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HEAT TRANSFER MEASUREMENTS DURING DC CASTING OF ALUMINIUM.

PART II: RESULTS AND VERIFICATION FOR EXTRUSION INGOTS.

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Measurements were carried out during ordinary production runs of DC hot top mould casting of extrusion ingots. Measured values cover the initial shell formation within the mould as well as direct water cooling zones/mechanisms below the mould. A separate two-dimensional mathematical casting model (Dystal) was then used to verify the measured heat transfer values. This was obtained by using these values as input, recalculating observed temperature time curves for selected points moving with the ingot. Also calculated and observed sump profiles were compared.

INTRODUCTION

Based on the computer program Harpcomp and a special measuring probe (the "Harp"), described in part I (1), this paper (part II) summarizes some practical results from measurements during industrial casting.

The measurements are part of a program to map systematically the heat transfer and cooling coefficients during practical casting of a large range of alloys, dimensions and casting conditions/ mould design.

EXPERIMENTAL PROCEDURE

Casting

Extrusion ingots of alloy 6063 type with diameters 173, 216 and 229 mm were cast in open hot top type moulds with internal water chamber type primary cooling. This water is subsequently led out of the water chamber through 3 mm water holes to establish secondary cooling directly on the emerging ingot surface below the mould. Water angle was approximately 25°. Casting conditions are summarized in table I.

Table I. Casting Conditions Used.

	Diameters		
	173 Ø	216 Ø	229 Ø
Casting temperature (^{o}C)	675-685	670-680	665-675
Casting rate (mm/min.)	110	95-100	100
Cooling water (l/min.)	83-94	83	125

Water temperatures: 15-19 ^{o}C.

The probe

After casting a minimum ingot length of about 1 m, the measuring "Harp" probe (1) with 2 or 3 thermoelements was placed in the melt for a few minutes to obtain melt temperature and thermocouple check. The probe was then led along the hot top insulation vertically downwards and positioned immediately below the bottom edge of the hot top insulation and as close as possible to the ingot surface. See figure I.

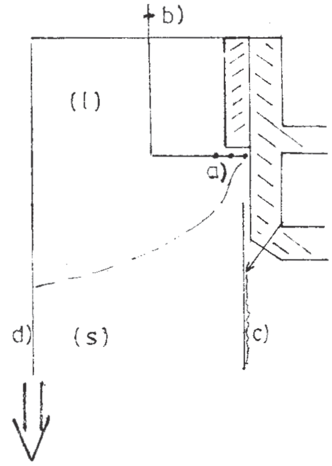

Figure I. Position of thermocouple probe (the "Harp") a) in the start. Reference mark = b). c) Ingot surface. d) Ingot center.

The probe then immediately froze onto the ingot shell forming below the mould insulation and followed with the ingot downwards at casting speed. A premarked position on the vertical probe rod is watched and clocked as the marking passes a known vertical reference point. Thus a necessary relation between time and vertical position of the probe is established.

Thermocouples

The 0.5 mm dia. Chromel-Alumel thermocouples were scanned with a frequency of 2 or 10 measurements per second and results logged on a Solartron Datalogger for later playback on computer and further data processing.

The radial thermocouple position as well as relative axial (casting direction) position were determined afterwards by careful machining off on suitable ingot cross sections to reveal the thermocouple tips.

The thermocouples thus obtained radial positions 4.7 to 10.3 mm from ingot surface for thermocouple No 1, 7.5 to 15.3 mm for No 2 and 11.4 to 13.5 mm for No 3. Axial deviations 0-2.7 mm.

Calculations

Based on measured radial and axial temperature gradients, the heat fluxes and heat transfer coefficients on the ingot surface were then calculated by the "Harp" program, as explained in part I (1).

These values were then used as input data for recalculation of temperature-distance curves for comparison by means of a much used mathematical model of the casting process, the Dystal model (2).

The material properties used in the calculations are shown in table II.

Table II
Material Properties Used in the Calculations

		20 °C	T_S	T_L	690 °C
Liquidus temperature	(°C)			655	
Solidus temperature	(°C)		635		
Thermal conductivity h	(W/m°K)	193	195	100	200
Density	(kg/m^2)	2694	2520	2450	2450
Specific heat	(J/kg °K)	900	1180	1088	1088
Heat of melting	(J/kg)		393.000		

RESULTS

The 229 mm diameter ingots

An example of calculated heat flux q (W/m^2) and heat transfer coefficient h (W/m^2 °K) values for the casting of 229 mm diameter ingot is shown in figure II.

The marked dip at about 400 °C is perhaps somewhat questionable. The position for the maximum values at about 120-140 °C seems, however, to be fairly typical.

Also shown are the somewhat smoothened-out values used in the calculation of the temperature-distance curves for the thermocouples by means of the Dystal model (2), figure III, and compared in figure IV.

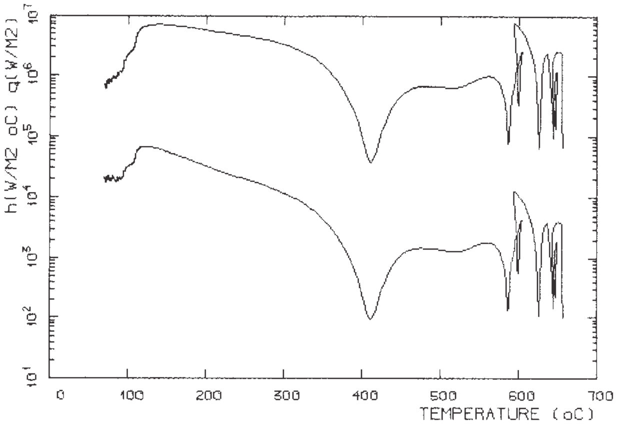

Figure II. Heat flux and heat transfer coefficients, 229 mm dia. ingot. Calculated values.

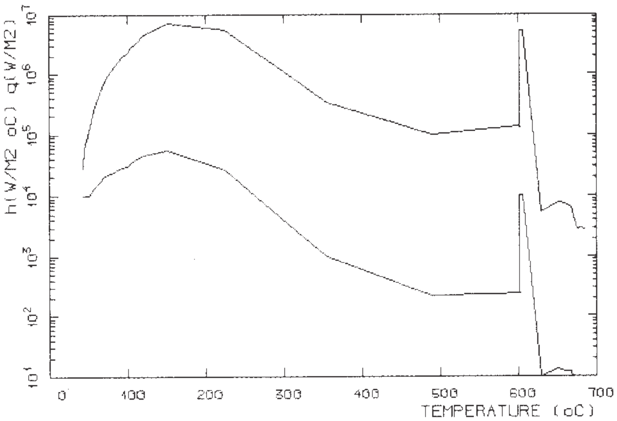

Figure III. Heat flux and heat transfer coefficient values used in the verification of figure II values.

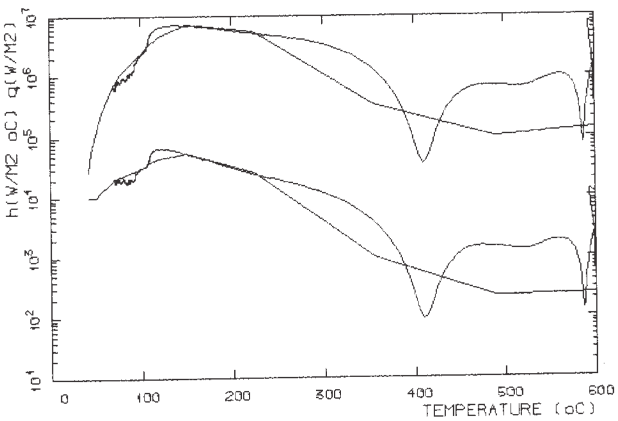

Figure IV. Figure II and III values compared.

Observed and recalculated temperature-distance curves are then compared in figure V. As can be seen, the overall agreement is very good.

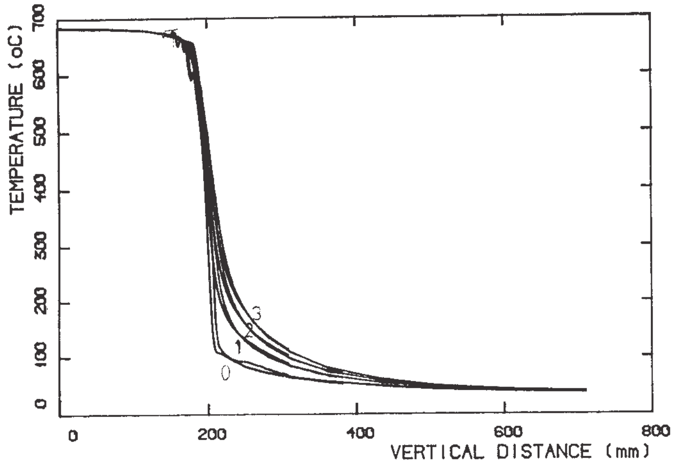

Figure V. Temperature distance curves for the "Harp" thermocouples as measured and back-calculated. 229 mm dia. ingot.
0 = surface temperature.
1-3 = thermocouples.

Observed and calculated position and form of the sump profile are compared in figure VI. (Position was also determined by the dip stick method during casting).

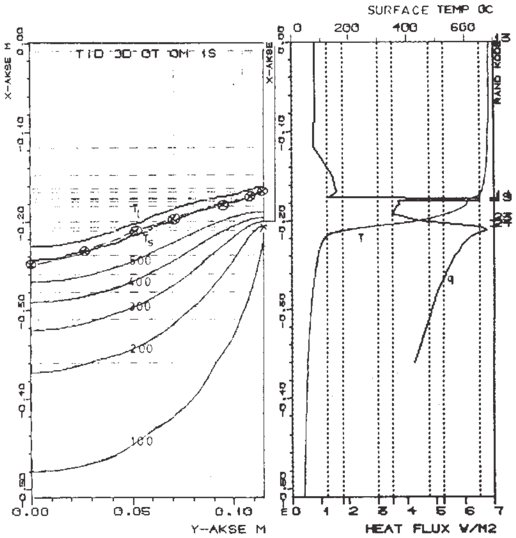

Figure VI. Observed and calculated sump profiles. 229 mm ingot.

The 173 mm diameter ingot

Figure VII summarizes the heat flow results from 6 castings. The accuracy is probably not as good as for the 229 mm diameter ingots because of experimental difficulties.

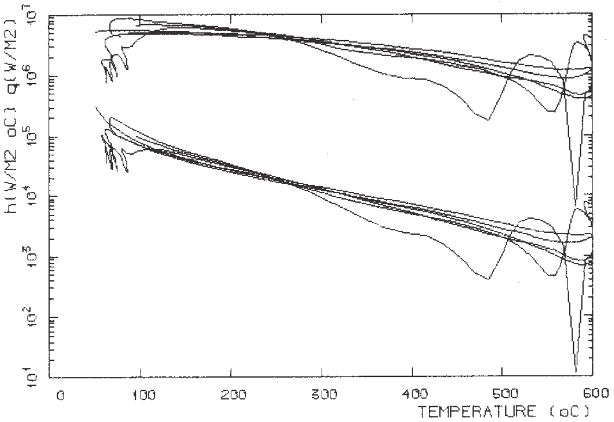

Figure VII. Heat flux and heat transfer coefficients, 173 mm dia. ingot. Calculated values.

No dramatic effect of the difference in amount of cooling water is seen.

A couple of the curves have a similar form as the one shown in figure II. A closer comparison is made in figure VIII.

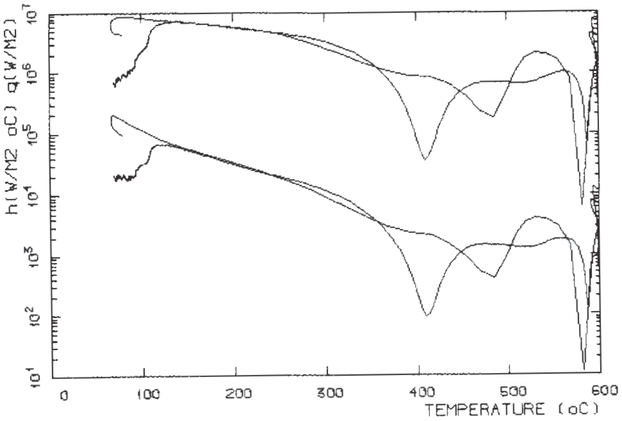

Figure VIII. Heat flux and heat transfer coefficients, 173 and 229 mm dia. ingots. Calculated values.

A slight shift for the max. heat flow to lower temperatures is indicated. The actual values used in these calculations are shown in figure IX, comparing again the two diameters.

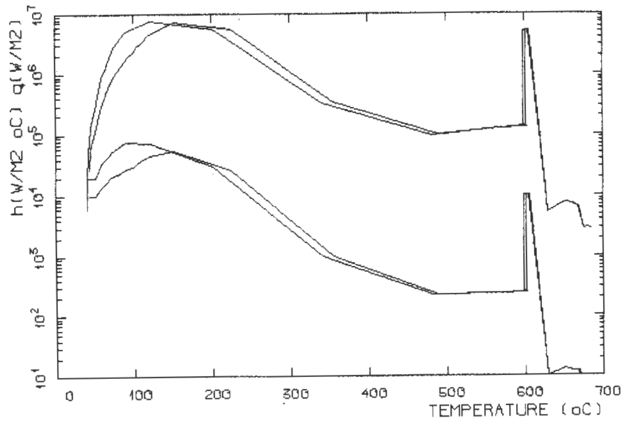

Figure IX. As figure VIII. Values actually used in the back-calculations. 173 and 229 mm dia. ingots.

The temperature-distance curves from "Harp" measurements and Dystal back-calculations again agree favourably in form (thouch the exact vertical position in this case was uncertain), see figure X.

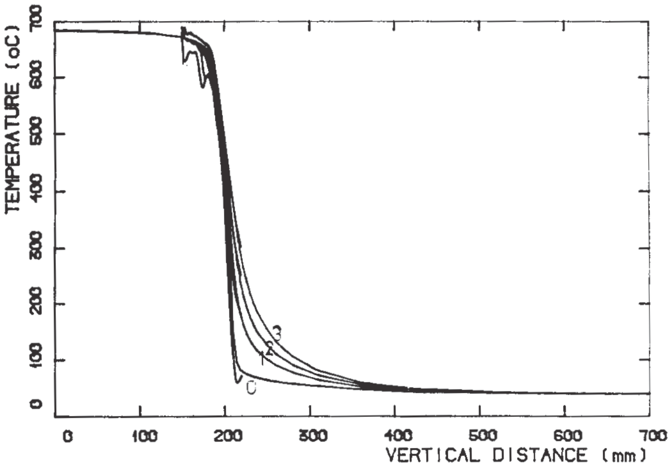

Figure X. Temperature-distance curves for the "Harp" thermocouples as measured and back-calculated. 173 mm dia. ingots.

The observed and calculated position of the sump profile is compared in figure XI.

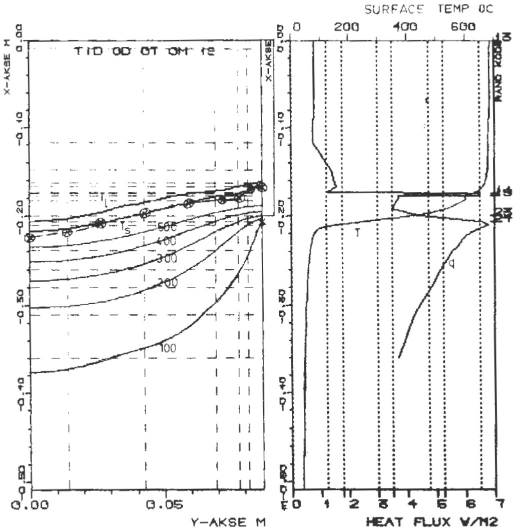

Figure XI. Observed and calculated sump profiles. 173 mm dia. ingot.

The 216 mm diameter ingots

The calculated heat flow and heat transfer coefficient results for 4 castings are summarized in figure XII.

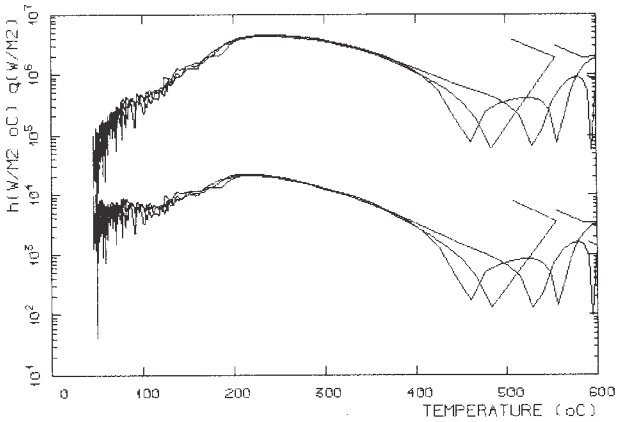

Figure XII. Heat flux and heat transfer coefficients, 216 mm dia. ingot. Calculated values.

In this case the maximum on the heat transfer curves seems to be positioned at higher temperatures, about 200 ^{o}C. This is perhaps somewhat surprising because of the lower specific amount of water per cm ingot circumference, about 1.2 l/min./cm versus 1.5-1.7 l/min./cm for the other two diameters. The values used in the calculations are shown in figure XIII.

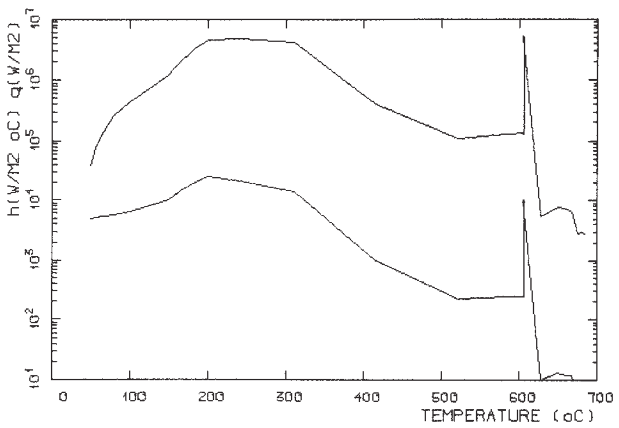

Figure XIII. Values used in the verification of figure XII values.

The temperature-distance curves for the thermocouples are compared in figure XIV, and the sump profiles compared in figure XV.

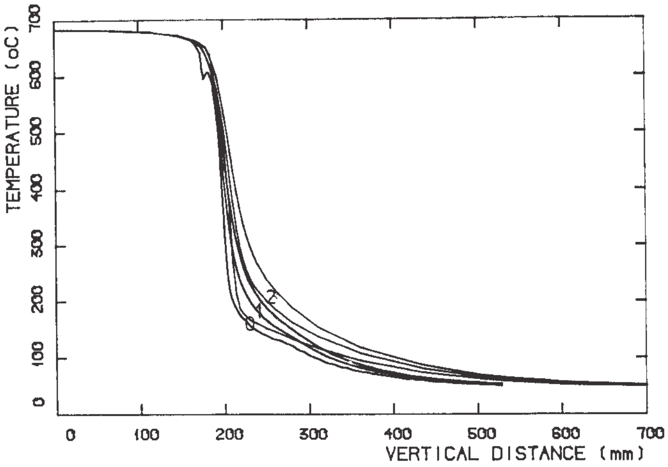

Figure XIV. Temperature-distance curves for the "Harp" thermocouples as measured and back-calculated. 216 mm dia. ingot.

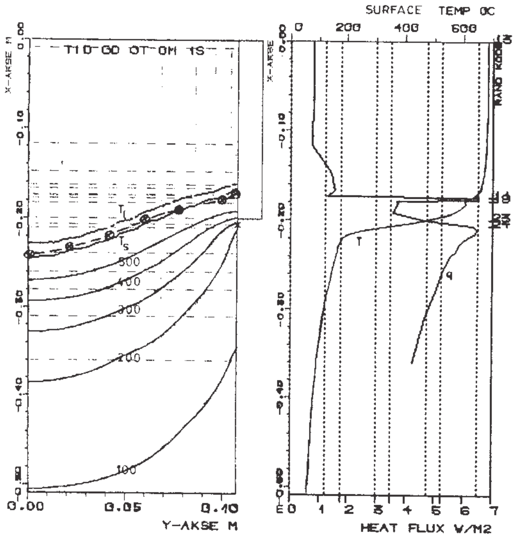

Figure XV. Observed and calculated sump profiles. 216 mm dia. ingot.

CONCLUSIONS

Though not much can be found in the literature about direct measurements of heat transfer during commercial DC casting of aluminium, the values found here appear to be of the correct size of order and agree with values used earlier (2),(3),(4).

Thus the computer program Harpcomp and the "Harp" thermocouple probe seem to be able to give relevant heat transfer values of direct practical as well as theoretical interest for commercial DC casting. A better and more detailed understanding of water cooling effects therefore seems within reach.

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