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COMPUTER ANALYSIS OF INFLUENCE OF MELT BLOWING MODES ON LADLE LINING MECHANICAL EROSION

The steel ladle lining protects the metal ladle body from overheating and the liquid steel from solidification. One of the reasons for the lining thinning is its erosion by fast flows of liquid steel near the walls and bottom of the ladle (for example, near the blow tuyere). Metallurgists periodically replace the lining, looking for places of the greatest wear, which consumes time and material resources. Predicting the lining wear process opens the way to optimizing and saving these resources.

In the process of blowing, turbulent melt flows erode the ladle lining and its thickness de-creases due to mechanical erosion. The thickness of the steel ladle lining gradually becomes thinner with each casting. The degree of erosion depends on the tangential melt speed. In steel production, they try to slow down this wear, because each lining repair costs considerable time and resources. Scientists paid attention to this problem in publications, in particular, on mathematical modeling of lining wear. A large number of conditions of this process are subject to research, in particular, the number and location of blowing tuyeres, as well as blowing power. Firstly, it is necessary to quickly mix the impurity in the melt, and secondly, to preserve the lining of the ladle. Computer visualization and analysis of this process involves its course and results in the form of calculated fields, in particular, wear. The result fields are stored in a database. Also they are added and processed through a specially designed website. It allows researchers to register and fill in the experiment form, as well as add literature sources of data. The list of literature is used in almost all experiments to compare results. Simulation of the process at blowout rates of 40, 60 and 90 l/min and the number of blowout plugs (tuyeres) from one to three showed that the greatest scouring is predicted at the bottom, near the blowout plugs, and the transition to each higher blowout rate increases the scouring intensity by about 15%. Turning off the tuyeres after 1 minute of blowing significantly reduces erosion by at least 35%. If we consider the ladle wall, without disconnecting the tuyere, the flow rate of 90 l/min is the most destructive.

Keywords: software, computational fluid dynamics, mechanical erosion of lining, teeming ladle.

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КОМП'ЮТЕРНИЙ АНАЛІЗ ВПЛИВУ РЕЖИМІВ ПРОДУВКИ РОЗПЛАВУ НА МЕХАНІЧНУ ЕРОЗІЮ ФУТЕРІВКИ КОВША

Під час транспортування з одного цеху в інший температура розплаву у ковші зберігається завдяки шару вогнетривкої футерівки всередині на стінках і дні. У процесі продування турбулентні потоки розплаву розмивають футерівку і товщина її шару зменшується через механічну ерозію. Особливістю ерозії є неоднорідність розмиття, викликану анізотропією поля швидкості. Дослідження різних конфігурацій фурм і витрат газу дозволить визначити оптимальні технологічні умови для збереження вартісної футерівки. Метою роботи є математичне моделювання механічного зносу футерівки ковша потоками розплаву під час продування аргоном за допомогою розробленого програмного забезпечення наукових досліджень. Ступінь розмиття залежить від швидкості дотичного розплаву. При виробництві сталі намагаються уповільнити це зношування, бо кожний ремонт футеровки вартує значного часу і ресурсів. Цій проблемі науковці приділяли увагу у публікаціях, зокрема, по математичному моделюванню зносу футеровки. Дослідженню підлягає велика кількість умов цього процесу, зокрема, кількість і розташування фурм продування, а також потужність продування. По-перше треба і домішку швидко перемішати у розплаві, а по-друге і футеровку ковша зберегти. Комп'ютерна візуалізація і аналіз означеного процесу передбачають його хід і результати у вигляді розрахованих полів, зокрема, зносу. Поля зберігаються у базі даних і додавання та їх обробка здійснюється через спеціально розроблений вебсайт. Він надає можливість дослідникам зареєструватися і заповнювати форму досліду, а також додавати літературні джерела даних. Перелік літератури використовується практично у всіх дослідах для порівняння результатів. Моделювання процесу в умовах потужності продування 40, 60 і 90 л/хв та кількістю пробок продування від однієї до трьох показало: найбільше розмиття прогнозується на дні, поблизу фурм продування, причому перехід на кожну вищу потужність продування підвищує інтенсивність розмиття приблизно на 15%. Вимикання фурм після 1 хвилин продування значно зменшує розмиття мінімум на 35%. Якщо ж розглядати стінку ковша, то без відключення фурм витрати 90 л/хв є найбільш руйнівними.

Ключові слова: програмне забезпечення, комп'ютерне моделювання, модифікації розплаву в ковші, газове перемішування.

Introduction

The steel ladle lining protects the metal ladle body from overheating and the liquid steel from solidification. One of the reasons for the lining thinning is its erosion by fast flows of liquid steel near the walls and bottom of the ladle (for example, near the blow tuyere). Metallurgists periodically replace the lining, looking for places of the greatest wear, which consumes time and material resources. Predicting the lining wear process opens the way to optimizing and saving these resources.

Related works

The article [1] is devoted to the study of two ladle designs (standard and with a reinforced striking part in the center of the bottom of the ladle). The figure of the experimental setup and the results of comparison of the two cases are given. The comparison showed a significant improvement in the resistance of the bucket lining to erosion wear.

In [2], the results of physical and mathematical modeling of the process of blowing the melt with one tuyere near the ladle wall are compared. The physical model includes oil and water to replace slag and metal melts, respectively. The comparison showed sufficient adequacy of the mathematical model, which takes into account the free surface. In papers [3-4], the authors investigate the process of destruction of a typical ladle lining. They present its physical properties and conduct numerical experiments to find out the best technological conditions in terms of the depth of lining destruction.

In [5], the finite volume method is used for numerical simulation of lining destruction. Using the model, the authors obtained the places of the deepest erosion – the middle of the bucket height. The bucket has a cylindrical geometry. The numerical study [6] is devoted to two cases: the lining is a homogeneous medium with average physical properties; the lining is a porous medium with liquid slag.

The aim of the work is to mathematically model the mechanical wear of the ladle lining by melt streams during argon purging using the developed research software.

Method

Simplifying the problem of mathematical modeling, it is accepted:

1) The melt has the geometry of a cylinder (Fig. 1). The melt depth is a constant value.
2) Wave motion of the melt surface is neglected and it is assumed to be flat.
3) The melt has all the features of a Newtonian viscous fluid with gas content.
4) The melt density is assumed to be constant.
5) Boussinesq's assumption of gas accelerating the vertical component of velocity is used.
6) Slag layer is not taken into account.
7) Lining erosion has a rate that depends linearly on the melt velocity in the vicinity.

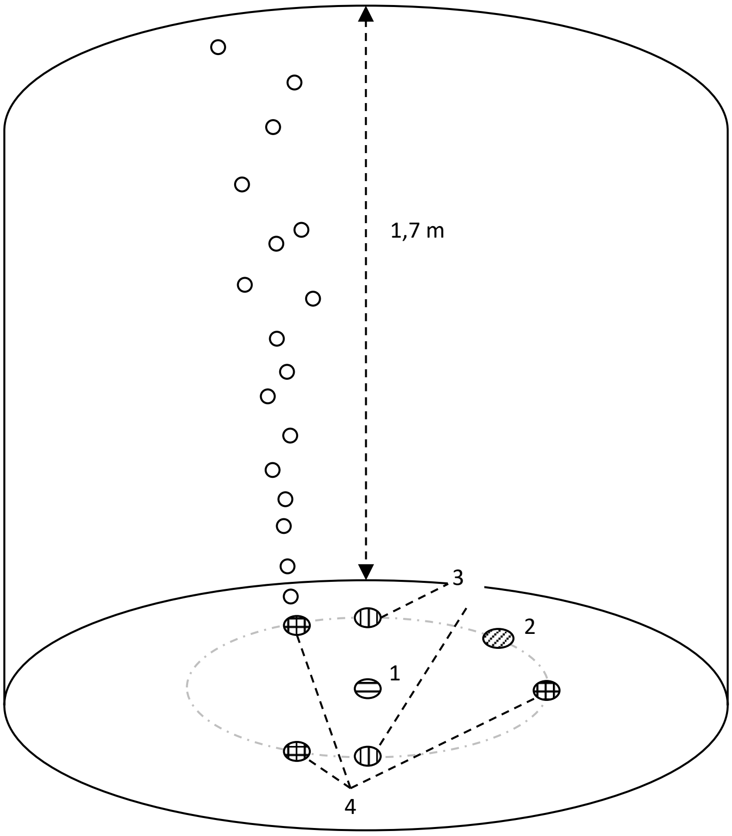

Fig.1. A geometry of the body melt (1/20 scale) with placements of tuyeres

Fluid dynamics is determined by the law of conservation of momentum. Continuity of fluid and gas motion corresponds to the law of conservation of mass:

$$\frac{\partial \vec{\mathbf{v}}}{\partial t} + (\vec{\mathbf{v}} \cdot \nabla)\vec{\mathbf{v}} - D_{\mathrm{v}} \nabla^2 \vec{\mathbf{v}} = -\nabla\left(\frac{p}{\rho_0}\right) - \alpha \vec{\mathbf{g}}, \tag{1}$$

$$\nabla \cdot \vec{\mathbf{v}} = 0, \tag{2}$$

$$\frac{\partial \alpha}{\partial t} + \nabla \cdot \left[\alpha\left(\vec{\mathbf{v}} + \vec{\mathbf{v}}_f\right)\right] - D_\alpha \nabla^2 \alpha = S_\alpha, \tag{3}$$

$$S_\alpha = \frac{q}{V}\frac{T_{air}}{T_m}, \tag{4}$$

where D_v, D_a – effective coefficients of kinematic viscosity and gas diffusion respectively; α – fraction of argon in the melt; g – free fall acceleration (assumed to be 9.81 m/s2); p – pressure field (found due to the condition of solenoidal velocity field); q – gas consumption; T_{air} and T_m – initial gas temperature and melt temperature (1800 C is assumed).

The field of residual damage to the lining is determined by the melt rate along the surface of the walls and bottom of the bucket:

$$\frac{\partial s}{\partial t} = k_s\left|\vec{v}^{\parallel}\right|, \tag{5}$$

where s – is the depth of lining erosion; k_s – coefficient, which adjusts the adequacy of the model to the real erosion process.

The velocity equation is supplemented by boundary conditions that correspond to its components – perpendicular and parallel to the surface w of the solid:

$$\left.\frac{\partial \vec{\mathbf{v}}^{\parallel}}{\partial n}\right|_w = 0, \tag{6}$$

$$\left.\vec{\mathbf{v}}^{\perp}\right|_w = 0, \tag{7}$$

where n – normal to the wall.

The gas transport equation is supplemented by impermeability boundary conditions on solid surfaces. A constant gas release rate is set on the upper surface of the melt.

The finite volume method and the Euler method are used. The problem of the explicit solution scheme is a significant limitation of the maximum value of the time step due to the presence of the Laplacian operator in the equations. This limitation can be avoided by using an implicit scheme.

The peculiarity of the model of the subject area of numerical study of bucket lining erosion, as well as other scientific studies, is the availability of a list of literature sources, which is used to review modern solutions to the problem, obtain reference data and verify the results.

It is proposed to implement the subject area model using a database based on MS SQL Server and a website based on MS ASP.NET MVC. These technologies are well combined with the MS Visual Studio programming environment, in which we will program in the popular C# language.

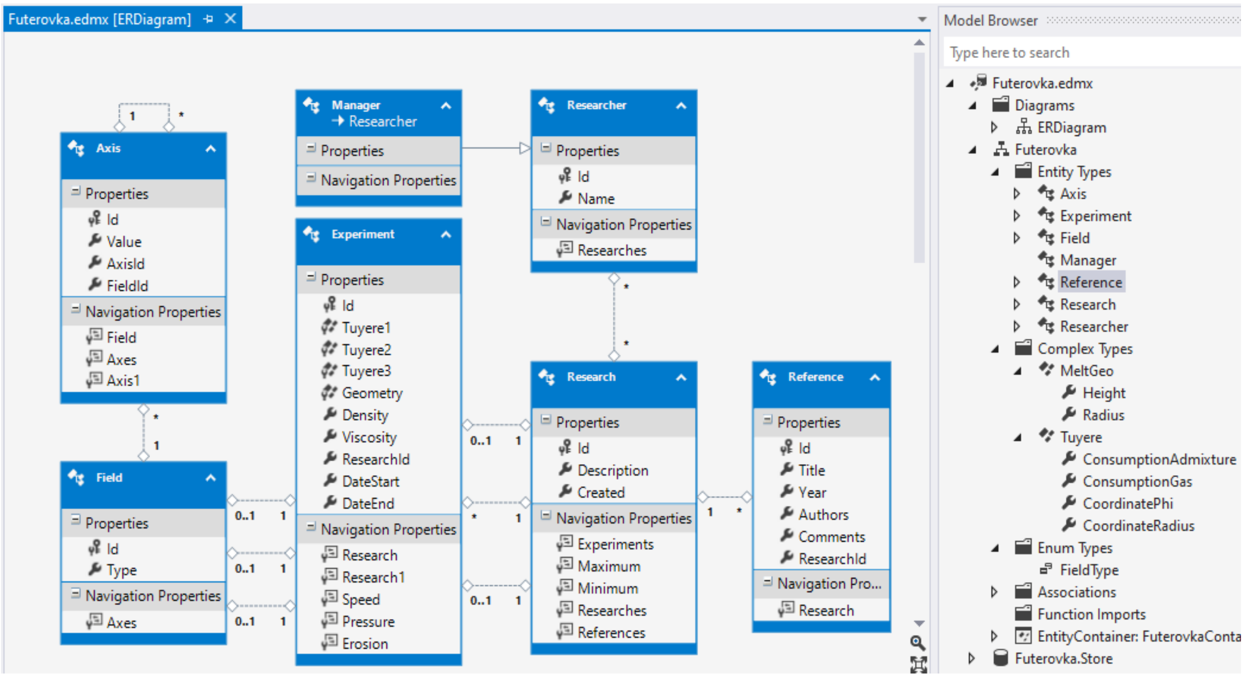

Fig. 2. Entity–Relationship diagram for the domain model of ladle erosion research

Experiments

To solve equations above the finite volume method was used having second order of derivative approximation and conservation property. Cylindrical coordinate system was used as the best choice for the ladle geometry. Time axis is divided on equal intervals and unknown values on the new timestep are calculated using previous ones. To conduct numerical experiments, we use the technological parameters and conditions given in the table 1 and 2.

Table 1

Melt parameters for lining erosion experiment

Parameter	Value
Radius	0,956 m (22 cells)
Height	1,7 m (18 cells)
Angular coordinate	2π (36 cells)
Density	7000 kg/m^3
Temperature	1800 K

Table 2

Parameters of blowing lances for the numerical experiment

Parameter	Value
Total gas consumption	40/60/90 l/min
Diameter of lances	0,1 m
1st setting	1 axial tuyere
2nd setting	1 tuyere at half radius
3rd setting	2 opposite tuyeres at half radius
4th setting	3 tuyeres at an angle of 120^o between them at half radius
Erosion coefficient	0,1

Fig. 3 shows charts of the erosion maximum depth depending on time. As seen, increasing gas blowing rate intensifies lining erosion almost linearly. Lines start not at zero time, because swirls reach lining in few seconds after experiment beginning. Turning off the blowing after the first minute significantly slows down further lining erosion.

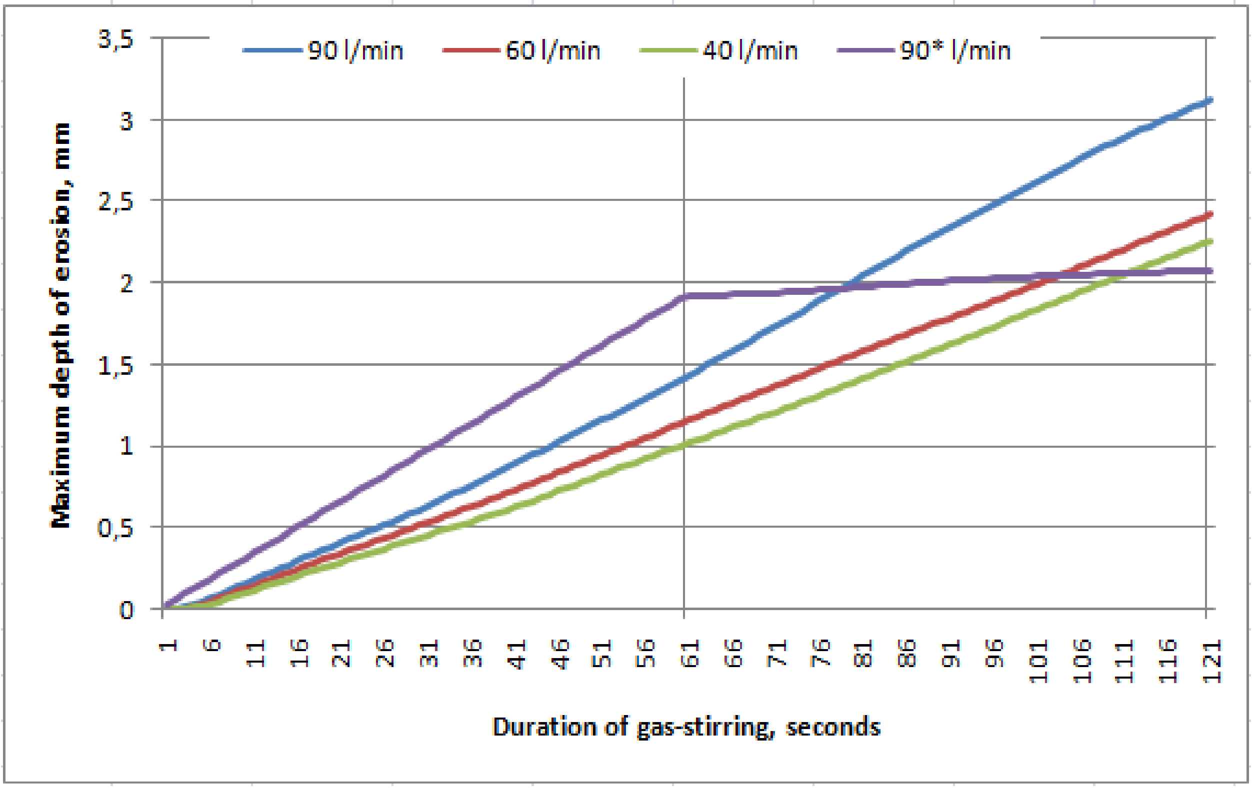

Fig. 3. Erosion in configuration with three tuyeres (the asterisk means turning blowing off at the 60 second)

Results of mathematical modeling can be seen at the website https://www.tensorion.com/lab/metallurgy/ladle/erosion.

Conclusions

The simulation of the process at blowout rates of 40, 60 and 90 l/min and the number of blowout plugs from one to three showed that the greatest erosion is predicted at the bottom, near the blowout tubes, and the acceleration of blowout intensifies erosion by about 15%. Turning off the tuyere after 1 minute of blowing significantly reduces the erosion by at least 35%. If we consider the bucket wall, without disconnecting the tuyere, the flow rate of 90 l/min is the most destructive.

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