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ScienceDirect
Procedia Engineering 105 (2015) 787 – 797
Procedia Engineering
www.elsevier.com/locate/procedia

6th BSME International Conference on Thermal Engineering (ICTE 2014)

Characteristics of transient heat transfer and wetting phenomena during laminar jet quenching on rotating cylinder

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Abstract

Hot strip leaving from finishing roll is quenched from about 850 to 500 ^{o}Cby array of laminar jets on cooling table (Run-Out-Table). Cooling temperature control of the hot strip is important to obtain better mechanical strength and grain size. However, the cooling process includes unstable transition boiling region as well as moving boundary problem due to relative movement between the hot strip and the jets. To improve quality of hot strip deeper understanding about laminar jet quenching process on the moving hot surface should be elucidated. In this study, single laminar jet quenching tests on a rotating hollow hot cylinder mounted horizontally have been conducted to understand characteristics of transient heat transfer and wetting phenomena. The experiments were done for 18-8 stainless steel (SUS304) hollow cylinder (O.D. 136mm, I.D. 116mm, W 150mm) under rotational speed ranged from 15 to 60 rpm, cooling water temperature ranged from 10 to 60 ^{o}C (corresponding degree of subcooling 40-90 K) and flow rate ranged from 6 to 23 L/min. Surface temperature and surface heat flux on the rotating cylinder were estimated from two sheath thermocouples embedded at two depths from the outer surface with one dimensional inverse heat conduction analysis. Visual observations over the top surface were done with two normal speed video cameras which were synchronized with rotating cylinder temperature recording. The observation results showed that unstable wetted area was gradually growing from the stagnation area and finally the wetted area became continuous around the circumference of the cylinder. It was found that the growth and shape of the wetted area were strongly affected by the liquid temperature and the liquid flow rate. Wetted front which is the boundary between wetted and dry areas repeated advance and recession. Since the wetting area propagated faster in the rotational direction, the shape of the wetted area was asymmetry on the hot surface. The liquid film flow was completely splashed out due to violent nucleate boiling on the wetted front line. The characteristics of local transient heat transfer were evaluated with boiling curves taken around the stagnation point. The boiling curves indicated shift to much

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Peer-review under responsibility of organizing committee of the 6th BSME International Conference on Thermal Engineering (ICTE 2014)
doi:10.1016/j.proeng.2015.05.072

higher wall superheat as compared with a steady state pool boiling curve and those were categorized into three regions such as 1) single phase heat transfer, boiling heat transfer and 3) transition boiling by inspecting gradient of the boiling curves and the observation of the boiling situations. The transition boiling region disappeared and the single phase heat transfer became dominant for higher subcooling and higher flow rate conditions.

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*Keywords:*Lamilar jet; Transient transition boiling; Wetting phenomenon;Quenching

1. Introduction

Steel manufacturing industries are trying to improve thermomechanical treatment processes to product high value added hot strips such as high tensile stress (HTS), dual phase (DP) and transformation induced plasticity (TRIP) steels. In order to reduce adding expensive minor metal elements like nickel or manganese to carbon steel, precise temperature control of low alloy hot strips over entire of width and length attracts great interest to produce such high value added steels. In case of the TRIP steel production process, the hot strip at about 800^{o}C is quenched to about 400 ^{o}C with laminar or spray jets impingement on run-out-table (ROT) after finishing roll. To ensure mechanical properties, a severe allowance error of terminate cooling temperature is required for controlled cooling of the strip. Even though state of art control technology such as learning or predictive control is applied to online control of hot strip temperature at the exit of the ROT, accuracy of temperature control and process yield still do not reach to a satisfactory level. Especially when the terminate strip temperature is in the transition boiling region empirically known as 500-550 ^{o}C in steel manufacturing industries, control of the hot strip temperature becomes difficult due to the unstable transition boiling heat transfer. In the transition boiling, boiling situation changes from film boiling to nucleate boiling due to recovery of wetting on hot surface. Since the surface heat transfer coefficient dramatically changes whether the surface is wetted or not, the temperature control faces with difficulties of the unstable boiling heat transfer. Rewetting phenomenon is also known to be very sensible to surface conditions such as surface roughness, thickness of poor heat conductive oxidization layer as well as coolant conditions as water temperature and intensity of liquid impact pressure on a hot surface. Despite of many studies and challenges to understand the transient transition boiling heat transfer and the wetting process on hot surface, a lot of elementary processes about this phenomenon are still remained for us.

Recently considerable studies on quenching hot surface at high initial temperature up to 800-900 ^{o}C with pipe laminar, slit laminar and flat spray jets were reported and characteristics of transient transition boiling heat transfer were reported to understand fundamentalboiling process from film to transition boilings. However, thin strip of a couple of millimeters in thickness is quenched during transfer on ROT at maximum velocity of 60 km/h. Thus quenching process of the strips becomes moving heat sink boundary problem. However, reproduce of similar experiments with real processes are very difficult in a laboratory. Most of existing experimental studies were done for stationery heated surface and experiments with moving surface are limited as far as the authors know.

For example, Gradeck, et al. [1] conducted experimental study on boiling heat transfer during quenching of rotating hot hollow cylinder with a slit laminar jet. Quenching heat transfer distributions were obtained for different rotational speed by using boiling curves. Aloke, et al. [2] also reported experimental study on laminar jet quenching on rotating hollow cylinder as our previous study. Characteristics of non-uniform wetting front propagation which was identified as the location at leading edge of the wetted area, and comparison of maximum heat flux with steady state critical heat flux were elucidated at two rotational speeds and different flow rates and coolant water temperatures.

In this study we conducted experiments using the previous experimental apparatus [2] over the extensive experimental range of coolant water temperature, laminar flow rate and rotational speed. Image analysis of boiling situation video provided the characteristic of rewetting process on the moving hot surface. Surface temperature and surface heat flux on the outer surface were evaluated with one dimensional inverse heat conduction analysis. Effects