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CALCULATING THE DEPTH OF THE INNER CAVITY RESULTING FROM SHRINKAGE OF MOLTEN METAL

PRORAČUN DUBINE UNUTRAŠNJE ŠUPLJINE KOJA POTIČE OD SKUPLJANJA RASTOPA METALA

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Keywords
- molten metal
- crystallization
- riser
- defects
- calculation

Abstract

In the present work an evaluation is made of the applied technological improvements in the process of metal crystallization. The risers (dead heads) of metal ingots weighing 10 kg, produced on a Layboud Heraeus installation, have been investigated. The defects occurring during crystallization are determined. Calculations are performed including the depth of the cavity in the dead head, the amount of hard metal in the ingots and dead heads, and the average radius r_m of the free surface S of the liquid metal in the dead heads, depending on the time of crystallization.

Ključne reči
- rastop metala
- kristalizacija
- ulivne čaše
- greške
- proračun

Izvod

U ovom radu urađena je procena primenjenih tehnoloških poboljšanja u procesu kristalizacije metala. Istražene su ulivne čaše (dodaci odlivka) ingota metala težine 10 kg, proizvedeni u pogonima Layboud Heraeus. Otkrivene su greške koje nastaju pri kristalizaciji. Izvedeni su proračuni koji uzimaju dubinu šupljine unutar dodataka ulivnih čaša odlivka, veličinu čvrstog metala u ingotu i od ulivnih čaša, kao i srednji radijus, r_m, slobodne površine, S, tečnog metala unutar dodataka od ulivnih čaša, u zavisnosti od vremena kristalizacije.

INTRODUCTION

This article represents a part of a project aimed at investigating the crystallization in blocks of nitrogen containing model alloys produced by the Laybold Heraeus installation for casting under nitrogen pressure. According to the provisions of the contract with KIMM (Korea Institute of Machinery and Materials), 14 ingots were cast with preliminarily assigned chemical composition. A mathematical model was numerically solved for the crystallization of the metal for different variants of the technological parameters, /1-3/. As a result, data were obtained for the temperature field in the area immediately beneath the riser (dead head) of the metal block, the solid phase growth in the riser and the block body, as well as for the type and situation of the open cavity due to metal shrinkage.

In the present work an evaluation is made of the applied technological improvements in the process of metal crystallization. The risers (dead heads) of metal ingots weighing 10 kg have been investigated, /1-3/. The defects occurring during crystallization have been determined. Calculation is made for the depth of the cavity in the dead head, the amount of the hard metal in the ingots and dead heads, and the average radius r_m (mm) of the free surface S (mm^2) of liquid metal in the dead heads, depending on the time of crystallization.

MATHEMATICAL MODEL AND CALCULATION

The initial volumes of liquid metal in the riser and ingot respectively are V_m^0 (mm^3) and V_{in}^0 (mm^3). After a certain time τ(s), they are respectively V_m and V_{in}. The alteration of the volume of metal in the riser is caused by the consolidation of some of the liquid melt into it. Some of it is spent to offset the contraction in the volume of the hardened metal in the riser and in the body of the ingot. This can be represented by the following equation:

$$V_m^0 - V_m = V_m^S + \varepsilon_V V_m^S + \varepsilon_V (V_{in}^0 - V_{in}) \quad (1)$$

where: V_m^S is the solid metal in the riser; ε_V – coefficient of contraction.

The coordinate of the free surface of liquid metal is $h(\tau)$ and the surface area of this free surface is $S(h)$, /4/. Then the volume flow of the liquid metal is $\frac{S(h)dh}{d\tau}$ and it is spent to offset the contraction of the hardened metal in the riser and in the ingot.

Hence

$$-S(h)\frac{dh}{d\tau} = \varepsilon_V \frac{d}{d\tau}(V_{in}^0 - V_{in} + V_m^S) \quad (2)$$

where: ε_V is the volume contraction of steel; h is the riser height; $S(h)$ – the surface of liquid metal in the riser at the respective horizon along the ingot height; τ – time.

According to V.A. Efimov, /5/, $\varepsilon_V = 0.05$. Equation (1) can be solved if the values $V_m^S = V_m^S(\tau)$, V_{in}^0 and $V_{in} = V_{in}(\tau)$, are known. The mathematical model /1, 2/ allows to define the isothermal field (Fig. 2), and hence the volumes of solid metal in ingot and riser, as well as the average radius of liquid metal free surface area S, depending on time (Table 1). Provided that the coordinate $h(\tau)$ is recorded from ingot-riser boundary, the initial condition acquires the following form:

$$h(\tau) = h_0 = 0.046m \text{ for } \tau = 0 \quad (3)$$

Then equations (1–3) can be solved numerically.

RESULTS

The quantities participating in Eq. (2) are presented in Table 1. Figure 1 shows a calculated dependence. The graph shows that the position of the free surface of liquid metal is reduced from 46 mm to 28 mm, recorded from the riser-ingot body boundary.

Table 1. The calculated quantities from Eq. (2).
Tabela 1. Proračunate veličine iz jednačine (2).

Time (s)	Volume of solid phase (mm^3)	Area, F_C (mm^2)	Middle depth of the riser skin (mm) $b = F_C/46$	Moving coordinate of hard skin in the riser volume (mm) $r_m = 55 - b$	Volume of the riser (mm^3) $V_C = 46\pi(55^2 - r_m^2)$	Area of liquid surface (mm^2) $S = \pi r_m^2$	Volume of solid phase (mm^3) $V_\Sigma = V_P + V_C$
5	114517.90	54.7	1.19	53.81	18698.62	9096.83	133216.52
10	243297.75	168.9	3.67	51.33	56419.37	8276.81	299717.12
15	342808.95	274.8	5.97	49.03	89806.72	7551.00	432615.68
20	425533.98	374.5	8.14	46.86	119839.45	6898.11	545373.43
25	498516.00	468.1	10.18	44.82	146799.00	6312.04	645315.00
30	567087.94	557.5	12.12	42.88	171431.50	5776.54	738519.45
35	634681.16	641.6	13.95	41.05	193607.16	5294.47	828288.32
40	703682.69	723.2	15.72	39.28	214200.19	4846.79	917882.88
45	784338.37	800.6	17.40	37.60	232892.80	4440.43	1017231.17
50	866313.38	881.1	19.15	35.84	251465.97	4036.67	1117779.36
55	900140.90	963.5	20.94	34.05	269560.79	3643.30	1169701.69
60	908417.12	1037.5	22.55	32.44	285020.57	3307.22	1193437.69
65	914696.60	1109.5	24.12	30.88	299344.59	2995.83	1214041.20
70	920236.24	1187.0	25.80	29.20	313971.52	2677.85	1234207.76
75	925442.14	1268.4	27.57	27.43	328451.15	2363.08	1253893.29
80	930455.14	1352.2	29.40	25.60	342412.23	2059.57	1272867.38
85	934854.37	1438.2	31.26	23.73	355742.53	1769.78	1290596.90
90	938589.43	1524.7	33.14	21.85	368131.27	1500.46	1306720.70
95	941714.40	1611.1	35.02	19.98	379485.46	1253.63	1321199.86
100	944455.55	1705.3	37.07	17.93	390702.80	1009.78	1335158.35
105	946482.17	1816.7	39.49	15.51	402404.08	755.40	1348886.26
110	946815.21	1959.5	49.60	12.40	414924.47	483.22	1361739.68
115	946815.21	2129.7	46.30	8.70	426208.94	237.90	1373024.15
120	946815.21	2304.8	50.10	4.90	433689.01	75.30	1380504.22
125	946815.21	2480.7	53.93	1.07	436986.63	3.61	1383801.84
130	946815.21	2529.8	55.00	0.0043	437152.62	0.000059	1383967.82

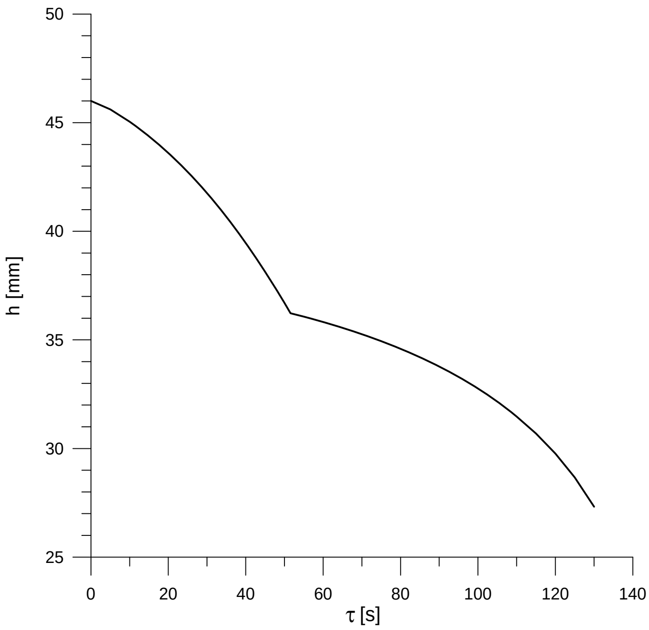

Figure 1. Dependence of the coordinate of the liquid metal free surface on time.
Slika 1. Zavisnost koordinate slobodne površine tečnog metala od vremena.

Comparing the values of h and r_m for one and the same, the line of points with coordinates r_m and h may be plotted, which forms the bottom of the shrinkage cavity in the steel riser (see Table 1). In Figure 2 the sectional shrinkage of the cavity in the riser is shown by a broken line. The isotherms T_s obtained by mathematical modelling are also shown here.

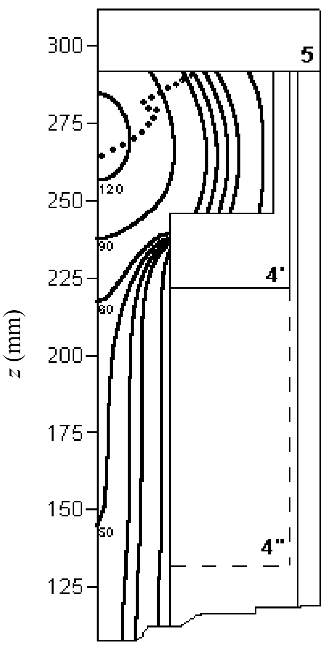

Figure 2. Location of actual hole in one section of the riser ingot.
Slika 2. Položaj stvarne šupljine u jednom preseku ulivnog sistema ingota.

It seems that the shrinkage cavity is located in the area where the last portions of liquid steel are crystallizing.

On the basis of data for the variation of h depending on r_m for one and the same time, the line forming the bottom of the cavity caused by steel shrinkage in the riser is plotted in Fig. 3. The location of the labelled part of the actual hole in one section of the riser is shown by a broken line. The figure shows $h(r_m)$ only to r_m = 15 mm, since the rest of the hole is irregularly shaped.

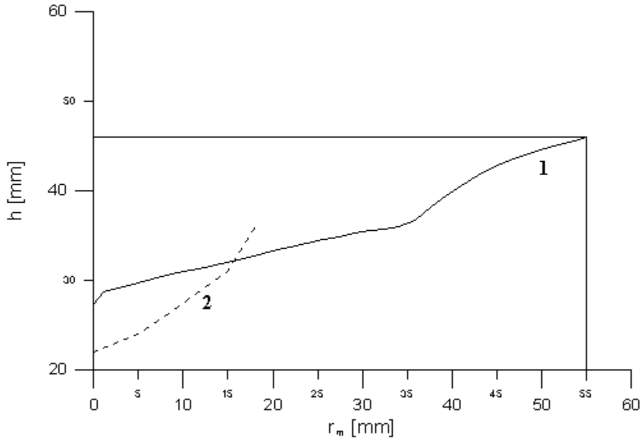

Figure 3. Shape and location of the cavity shrinkage in the volume of riser, obtained by numerical simulation. The broken line shows the location of the real cavity.
Slika 3. Oblik i položaj skupljanja šupljine u zapremini ulivnog sistema, dobijen numeričkom simulacijom. Izlomljena linija pokazuje položaj stvarne šupljine.

We could say that the maximum deviation of measured and calculated values of $h(\tau)$ is 18%. The fact that the cavity shape is asymmetric in the different sections of the riser and that the determination of its exact location is extremely difficult has to be taken under consideration too. Therefore, the result is satisfactory for the approximate calculation of the open pit depth provoked by contraction of the metal in the riser.

The results obtained for melt LH 537, which is cast by implementing technological improvements, are compared with the base melt, cast under the same conditions – nitrogen pressure and initial temperature, but in a classical sand mould and without additional heating of the riser. The data for the performed casts are given in Table 2.

Table 2. Comparison of results.
Tabela 2. Upoređivanje rezultata.

Ingot	Weight of risers (g)	Volume of risers (cm^3)	Volume of shrinkages
Base ingot Cr23N1.2	2540	335	59 cm^3; 17.6%
LH 522 00Cr20N1.2	4200/3910	520	24 cm^3; 4.62%
LH 523 00Cr20N1.2	2670/2395	320	18 cm^3; 5.63%
LH 524 00Cr20N1.4	3710/3565	480	13.1 cm^3; 2.73%
LH 537 Cr22N1.0	3420	460	The area under the riser metal is acceptable, without holes.

CONCLUSIONS

As a result of the implemented technological improvements, the process in the end of casting, when the riser is formed, runs at lower rates. The liquid bath crystallization is retarded, feeding and shifting the cavity to the front surface part of the ingot. The ingot remains dense, with a slightly concave front part and no cavity is observed in the transverse template, but only minor leaks are recorded in the last 20–25 mm along its height.

It has been established from the measurements of the location and size of the resulting holes that they are the smallest for the option with inserted bush of SiO_2 and pearlite, clutching almost half of the volume of the ingot. In the area below the riser, the metal is solid and flawless. In this way, the reduced capability of the mould to release the heat of the molten metal in the riser zone improves the quality of the cast block.

The results from technological improvements concerning the defects in the bulk volume of a nitrogen steel riser were published in our recent work (references /1-3/).

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