[Article ID] 1003- 6326(2002)01- 0102- 03

Simulation on flow process of filtered molten metals①

FANG Wen-bin(房文斌), GENG Yao-hong(耿耀宏), WEI Zun-jie(魏尊杰),
AN Ge-ying(安阁英), YE Rong-mao(叶荣茂)
(School of Materials Science and Engineering, Harbin Institute of Technology,
Harbin 150001, China)

[Abstract] Filtration and flow process of molten metals was analyzed by water simulation experiments. Fluid dynamic phenomena of molten metal cells through a foam ceramic filter was described and calculated by ERGOR equation as well. The results show that the filter is most useful for stable molten metals and the filtered flow is laminar, so that inclusions can be removed more effectively.

[Key words] molten metals; filtration; flow process; dynamics
[CLC number] TG146.2$^+$1 **[Document code]** A

1 INTRODUCTION

Molten metals (aluminum alloys, cast steels and cast irons) often fill in mold chambers as turbulence in the pouring purification process through a foam ceramic filter. Due to turbulent influence, inclusions in cross gate have no chance to go up or down completely and lots of them are easily piled up at the filter inlet[1~5]. To better understand the flowing rules of molten metals and refining mechanics of the inclusions, the flow process of filtered molten metals are tested theoretically and dynamics equations for the process are established, which is an important rationale for alloy filtration technology in production.

According to similarity principle, Mach number (M) of incompressible flow of water and molten metals as well as Weber number (We) are negligible, since surface tension in large chambers isn't apparent. Euler number (Eu) of incompressible flow is a function of Re and Fr, i.e. $Eu = f(Re, Fr)$, which indicates that Re and Fr of similarity can bring Eu in the same condition. Therefore, plastic particles used in hydraulics simulation experiments are prepared by controlling foaming conditions to satisfy $\rho_{\text{inclusion}} : \rho_{\text{molten metal}} = \rho_{\text{particle}} : \rho_{\text{water}}$. As for Froude number ($Fr = V^2/gL$), it's necessarily unanimous if flow model of actual molten metals and simulation equipments are of the same size and flow velocity, which means that water simulation experiments can be taken in emulating flow process of actual molten metals[6].

2 WATER SIMULATION EXPERIMENTS

Fig. 1 is a draft of water simulation apparatus. Adding water and solid particles into the pouring bush and lifting the faucet, they can flow in the mold chamber through pouring system and solid particles can be stopped behind the foam ceramic filter. As the data obtained by water simulation experiments can approximately visualize the flow process of molten metals, it's an important preliminary examination of the filling process of molten metals.

Considering that mechanical interception leads to more inclusions at the filter inlet when molten metals flow by, the complex network structure of the filter functions as a rectifier by refining currents and flow resistance is enhanced by the filter, filtered water in the simulation experiment is calculated by secondary ERGOR equation of hydromechanics to figure out the flow velocity variations and inclusion distribution tendencies of filtered and unfiltered molten metals.

3 ESTABLISHMENT OF DYNAMICS EQUATIONS

ERGOR equation is

$$-\nabla P = V(f_1 + f_2|v|) \tag{1}$$

where f_1, f_2 are coefficients and can be expressed as

$$f_1 = \frac{4.2\eta S_0^2(1-f_b)^2}{f_b^3}$$

$$f_2 = \frac{0.292\rho S_0(1-f_b)}{f_b^3}$$

Using Cartesian coordinate in the bivariate equations:

$$-\frac{\partial p}{\partial x} = (f_1 + f_2|u|)u \tag{2}$$

$$-\frac{\partial p}{\partial y} = (f_1 + f_2|u|)v \tag{3}$$

Derivations of Eqns. (2), (3) are

① [Foundation item] Project supported by the Youth Fund of Harbin Institute of Technology
[Received date] 2001- 08- 30; [Accepted date] 2001- 11- 05

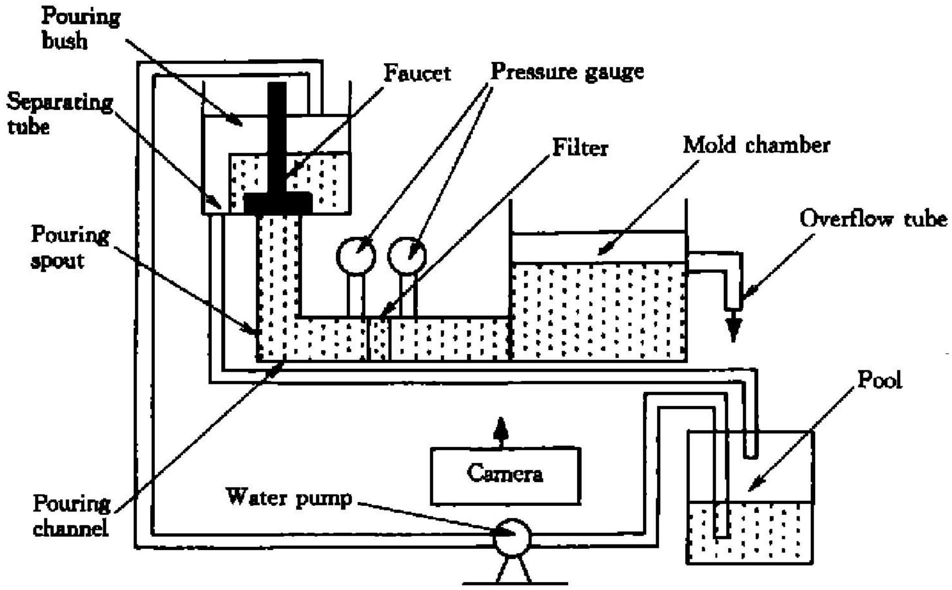

Fig. 1 Draft of water simulation apparatus

$$-\frac{\partial^2 p}{\partial x \partial y} = f_2 u \frac{\partial |u|}{\partial y} + (f_1 + f_2 |u|)\frac{\partial u}{\partial y} \tag{4}$$

$$-\frac{\partial^2 p}{\partial y \partial x} = f_2 v \frac{\partial |u|}{\partial x} + (f_1 + f_2 |u|)\frac{\partial v}{\partial x} \tag{5}$$

Let

$$|u| = \sqrt{u^2 + v^2} = \sqrt{(\partial \varphi/\partial x)^2 + (\partial \varphi/\partial y)^2},$$

Then,

$$-\frac{\partial^2 p}{\partial x \partial y} = f_2 \frac{\partial \varphi}{\partial y}\frac{1}{2}\frac{1}{\sqrt{(\frac{\partial \varphi}{\partial x})^2 + (\frac{\partial \varphi}{\partial y})^2}} \cdot \left(2\frac{\partial \varphi}{\partial x}\frac{\partial^2 \varphi}{\partial x \partial y} + 2\frac{\partial \varphi}{\partial y}\frac{\partial^2 \varphi}{\partial y^2}\right) + \left[f_1 + f_2\sqrt{(\frac{\partial \varphi}{\partial x})^2 + (\frac{\partial \varphi}{\partial y})^2}\right]\frac{\partial^2 \varphi}{\partial y^2} \tag{6}$$

$$-\frac{\partial^2 p}{\partial y \partial x} = -f_2 \frac{\partial \varphi}{\partial x}\frac{1}{2}\frac{1}{\sqrt{(\frac{\partial \varphi}{\partial x})^2 + (\frac{\partial \varphi}{\partial y})^2}} \cdot \left(2\frac{\partial \varphi}{\partial x}\frac{\partial^2 \varphi}{\partial x^2} + 2\frac{\partial \varphi}{\partial y}\frac{\partial^2 \varphi}{\partial x \partial y}\right) - \left[f_1 + f_2\sqrt{(\frac{\partial \varphi}{\partial x})^2 + (\frac{\partial \varphi}{\partial y})^2}\right]\frac{\partial^2 \varphi}{\partial x^2} \tag{7}$$

where $u = \frac{\partial \varphi}{\partial x}$, $v = -\frac{\partial \varphi}{\partial y}$, φ is a function of fluidity.

Let Eqs. (6), (7) multiply $\sqrt{(\frac{\partial \varphi}{\partial x})^2 + (\frac{\partial \varphi}{\partial y})^2}$, then subtract each other, the result can be expressed as

$$\frac{\partial^2 \varphi}{\partial y^2}\left\{f_1\sqrt{(\frac{\partial \varphi}{\partial x})^2 + (\frac{\partial \varphi}{\partial y})^2} + f_2\left[(\frac{\partial \varphi}{\partial x})^2 + 2(\frac{\partial \varphi}{\partial y})^2\right]\right\} + \frac{\partial^2 \varphi}{\partial x^2}\left\{f_1\sqrt{(\frac{\partial \varphi}{\partial x})^2 + (\frac{\partial \varphi}{\partial y})^2} + f_2\left[2(\frac{\partial \varphi}{\partial x})^2 + (\frac{\partial \varphi}{\partial y})^2\right]\right\} + 2f_2\frac{\partial \varphi}{\partial x}\frac{\partial \varphi}{\partial y}\frac{\partial^2 \varphi}{\partial x \partial y} = 0 \tag{8}$$

Suppose approximate central difference is taken on Eqn. (8), then

$$\frac{\varphi_{i,j+1} - 2\varphi_{i,j} + \varphi_{i,j-1}}{\Delta y^2}A + \frac{\varphi_{i+1,j} - 2\varphi_{i,j} + \varphi_{i-1,j}}{\Delta x^2}B + C = 0 \tag{9}$$

i. e.

$$\varphi_{i,j} = \frac{\Delta x^2 \Delta y^2}{2(A\Delta x^2 + B\Delta y^2)} \cdot \left[\frac{\varphi_{i,j+1} + \varphi_{i,j-1}}{\Delta y^2}A + \frac{\varphi_{i+1,j} + \varphi_{i-1,j}}{\Delta x^2}B + C\right] \tag{10}$$

According to flow velocity and direction at the filter inlet, fluidity behavior is complex while its horizontal velocity (u), vertical velocity (v) are evenly distributed after it approaches stability condition, i. e. such filter is a useful rectifier and filtered water is laminar so that inclusions of pouring system can be removed more effectively.

Fig. 2 describes stratification in the filter. When it's laid vertically, flow velocity reaches highest in the middle of it and tend to slow down, which means more inclusions will be piled up in middle and lower part of it. At this time, the major mechanism for the filter is rectification deposition and the minor is mechanical intercept and absorption. All the conditions mentioned above are shown in Fig. 3 by flow velocity, that is the relative volume flow, and inclusion distributions.

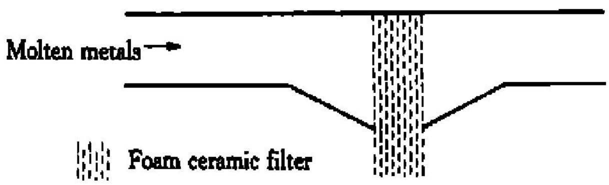

Fig. 2 Sketch of filter arrangement

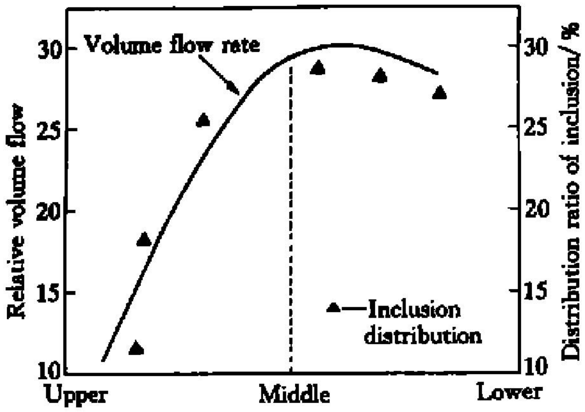

Fig. 3 Calculated results

4 CONCLUSIONS

1) Based on hydraulics simulation experiments, dynamics equation on flow process of filtered molten metals is given and can be used in liquid aluminum alloys, cast steels and cast irons.

2) Analysis of flow process shows that the filter is most useful for stable molten metals and filtered flow is laminar so that inclusions of pouring system can be removed more effectively.

3) Flow velocity reaches highest in the middle of the vertical filter and tends to decrease slowly with rectification deposition as the major, mechanic intercept and absorption as the minor mechanicals in the filter.

[REFERENCES]

[1] Glemings M C, Niiyama E, Taylor H F. Fluidity of aluminum alloys, an experimental and quantitative evaluation [J]. AFS Transactions, 1961, 169: 625.

[2] FANG Wen-bin. Development and application of foam ceramic filters used in cast irons [J]. Mechanical Engineering Material, (in Chinese), 1996, 20(6): 48-50.

[3] FANG Wen-bin, GENG Yao-hong. Development of foam ceramic filters [J]. Casting, (in Chinese), 1996, 9: 45-49.

[4] Wiser P E, Dutta. Priming and flow through filters [J]. AFS Transaction, 1986: 85.

[5] Sutton W H, Morris J R. Development of ceramic foam materials for the filtration of high-temperature investment casting alloys [A]. 31th Annual meeting ICI [C]. Dallas, TX, 1983. 901-921.

[6] PEI Qing-jian. Study on tridimensional numerical simulation and casting process CAD system [D]. Beijing: Tsinghua University, 1991.

(Edited by YUAN Sai-qian)