MOVEMENT OF MAXIMUM HEAT FLUX AND WETTING FRONT DURING QUENCHING OF HOT CYLINDRICAL BLOCK

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Surface temperature and heat flux are determined experimentally during quenching of a high temperature surface with an impinging jet at atmospheric pressure by using two-dimensional inverse heat conduction solution. These surface conditions are estimated from the eight measured temperatures at each depth of 2.1 mm and 5.1 mm inside the solid by using a half polynomial function with time and Fourier series of Bessel function. During quenching, the movement of wetting front and the maximum heat flux are calculated with time. The maximum heat flux is compared with the estimated wetting front during a corresponding impinging jet cooling. It is found that the position at maximum heat flux is in good agreement with the observed wetting front.

Key Word: Inverse solution, Impinging jet, Quenching, Two-dimensional transient heat conduction.

INTRODUCTION

During quenching high temperature solid with impinging liquid jet, surface heat flux and temperature rapidly change with the wetting front. The Inverse Heat Conduction Problem (IHCP) is a necessary technique to determine the surface temperature and heat flux from measured temperatures inside a body since the direct measurement of the surface temperature becomes impossible. Recently, the authors have succeeded in getting the inverse solution from which the surface conditions can be numerically predicted well. The main objective of the present research is to estimate the surface temperature and heat flux from the actual measured temperatures during quenching of high temperature cylindrical solid with an impinging jet. The surface temperature and heat flux, and the movements of the maximum heat flux and the wetting front are estimated. The maximum heat flux is compared with the wetting front during a corresponding impinging jet cooling.

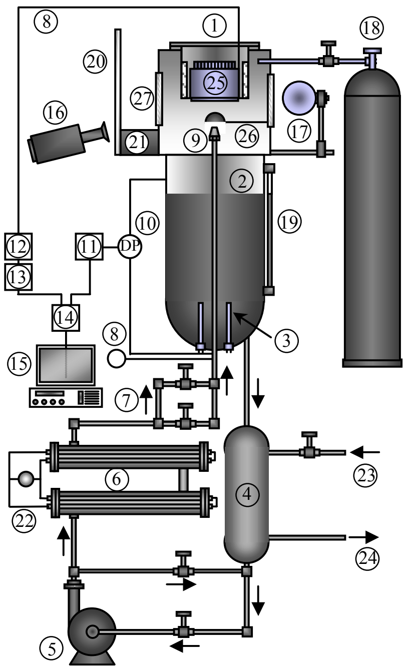

Fig.1 Experimental apparatus.

EXPERIMENTAL SETUP

The experimental setup, as shown in Fig.1, consists of four major parts; a) Heated block capsule, b) Liquid circulation system, c) Data acquisition system, and d) High-speed video camera. The heated block has cylindrical shape with 94 mm diameter and 60 mm height. The used 1 mm^2 diameter C-A thermocouples are inserted into the block in *r*-direction at two different depths from the surface; z_1=2.1 mm and z_2=5.1 mm, with 8 thermocouples for each. The block is electrically heated by sheath heater of 0.94 kW. Two auxiliary heaters are used as thermal insulation of the block. One of them is of band type and is placed around the block circumference, while the second is of slot type and is placed in the four groves in the upper part. The capacities of the auxiliary heaters are 0.65 kW and 0.5 kW respectively.

EXPERIMENTAL PROCEDURE

The water in the container (2) is heated by main heater (3) and auxiliary heater (6). The regenerative pump (5), then, pumps the water to strike shutter (26) to maintain constant water temperature by making closed loop. When all the desired experimental conditions are fulfilled the shutter (26) is removed and the water jet strikes the center of the block (25). The high speed video camera (16) records the wetting front. Temperature is also measured with an accuracy of ±0.1°C.

EXPERIMENTAL RESULT AND DISCUSSION

The wetting of the heated surface spreads from the center towards the circumference after the impingement of liquid and is recorded by the high-speed video camera. The recorded images show the wetting spread as a function of time, and Fig.2 is a still of the images. From Fig.2, we can define the wetting front as the beginning of single-phase forced heat transfer, which is slightly behind the actual wetting front, namely the distance of Δr_b. The position of the wetting front will be plotted on *r-t* plane as a dash line as shown in Fig.4 and Fig.5.

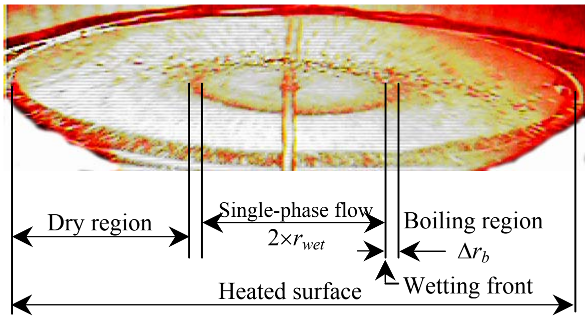

Fig.2 Photograph of flow boiling. (T_{block}=300°C, d_j=2 mm, u_j=5 m/s, T_{liq}=50°C, t=2.2 sec)

ESTIMATION OF SURFACE HEAT FLUX AND TEMPERATURE

The measured temperatures of the 8 thermocouples at the depth of z_1=2.1 mm only are shown in Fig.3. Figures 4 and 5 show the surface heat flux and temperature estimated from the measured temperature by inverse solution [1], respectively. In Fig. 4 the maximum heat flux, q_{max}, is shown by the thick solid curve, while the thin one shows its projection on *r-t* plane. Surface temperature, $T_{w,max}$, at q_{max} is also shown as a solid thick curve in Fig. 5 and its projection on *r-t* plane as a thin one. Figure 4 shows that q_{max} and the wetting front move outer words over the heated surface and q_{max} decreases along the *r*-direction. The *r-t* plane shows that the q_{max} is very close to the wetting front. Figure 6 shows that q_{max} decreases slightly with increasing liquid temperature, T_{liq}, while Fig. 7 shows that it increases with increasing jet velocity, u_j, with an exception for *r* less than 4 mm where q_{max}, surprisingly, increases with decreasing u_j. Figure 8 shows that q_{max} for copper is higher than that for brass at the same initial temperature. In Figs. 6, 7, and 8 we can notice that $T_{w,max}$ behaves similarly; almost no change with the radius *r*, regardless of the liquid temperature, jet velocity, initial temperature, or the material considered.

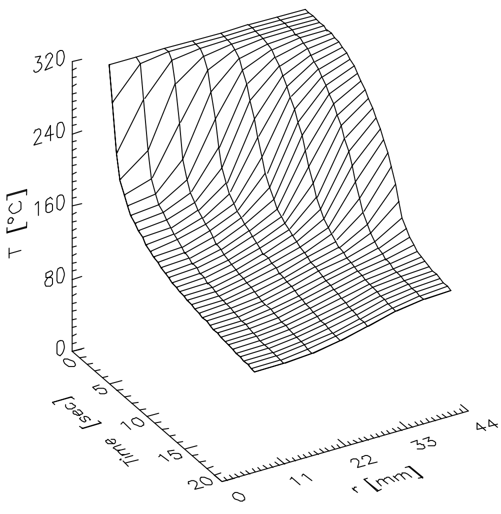

Fig.3 Measuring temperature data at z_1=2.1 mm. (Brass, T_{block}=300°C, d_j=2 mm, u_j=5 m/s, T_{liq}=50°C)

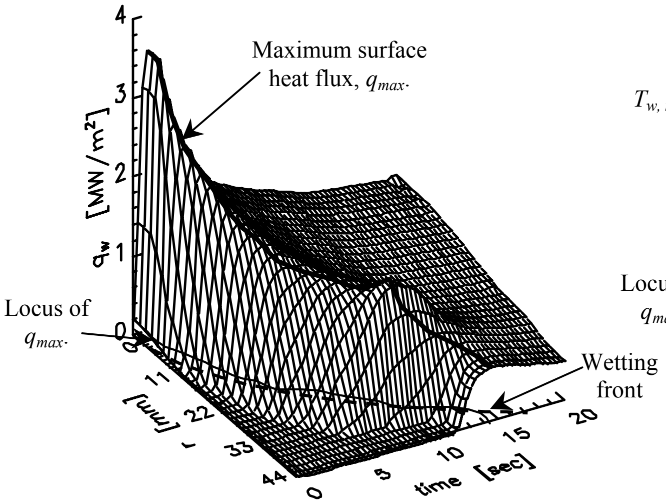

Fig.4 Surface heat flux during cooling.
(Brass, T_{block}=300°C, d_j=2 mm, u_j=5 m/s, T_{liq}=50°C)

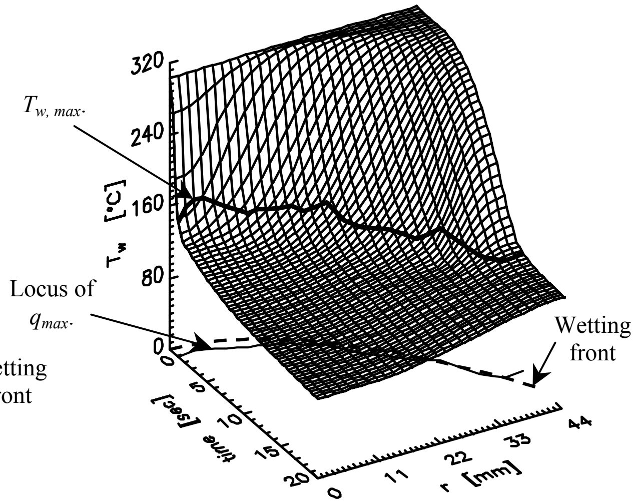

Fig.5 Surface temperature during cooling

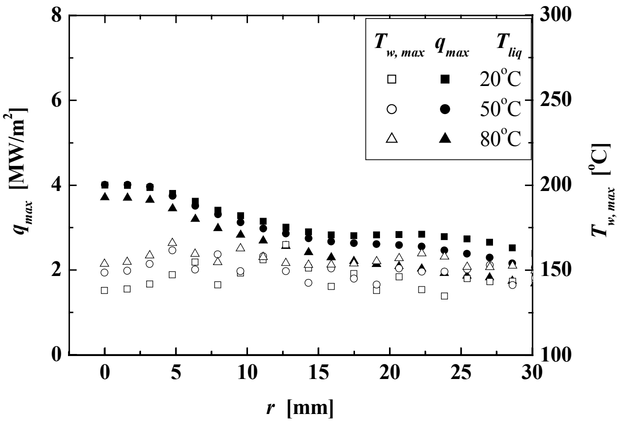

Fig.6 Maximum surface heat flux and surface temperature. (Brass, T_{block}=300°C, d_j=2 mm, u_j=10

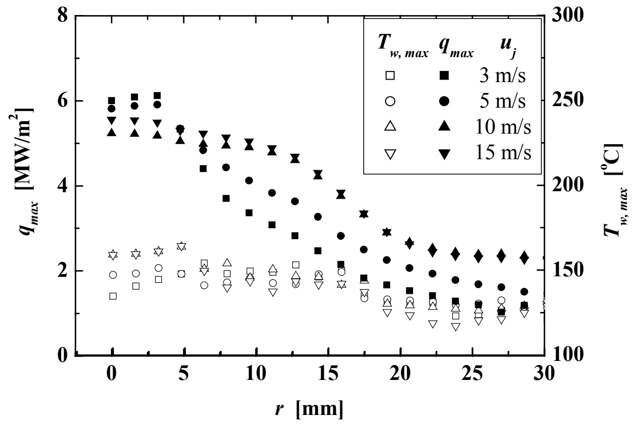

Fig.7 Maximum surface heat flux and surface temperature. (Copper, T_{block}=250°C, d_j=2 mm,

CONCLUSIONS

1. The surface temperature and heat flux are predicted over the whole surface.
2. Maximum heat flux occurs very close to the wetting front position.
3. The $T_{w,max}$ changes slightly during quenching.

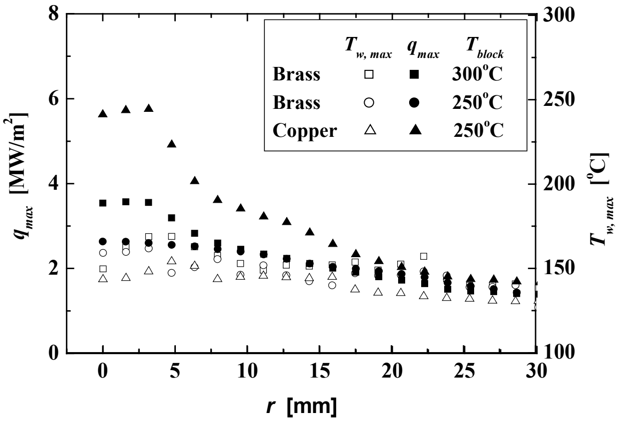

Fig.8 Maximum surface heat flux and surface temperature. (T_{liq}=50°C, d_j=2 mm, u_j=5 m/s)

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