

The above mentioned methods for water temperature regulation were realized by means of an ON/OFF system for water tower fans control (changing of hysteresis value ± 2,0°C). To achieve better results, it is necessary to have more precise control and the inlet water temperature of casting rollers to be „constant”. For the purpose, a project for control of the cooling tower temperatures using automation system was implemented.

The Siemens controllers are a powerful tool for control, management and monitoring of important production parameters - in our case this is cooling water temperature. The project was implemented by a programmable logic controller (PLC) by Siemens and a frequency inverter Danfoss.

PID control (proportional–integral–derivative controller) of cooling tower output water temperature, which actually is the inlet temperature of rolls, is implemented in the programmable controller. This is achieved by rotational speed control of the cooling fans, depending on desired value of cooling temperature. The achieved effect has been very good; the results for temperature fluctuations are shown in Table 3.

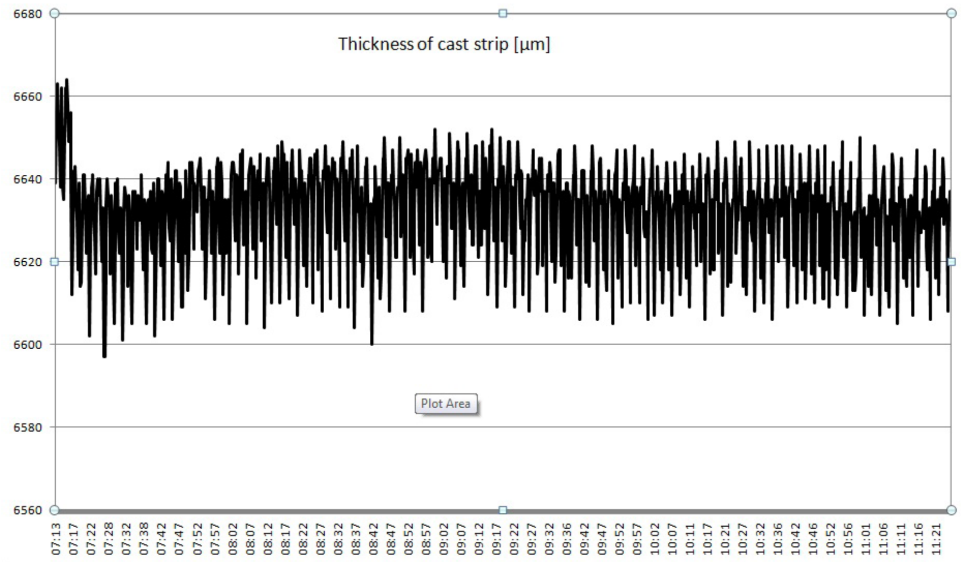

Fig. 8. Thickness profile of the 6.5 mm thick cast strip - coil No. 4160813.

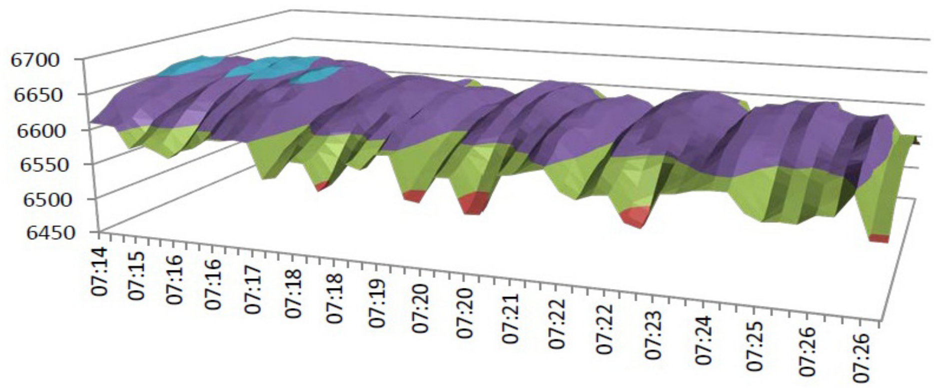

Fig. 9. Variation of the thickness of the cast strip (microns) with the dedicated control system, on the cooling water temperature.

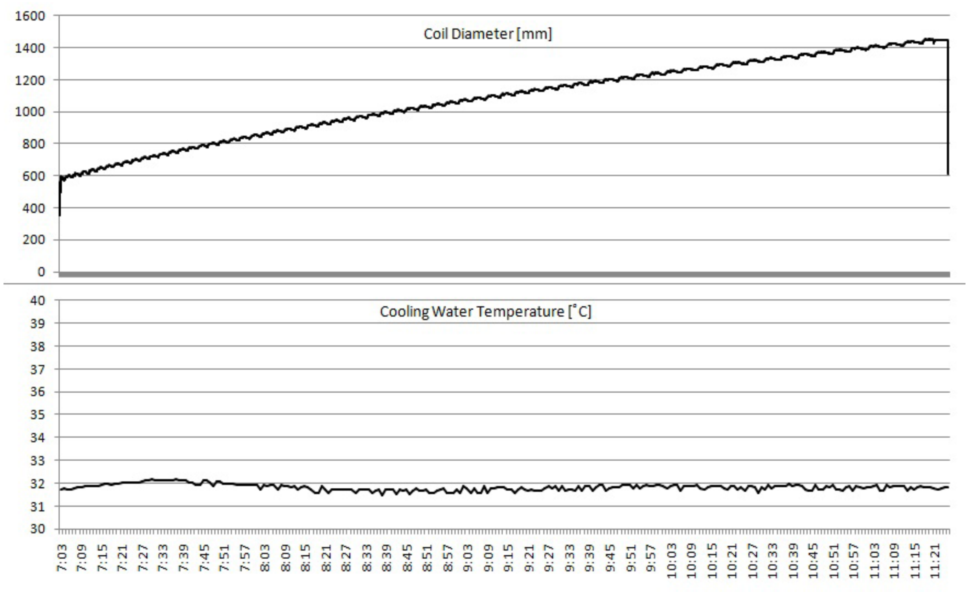

Fig. 10. Temperature fluctuations of the water through the rolls - coil No. 4160813.

Table 3. Difference between the maximum and minimum temperature of inlet water.

Water temperature	Maximum (t_{max})	Minimum (t_{min})	Difference
Inlet	31.94ºC	31.83ºC	0.11ºC

The achieved effect of the PID control usage can be seen also from the scanned results of X-Ray –Graph of the trend for coil No. 4160813, as evidenced by Fig. 8. The variation of the thickness of the cast strip with the dedicated control system of cooling water temperature can be seen on Fig. 9. For coil No.4160813dated 23 June 2016, the maximum temperature of inlet water was t_{max} = 31.94ºC, and the minimum temperature t_{min} = 31.83ºC. The difference between maximum and minimum water temperature is around 0.11ºC (Table 3). Considering the difference of 0.11 ºC, we can conclude that the management of analog value - in our case – temperature, by the PLC, is leading to levels of oscillation of the water temperature, which in practice are negligible (Fig. 9). This leads, also, to smaller deviations in the Trend profile of casting coil (see Fig. 8). Last but not least, this results into a significant improvement of manufactured product qualities.

CONCLUSIONS

The issues discussed in this paper provide a clear indication of the need for new technologies. The discovery, analysis and actions taken, to eliminate the negative impact of external factors, affecting the product quality became possible because of the investments in high-tech equipment, made by the management. The effective use of new technologies is essential to maintain competitiveness, cost reduction and quality improvement.

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