METHODS OF SURFACE TEMPERATURE MEASUREMENT FOR THE CASTING BILLET IN THE CONTINUOUS CASTING PROCESS UNDER INDUSTRIAL CONDITIONS

[1]Katarzyna MIŁKOWSKA-PISZCZEK, [1]Paweł DROŻDŻ, [1]Marcin RYWOTYCKI,
[2]Paweł KRAJEWSKI, [2]Piotr PRZEGRAŁEK

[1]AGH University of Science and Technology, Faculty of Metals Engineering and Industrial Computer Science, Cracow, Poland, EU, kamilko@agh.edu.pl

[2]ArcelorMittal Poland S.A, Dąbrowa Górnicza, Poland, EU, pawel.krajewski@arcelormittal.com

https://doi.org/10.37904/metal.2019.839

Abstract

Cooling in the continuous steel casting process starts within the primary cooling zone. Controlling the amount of water flowing through the mould cooling system allows the shell thickness growth to be directly controlled. Depending on the continuous casting machine type, the secondary cooling zone is divided into a few spray sub-zones. The cooling intensity monitoring within the secondary cooling zone is more and more often related to the strand surface temperature measurement in the cooling chamber. This measurement is performed on the basis of modern systems using optical pyrometers. In this paper, the authors present the method of strand surface temperature measurement in the cooling chamber using optical pyrometers. In addition, the solidifying strand surface temperature was monitored with a thermovision camera, and direct measurements were performed with a contact thermocouple - immediately after the strand had left the secondary cooling chamber. The experiments were carried out in industrial conditions at ArcelorMittal Poland S.A. Unit in Dąbrowa Górnicza, on a six-strand machine for casting billets. The measurements covered a sequence comprising five heats of a high carbon steel grade, dimensions 160x160 mm. The authors used a proprietary measurement method presented in the awarded patent: PL 225107 B1 „Method of a continuous temperature measurement at any point of a wide area of the strand after falling off the solidified mould slag in the secondary cooling chamber of a machine for the continuous casting of flat ingots during the entire casting sequence”.

Keywords: Continuous casting, high carbon steel, temperature measurement, optical pyrometer, thermal imaging camera

1. INTRODUCTION

Measuring the strand surface temperature in industrial conditions is a very difficult and complex research challenge. In the primary cooling zone, the strand surface temperature cannot be measured directly. The conditions prevailing in the secondary cooling zone (high temperature, water vapour, scale bits on the strand) often make a credible measurement impossible. At the same time, note that measurement results obtained directly from an industrial plant operating in the actual conditions are necessary to verify numerical computing based upon the temperature distribution in the continuous casting process [1-4]. The authors of this paper made a continuous measurement of the strand surface temperature when the billet continuous casting machine was in operation. Two optical pyrometers and a thermographic camera were used for the measurements. The following fundamental difficulties can be encountered when making this type of measurements: a high ambient temperature, disturbances in the form of a large amount of water vapour, and difficult access to the strand due to structural components of the continuous steel casting machine. The described work was performed as part of a research project pursued in collaboration between ArcelorMittal Poland, Dąbrowa Górnicza and AGH University of Science and Technology in Krakow. The performed strand surface temperature measurement is a non-destructive examination and does not disturb the production process in an industrial plant.

2. STRAND SURFACE TEMPERATURE MEASUREMENT WITH PYROMETERS

Measurements of the cast billet surface temperature were made for strand no. 1 of the CCM machine in service at ArcelorMittal Poland, Dąbrowa Górnicza. The tests covered one sequence, consisting of 5 heats. The last two heats in the sequence were analysed in detail, they were cast of grade C82D2/1. The pyrometric measurement of the surface temperature of the strand withdrawn within the cooling chamber of the continuous casting machine was performed using a device with the recommended measurement range 700 - 1800 °C. In order to measure the strand surface temperature during casting, a measurement set was prepared, consisting of a two-colour pyrometer in a ThermoJacket casing to enable the pyrometer to operate at an ambient temperature up to 315 °C, with water cooling and blowing the lens with compressed air. The whole set was installed on a stand adjusted to the local conditions of the continuous casting machine [5]. In order to obtain a more accurate image of the temperature distribution map on the strand surface along the whole metallurgical length, the continuous steel casting machine was additionally fitted with 2 measurement sites using pyrometers. Pyrometer P1 was installed within the secondary cooling zone at a distance of 5.5 m from the metal level in the mould, whereas pyrometer P2 was placed downstream the secondary cooling chamber at a distance of 14.5 m from the metal level in the mould. The pyrometer locations were not changed during the measurements. The measurements were continuously recorded at 1 second intervals when casting all heats.

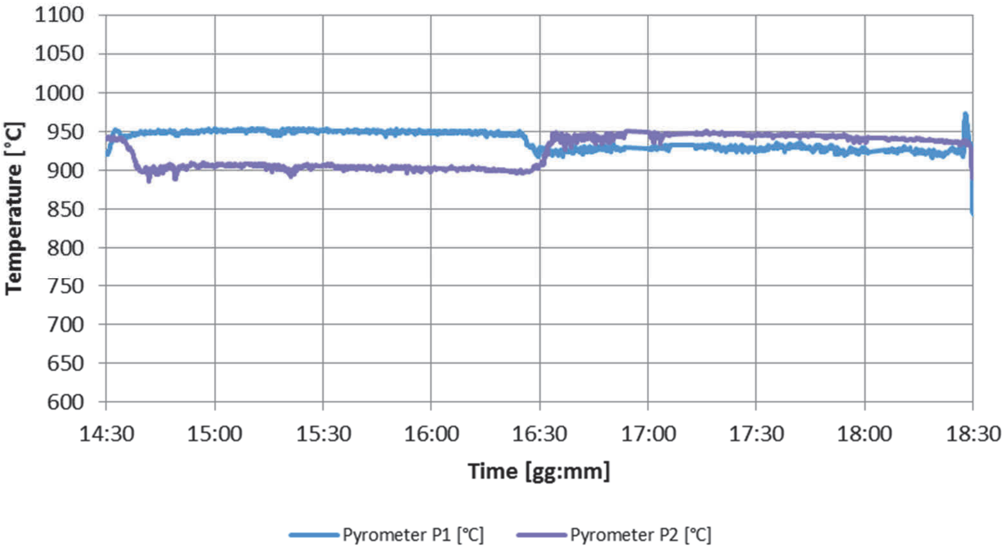

Figure 1 Changes of the strand surface temperature during casting the whole sequence [own study]

The P1 pyrometer measurement point was located on the left hand side offset by 30 mm from the billet axis, whereas for pyrometer P2 the measurements were performed on the billet axis. The offset of the P1 pyrometer measurement point from the billet axis resulted from installation limitations because the header supplying the spray nozzles within the secondary cooling zone 2B was located on the axis of the billet. The recorded findings are presented as a graph. **Figure 1** presents the change in the strand surface temperature during casting the whole sequence. Heat no. 1 was cast at a speed V = 1.8 m min^{-1}, while heat no. 2 at a speed V = 2.5 m min^{-1}. The obtained measurement results for stable casting conditions are characterised with little changes in the strand surface temperature.

3. STRAND SURFACE TEMPERATURE MEASUREMENT WITH A THERMOGRAPHIC CAMERA

The principle of the thermographic temperature measurement is based upon scanning a surface with a high sensitivity and high resolution camera. This measurement utilizes the fact that every substance at a temperature above 0K emits radiation with its energy dependent on the temperature and the wavelength. This radiation goes through the camera lens onto a thermo-sensitive detector to obtain an image. A camera analogue signal is converted into a digital signal, and subsequently it is transferred to the computer memory. Using suitable computer software, one can analyse the image of the surface scanned in detail to assess its temperature. The thermal radiation beam reaching the detector (**Figure 2**) consists of:

- a beam emitted by the object examined φob,
- a beam emitted by the environment and reflected from the object examined φrdb,
- a beam emitted by the atmosphere φatm,
- a beam emitted by optical components and camera filters φop.

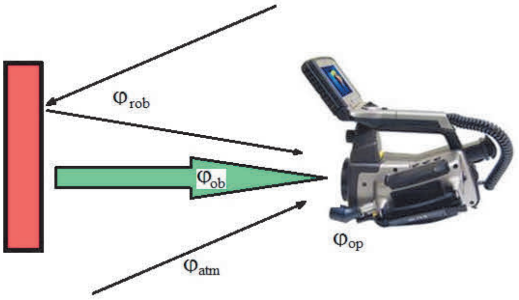

Figure 2 Thermal radiation beams occurring during the measurement in the industrial conditions

Components determining the measurement accuracy:

- The atmospheric barrier, or the lens distance to the object analysed. The parameter, whose correct setting is the first of factors determining the measurement accuracy,
- The ambient temperature of the object and the measuring instrument - the instrument can operate at the ambient temperature up to 50 °C,
- The predetermined emissivity coefficient ε of the object.

Thermal images recorded in the continuous casting machine bay at AMP Dąbrowa Górnicza were made with a thermographic camera FLIR THERMA CAM S60. The thermograms recorded during the measurement were transferred to a computer equipped with the ThermaCAM Resarcher Professional software allowing the thermograms to be thoroughly analysed. The thermograms obtained with this method allowed the temperature distribution on the surface of the strand examined to be determined. The first stage of processing the thermographic measurement results is the determination of emissivity coefficient. To this end, a method proposed in references [6] was applied. It is based upon a comparison of readings of the thermocouple measuring the surface temperature with readings of the thermographic camera and determining the emissivity coefficient so that these values are equal. The picture (**Figure 3**) shows the measurement stand for determining the emissivity coefficient. The sample was made in the form of a cubicoid with dimensions 160 mm x 100 mm x 10 mm. The surface temperature was established with type K thermocouples with a diameter of 0.5 mm. After the temperature indicated by the thermocouples had stabilised, the thermogram was made. **Figure 4** presents an example of a thermogram recorded during tests to determine the emissivity coefficient. The values of the emissivity coefficient were determined for four temperatures (**Table 1**).

Table 1 The values of emissivity coefficient determined at the test stand [own study]

Surface temperature, °C	**Emissivity coefficient,-**
900	0.91
850	0.88
800	0.87
750	0.86

Figure 3 The test stand for determining the emissivity coefficient [own study]

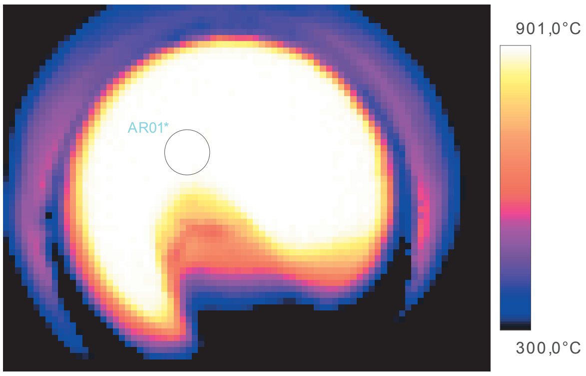

Figure 4 The thermogram for determining the emissivity coefficient [own study]

4. RESULTS OF INDUSTRIAL MEASUREMENTS WITH A THERMOGRAPHIC CAMERA

The industrial measurements were performed for the selected times (Measurements I - IV) in the steel casting sequence at the CCM at ArcelorMittal Poland, Dąbrowa Górnicza. After the thermograms had been made, they were analysed using the ThermaCAMResarcher Professional program. The obtained temperatures, along with their corresponding graphs of temperature distribution on the length of the marked measurement line (**Figure 5**), are presented below. The colours on the presented thermograms denote the strand surface temperature, which is computed for the assumed emissivity, distance to the object, background temperature, air temperature, reference temperature and relative humidity of the ambient air.

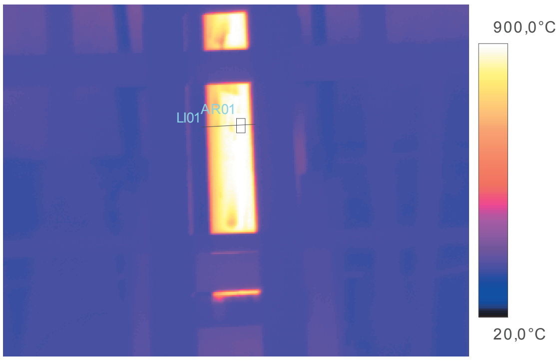

Figure 5 Example of a thermogram recorded during industrial measurements along with the elements of surface temperature analysis [own study]

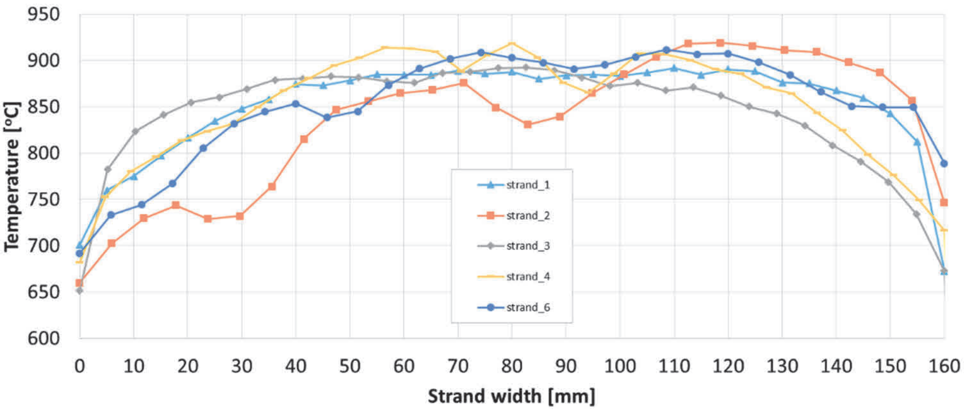

Figure 6 Temperature distribution on the width of the strand top surface for all strands (line LI01) [own study]

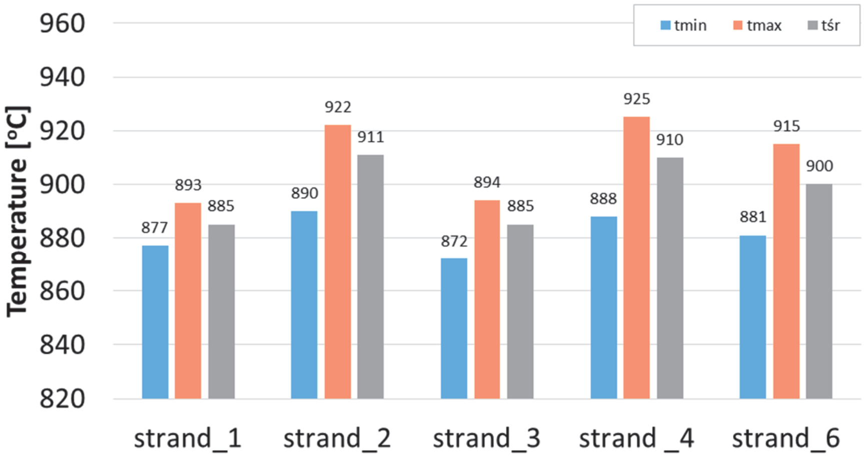

Figure 7 Temperature distribution on the width of the strand top surface for all strands (line LI01) [own study]

The temperature distribution on the strand width (**Figure 6**) is characteristic for the cooling process. It has its maximum on the surface axis, and its minimums at the strand corners. Local temperature drops occurring on the linear graph are caused by flowing down water drops, which reduce the strand surface temperature locally, not reflecting the global surface temperature resulting from the heat transfer conditions. To verify numerical models [4, 7-10], it is better to apply the result from averaged values obtained at the surface temperature analysis using a rectangular area situated on the strand surface axis (**Figure 7**). It allows strand surface temperature disturbances caused by the occurrence of water streams flowing down on the strand surface to be eliminated.

5. CONCLUSION

The paper presents methods of solidifying strand surface temperature measurement at the continuous casting machine in industrial conditions. Such measurements pose many difficulties resulting from the size of the plant and operating conditions. However, they provide necessary data to verify numerical models of the continuous steel casting process. During the measurements, two contactless temperature measuring devices were used: a pyrometer and a thermographic camera. The analysis of the obtained results allowed the strand surface temperature to be established at three points. This data was then used to verify models of boundary conditions applied in numerical computing of the continuous steel casting process in further work in the research project: The application of electromagnetic stirrers of a continuous billet casting machine in order to produce a new grade of steel designated for steel cord production, Project No.: POIR.01.02.00-00-0219/17.

ACKNOWLEDGEMENTS

This research work was completed as part of project INNOSTAL in collaboration with the National Centre for Research and Development, Project No.: POIR.01.02.00-00-0219/17 and was financed through founds at AGH University of Science and Technology 5.72.110.629.

REFERENCES

[1] THOMAS, Brian G. Review on Modeling and Simulation of Continuous Casting. *Steel Research International*. 2018. vol. 89, no. 1, pp. 1-21.

[2] MENG, Ya and THOMAS, Brian G. Heat Transfer and Solidification Model of Continuous Slab Casting: CON1D. *Metallurgical and materials transactions B*. 2004. vol. 34, no. 5, pp. 685-705.

[3] HADAŁA, Beata, MALINOWSKI, Zbigniew and TELEJKO, Tadeusz. Analysis of the slab temperature, thermal stresses and fractures computed with the implementation of local and average boundary conditions in the secondary cooling zones. *Archives of Metallurgy and Materials*. 2016. vol. 61, no. 4, pp. 2027-2035.

[4] MIŁKOWSKA-PISZCZEK, Katarzyna and FALKUS, Jan. Applying a numerical model of the continuous steel casting process to control the length of the liquid core in the strand. *Archives of Metallurgy and Materials*. 2015. vol. 60, no. 1, pp. 251-256.

[5] FALKUS, Jan, DZIARMAGOWSKI, Marek, DROŻDŻ, Paweł, MIŁKOWSKA-PISZCZEK, Katarzyna, PAWŁOWSKI, Czesław, ŚLĘZAK, Wojciech and KONOPKA, Krzysztof. Method of a continuous temperature measurement at any point of a wide area of the strand after falling off the solidified mould slag in the secondary cooling chamber of a machine for the continuous casting of slabs during the entire casting sequence. Patent PL no. 225107 B1.

[6] LABER, Konrad, KNAPIŃSKI, Marcin DYJA, Henryk, MUSIAŁ, Dorota. The experimental determination of the emissivity for the S355J2G3 steel in the temperature range 800 °C÷1200 °C. *Hutnik Wiadomości Hutnicze*. 2009. vol. 76, no. 7, pp. 504-506.

[7] MERDER, Tomasz and WARZECHA, Marek. Optimization of a Six-Strand Continuous Casting Tundish: Industrial Measurements and Numerical Investigation of the Tundish Modifications. *Metallurgical and materials transactions B*. 2012. vol. 43, no. 4, pp. 549-559.

[8] CWUDZIŃSKI, Adam. Numerical and Physical Modeling of Liquid Steel Flow Structure for One Strand Tundish with Modern System of Argon Injection Physical and mathematical modeling of bubbles plume behavior in one strand tundish. *Steel Research International*. 2017. vol. 88, no. 9, pp. 1-14.

[9] THOMAS, Brian G. Modeling of the continuous casting of steel-past, present, and future. *Metallurgical and materials transactions B*. 2002. vol. 33, no. 6, pp. 795-812.

[10] VOLLRATH, Klaus. Casting simulation using numerical processing becomes more important in steel mills. *Stahl und Eisen*. 2013. vol. 133, no. 5, pp. 45-53.