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Experimental Investigation of Quenching Of Moving Hot Metal Plate with Water Using Flat Spray Nozzles

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Abstract **–** In metal manufacturing, the controlling of cooling rate during the course of quenching is crucial and has to be controlled accurately in order to get desired mechanical properties, prevent metal deformation and henceforth increasing the productivity. Therefore, the investigation of sprays and corresponding heat transfer during the metal quenching is essential for process optimization. In iron and iron alloys metal casting industry, spray cooling is employed as secondary cooling complimentary to the primary cooling. The aim of this work is to investigate the flat spray quenching of moving metals.

Keywords**:** Flat sprays, Metal quenching, Infrared thermography, Eulerian steady state

1. Introduction

In continuous casting, molten metal is discharged down from a launder into water cooled mould, where a billet or slab is partially cooled known as primary cooling. The billet or slab is then further cooled in a secondary cooling process using water jets or array of water sprays for continuous and constant production of solidified metal slabs. Secondary cooling plays a vital role in metal manufacturing, heat treatment process and strongly influence the quality and hardness of produced metals.

The cooling rate in the secondary cooling process depends on many factors, type of metal, thickness and casting speed and must be relatively controlled to avoid deformation and surface cracks.

Prediction of heat transfer experimentally and analytically from impinging jets has been studied by many authors [1], [2]. Kulkarni and Specht [3] analysed quenching of various metals moving with different velocities using array of jets and proposed a Eulerian steady state solution of boiling curve. However, the influence of flat sprays on Eulerian steady state solution of boiling curve has not been investigated. The present study investigates flat sprays using Eulerian steady state model proposed by Kulkarni and Specht.

The flat spray is characterized by spray angle β, spray width b and impacting length B, which then forms a rectangular shape liquid film B x b on the hot surface as shown in figure 1. The two flat sprays 35 mm apart from each other are employed for present study.

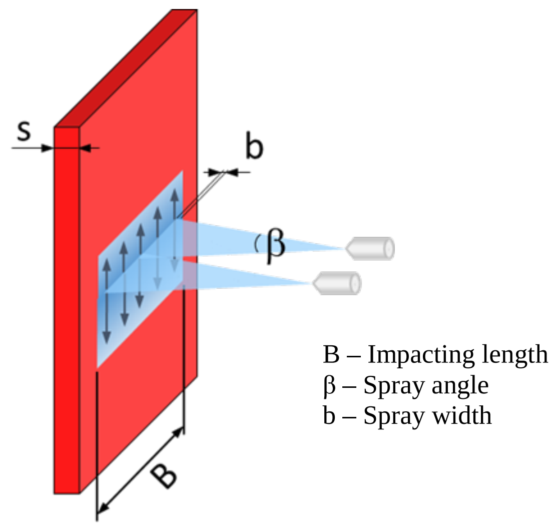

Fig. 1: Schematics of investigated two flat spray nozzles

The experimental setup is shown in figure 2. The nickel, nicrofer and AA6082 metal plates are heated in an electrical furnace to desired start temperature and quickly moved to the cooling chamber, the vertically moving plates with set velocity are quenched with water under controlled conditions. Simultaneously, the thermal data of the metal plate being quenched is recorded from the non-impinging side with an infrared camera of 200 fps frame rate.

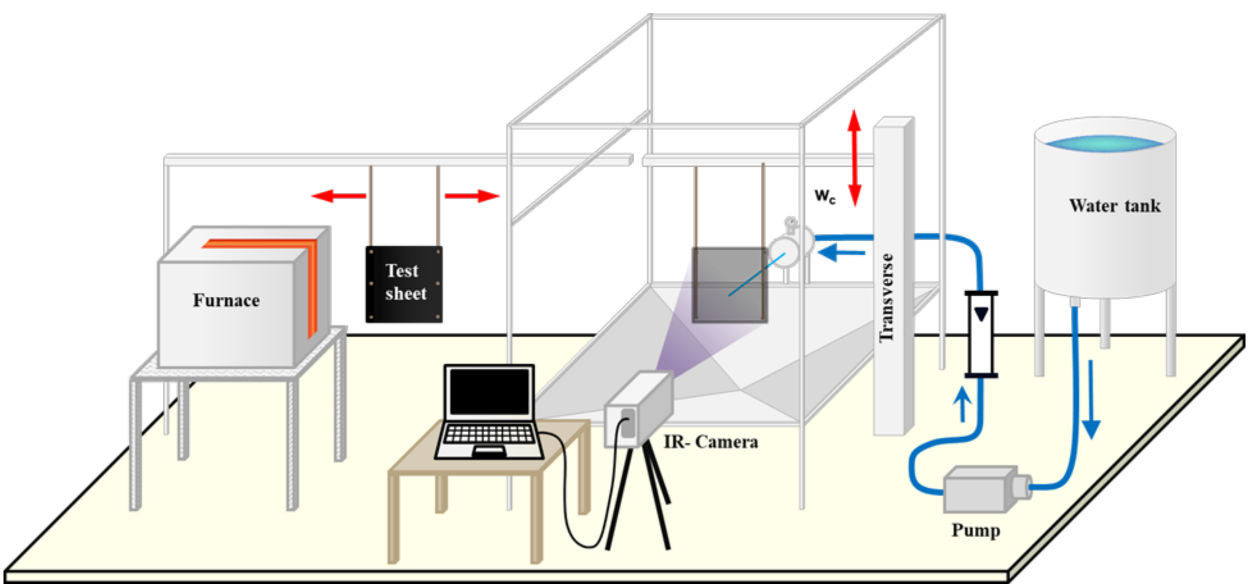

Fig. 2: Experimental setup

2. Analysis Method

Figure 3 shows an example of infrared image of 5 mm thick AA6082 metal plate moving with 15 mm/s at quasi steady state time during quenching process. The obtained temperature data by the infrared camera is further processed to obtain the temperature profile as function of Eulerian position z*.

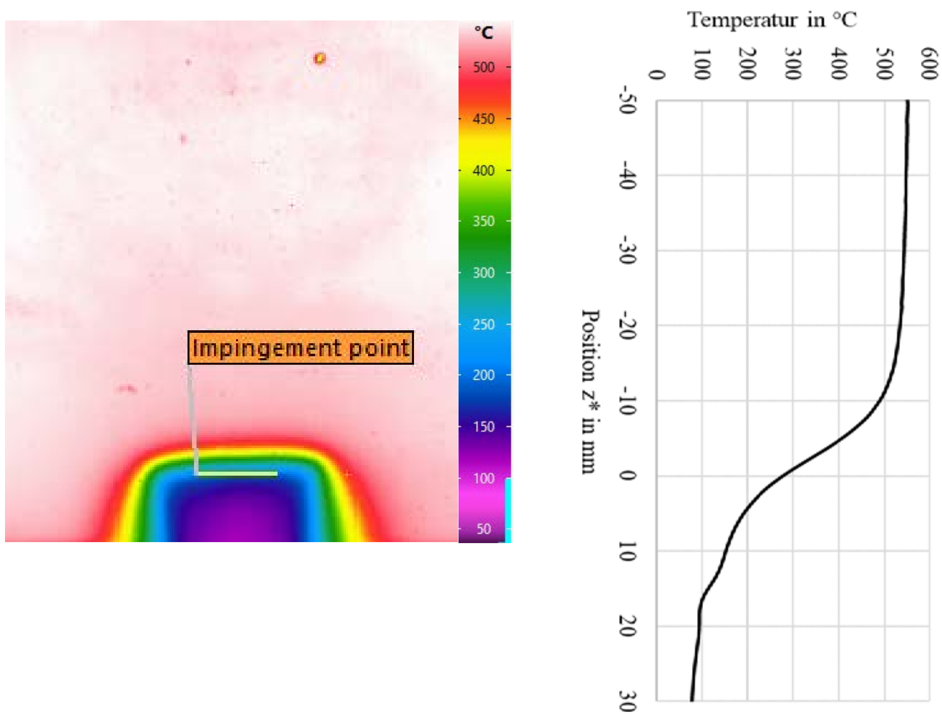

Fig. 3: Infrared image and temperature profile at quasi steady state

The metals of high thermal conductivity, significant amount of heat diffuses in axial direction before the start of cooling in quenching region. As it can been seen in figure 4, there is a temperature gradient even before the impingement point reaches on plate, known as precooling region.

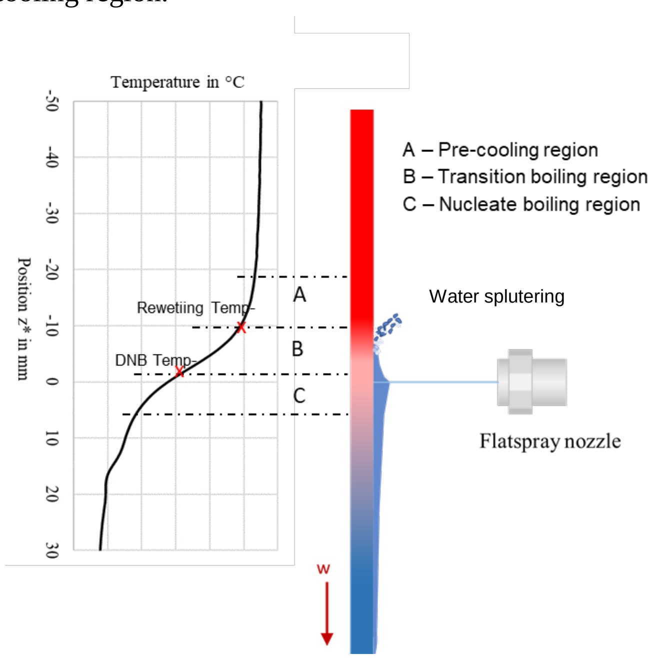

Fig. 4: Schematics of various quenching regions

The transition boiling region and the nucleate boiling regions, in which the metal plate cools down due to heat transfer to the cooling water is referred as quenching region.

The analytical expression is determined at Eulerain steady state for the obtained temperature profile by using Boltzmann curve fitting. The simplified governing equations combine with energy balance are solved numerically in two-dimensional model in order to obtain the heat flux on quenching side. The additional and deep details of used model can be found in [3] and [4].

3. Results

Figure 5 shows the boiling curves of 5 mm thick nicrofer sheet at different plate velocities It can be observed that the DNB temperature decreases minimal with increase in plate velocity.

For plate velocity 5 mm/s, it is 230°C and at plate velocity 10 mm/s it is 210°C. Whereas, the rewetting temperature and the maximum hear flux increase with increase in plate velocity.

This result agrees with other researchers [3], [4], [5].

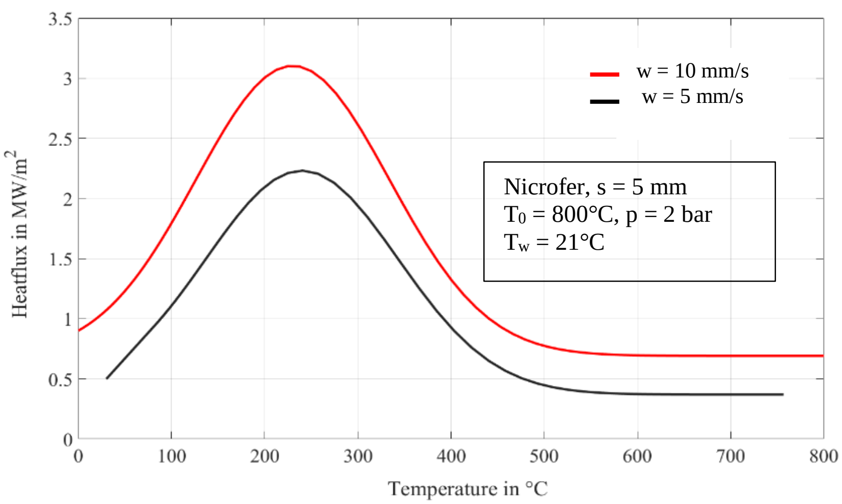

Fig. 5: Boiling curve of 5 mm nicrofer plate at various plate velocities

The boiling curves of 5 mm nickel plate at various plate velocities are shown in figure 6. The similar trend can be seen that the maximum heat flux and the rewetting temperature rises with higher plate velocity as in figure 5. However, the DNB temperature increases from 200°C to 260°C with increase in plate velocity from 5mm/s to 10 mm/s. The boiling curve is highly influenced by kind of metal; therefore, the maximum heat flux is higher for nickel compared to nicrofer plates.

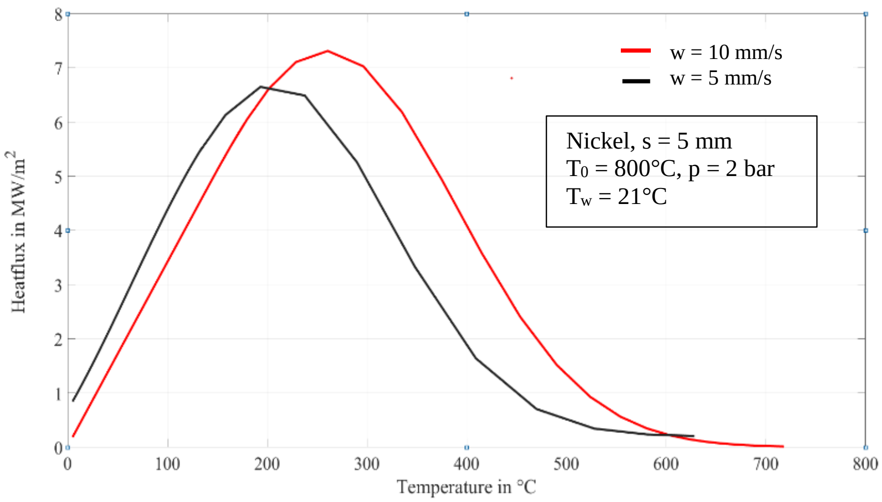

Fig. 6: Boiling curve of 5 mm nickel plate at various plate velocities

4. Conclusion

The Eulerian steady state of boiling curve is successfully applied for 5 mm nickel and nicrofer plates moving with 5 mm/s and 10 mm/s. The maximum heat flux increases with increase in plate velocity. The two flat sprays 35 mm distant from each other can cause uniform steady state cooling for 5 mm thick plates moving till 10 mm/s velocity. The liquid film for higher velocities is thrown away below the impingement point due to water ejection phenomenon.

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