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The Run Out Table in the Lab: Quenching of Fast Moving Steel Plates

C.F. Gomez[1], C.W.M. van der Geld[1], J.G.M. Kuerten[1], M. Bsibsi[2], B.P.M. van Esch[1]
[1]Eindhoven University of Technology, Mechanical Engineering
P.O. Box 513 5600MB, Eindhoven, The Netherlands
c.f.gomez@tue.nl; B.P.M.v.Esch@tue.nl
[2]Tata Steel Nederland Technology B.V.
Postbus 10.000 1970CA, IJmuiden, The Netherlands

***Abstract* –** In the Run Out Table, red hot steel slabs moving at speeds between 2 and 22 m/s are quench cooled by impingement of hundreds of water jets. Proper control of the Run Out Table process is crucial to ensure the desired steel microstructure and mechanical properties and can only be achieved with insight based on accurate experimental data. Although quenching experiments have been widely reported in literature, the few on moving surfaces reached maximum surface speeds of 1.5 m/s, which is much lower than in the actual Run Out Table process. In this paper, we present the first measurements with a new laboratory setup that allows surfaces to move at speeds between 0 and 8 m/s. To the best of our knowledge, this is the highest laboratory speed ever reported. The preliminary results show good reproducibility. Importantly, a transition in the heat flux history trends is found at speeds above 1.5 m/s. This finding confirms the need to perform experiments at surface speeds exceeding those of the past.

***Keywords*:** Quenching, Water Jet Impingement, Boiling Heat Transfer, Run Out Table

1. Introduction

During the production of steel for the automotive and other industries, red hot steel slabs moving at speeds between 2 and 22 m/s are quenched by water jet impingement in the so-called Run Out Table (ROT). The steel microstructure, and therefore mechanical properties, depend on the temperature history during quenching. Therefore, thorough understanding of the heat and flow phenomena occurring in the ROT are crucial to maximizing product quality and process reliability. For this reason, quenching by water jet impingement has been widely studied in literature. However, most of the experimental studies reported in literature have focused on static surfaces [1]–[3] or surfaces moving at maximum speeds of 1.5 m/s [4]–[6], much lower than the real ROT conditions. In order to obtain heat transfer predictions that are applicable and representative of the ROT process, the effect of high surface speeds on the thermal boundary layer must be considered and studied experimentally.

In this paper, we present the preliminary and first results of a new experimental setup that allows to study quenching of moving steel plates at speeds between 0 and 8 m/s. This is the highest speed range ever reported in laboratory quenching experiments, as far as we know, and close to real ROT speeds.

2. Experimental setup

A schematic of the experimental setup is shown in Figure 1. The water system and high-speed cameras arrangement is as reported before [7]. The water jet system has been upgraded to allow for installation of both a circular jet nozzle of 9 mm diameter and a planar slit jet nozzle of 2x50 mm. As reported elsewhere [1], [7], a borescope and high speed camera arrangement enables the direct observation of the boiling activity in the jet stagnation zone. Additionally, a side view high speed camera is installed to record the jet and flow development on the complete test plate.

The stainless steel AISI 304 test plate is sandblasted and has dimensions 5x40x200 mm, with an average surface roughness of 5 μm. The temperature during quenching is measured by 7 K-type thermocouples installed every 25 mm along the centreline of the test plate with the thermocouple tip at a distance of 0.5 mm to the top surface of the test plate.

The test plate is moved at speeds between 0 and 8 m/s by using a so-called linear unit. The selected linear unit is model MRJE65 by Unimotion and has a total length of 3180 mm. The system is belt-driven and wheel-guided, powered by an electric motor. The linear unit allows maximum speeds of 10 m/s in unloaded conditions and 8 m/s with a load of 1.5 kg. In the section located right below the water jet, a constant speed is reached over a length of 500 mm. The test plate is repeatedly moved back and forth underneath the water jet at the desired surface speed until cooled.

Heat flux at the top of the moving plat is found by solving the Inverse Heat Conduction Problem (IHCP) in INTEMP [8], [9]. In order to justify simplification of the IHCP to a 2D domain, a planar jet is installed perpendicular to the motion of the rectangular test plate. Internal conduction in the lateral direction is negligible when using the planar jet.

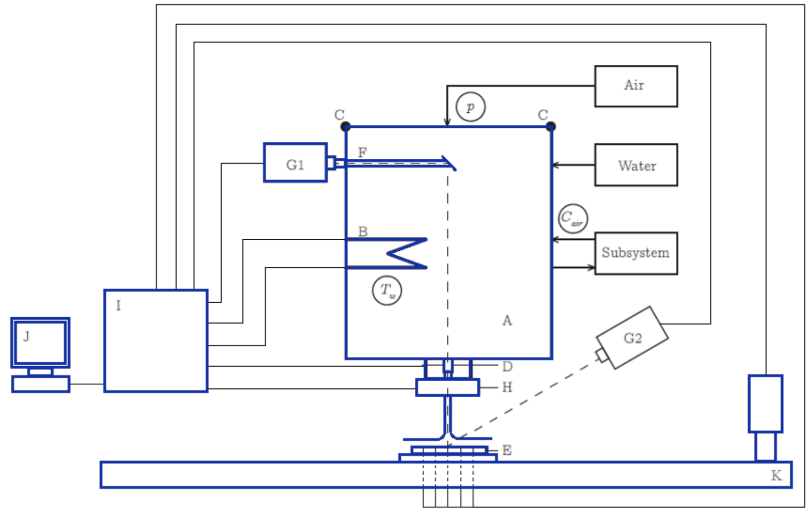

Fig. 1: Schematic representation of the experimental setup. A: Water tank. B: Heater. C: Load cells. D: Valve and nozzle. E: Test plate. F: Borescope. G1: Stagnation zone camera. G2: Side view camera. H: LEDs ring. I: Control box. J: Computer. K: Linear unit.

3. Experimental results

Figure 2 shows experimental results when quenching a test plate at initial temperature 550 °C and surface speed 3.5 m/s, using a planar water jet at 25 °C. The high speed camera results shown in Fig. 3 correspond to experiments done at identical conditions, but using a circular water jet, which leads to a clearer visualization of flow and boiling phenomena on the plate in the stagnation zone underneath the jet.

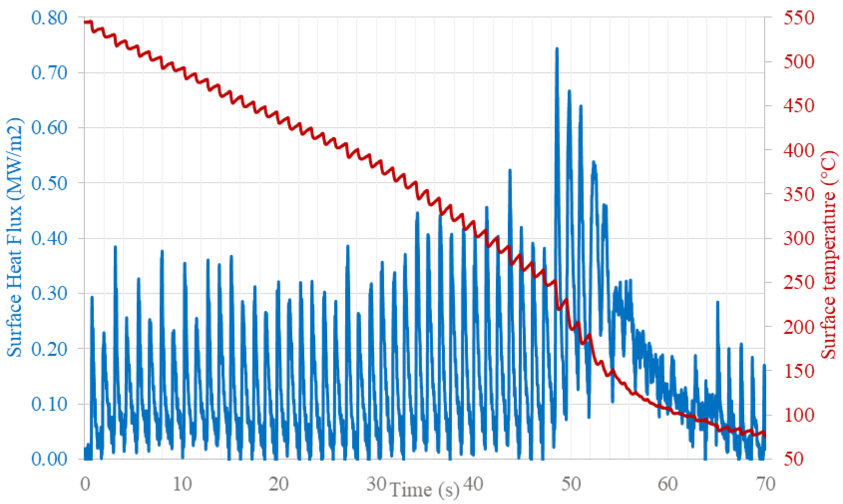

Fig. 2: Surface heat transfer and temperature estimations when quenching a 550 °C test plate moving at 3.5 m/s with a planar water jet at 25 °C.

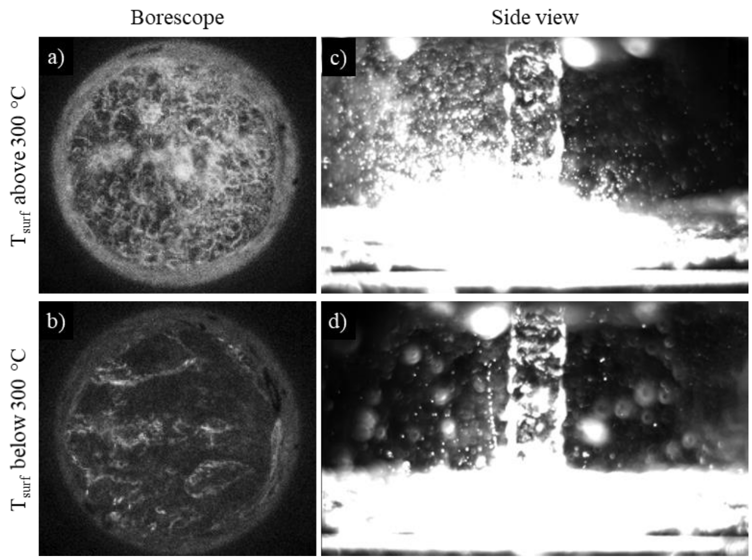

Fig. 3: Representative snapshots of high-speed recordings when quenching a 550 °C test plate moving at 3.5 m/s with a circular water jet at 25 °C.

As expected, the surface temperature shows a sharp decrease during each jet contact followed by a temperature recovery due to internal conduction during the dry acceleration and deceleration periods. Each jet contact episode leads to a sharp surface heat flux peak. The maximum of each heat flux peak is expected to correspond to the actual surface heat flux of the water jet impingement. At surface temperatures above 250 – 300 °C, a gentle temperature decrease and constant surface heat flux between 0.3 and 0.4 MW/m2 are observed. In this same temperature range, the borescope camera shows explosive boiling regime [7] and the side view camera shows strong water deflection, see Fig. 3a and 3c respectively. At a plate temperature of around 300 °C, two observations are simultaneously made:

1. An increase in surface heat flux and a consequently stronger temperature decrease than before
2. A more stable boiling activity in the stagnation zone is observed through the borescope (Fig. 3b) and no water deflection in the side view recordings (Fig. 3d).

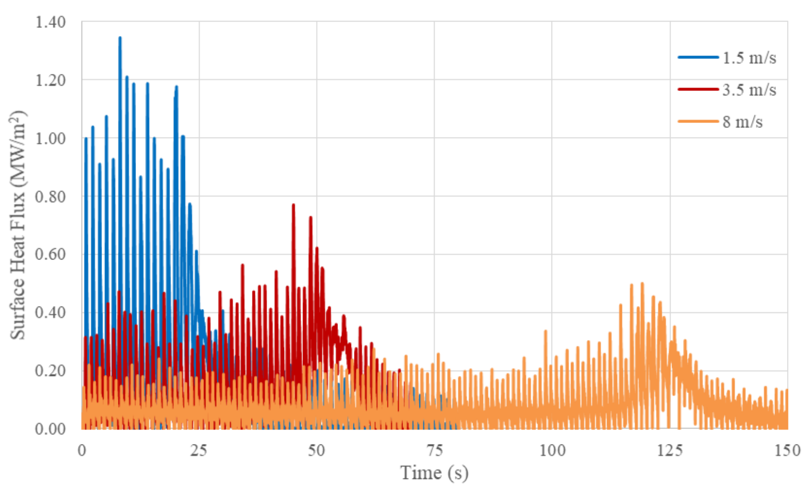

Fig. 4: Surface heat flux history when quenching a 550 °C test plate at different speeds with a water jet at 25 °C.

Preliminary testing of the experimental setup at surface speeds up to 8 m/s has shown good performance and reproducibility. Figure 4 shows the effect of surface speed on the surface heat flux history during quenching. In agreement with the findings of others [4], [6], higher surface speed leads to lower surface heat flux overall. A clear difference is observed between the low speed and moderate or high speed heat flux histories. At initial temperature of 550 °C, the experiment at 1.5 m/s does not show the initial constant heat flux regime observed in the 3.5 and 8 m/s experiment. These preliminary results indicate that high surface speeds might affect the boiling regimes occurring during quenching, possibly as a consequence of changes in the thermal boundary layer development. The occurrence of this transition proves the need to extend the surface speed range beyond what was reported in the literature.

4. Conclusion

In this paper, a new experimental setup has been found to produce reproducible quenching of moving surfaces at speeds between 0 and 8 m/s. Interestingly, a strong change in heat flux history trends is observed at moderate and high plate speeds. This goes to show the importance to extend our experimental facilities to the realm of actual plate speeds in a Run Out Table.

Future work will concern not only quantitative borescope on-plate and external side view recordings, but also an attempt to account for the change in thermal boundary layer thickness and the resulting modification of heat flux and water-vapor interface topologies.

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