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The Role of Surface Roughness on the Increased Heat Transfer Rate in Pool Film Boiling of a Flat, Upward Facing Surface

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Extended Abstract

Boiling heat transfer is commonly utilised in the steel making process to achieve high heat transfer rates during casting or hot rolling of steel products. Various process parameters, such as water flow rates, water temperature, or time of exposure of steel surface to water jet, can be adjusted to achieve the desired heat transfer rates and uniform cooling. This uniform cooling across the surface of steel is particularly important to avoid residual thermal stresses and achieve the flatness of the product.

When water is deposited on the hot metal surface, which is typically in the range of 850 - 900 ºC, film boiling quickly becomes the dominat heat transfer mode. As the surface is cooled beyond the Leidenfrost point, the heat transfer mode changes to transition boiling and eventually to nucleate boiling. Water cooling for most steel products ends when metal surface temperatures are still sufficiently high, such that nucleate boiling is seldom achieved.

Surface roughness has been identified as an important factor affecting the cooling rate of steel products in the hot rolling process [1-2]. The quality of the product is often reduced by uneven cooling of steel, which is contributed by variable roughness of the surface. While most cooling systems employ jets or sprays to deposit water on the cooled surface, understanding the effect of surface topography on cooling characteristics in pool boiling represents an important benchmark from a phenomenological point of view. Previous experimental work on pool film boiling of hot metal plates with various surface roughness [3-5] revealed earlier onset of transition boiling with an increase in surface roughness, resulting in faster cooling and non-uniform surface temperature distribution. It is equally important to develop models which can be used as predictive tools to adjust process parameters in cooling equipment, and optimise the process for better quality control.

Several hydrodynamic models based on Rayleigh-Taylor instability, which addresses the structure of the vapour-liquid interface, have been developed in the past to predict the onset of transition boiling at the Leidenfrost temperature. While these models make accurate predictions for smooth surfaces, incorporating the effect of surface roughness is still a challenging task. This paper presents a simplified model to describe the role of surface roughness in pool film boiling and at the Leidenfrost point, for an upward facing flat surface. The model is based on quantifying liquid intrusion due to instabilities of the liquid-vapour interface, and assumes that enhanced heat transfer from a rough surface results from frequent transient contact between the liquid and rough elements. Based on modelling of the vapour-liquid interface with respect to the most dangerous wavelength of Rayleigh-Taylor instability, it addresses the area fraction of liquid-solid contact with respect of surface roughness, and the duration of liquid-solid contact.

The model has been validated with pool boiling experiments on samples with surface roughness between 1-40 µm. The experimentat data indicated an increase of cooling rate of about 50% with the increase of surface roughness. Model predictions, which align well with experimental data, suggested intermittent liquid-solid contact area occuring at a frequency of about 10 ms, and the fraction of the total contact area increasing with surface roughness up to 20% of the contact area in the vicinity of the Leidenfrost point.

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