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MODELING OF INTERFACE OF ELECTROLYTE/ALUMINUM MELT IN ALUMINUM REDUCTION CELL WITH NOVEL CATHODE STRUCTURE

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Abstract

A finite element model has been developed to examine the electromagnetic field and interface wave of electrolyte/aluminum melt in aluminum reduction cell with the novel cathode structure. The edge-based method is used to solve the Maxwell equations. The results show that the current density distribution in the novel cathode structure aluminum reduction cell becomes more uniform than the traditional cells, weak horizontal current appears on the convex surface, and weakened the longitudinal waves of molten aluminum. The voltage drop of the whole novel aluminum reduction cell has reduced. The result shows that the movement of molten aluminum affected by the electromagnetic force dominates and two reverse eddies in horizontal plane arise in aluminum reduction cell. The velocity and amplitude of molten aluminum wave reduce in the novel cathode structure aluminum reduction cell.

Introduction

An electrolysis cell used to produce primary aluminium is sensitive to waves at the interface of liquid aluminium and electrolyte. The cell current generates magnetic fields within and around the cell. The interaction of these fields with the current cause electromagnetic forces, which induce circulation in molten aluminium and wave of bath layers in the cell voltage. Many research works[1-5] had been conducted on the flow in aluminium reduction cells due to the electromagnetic forces, however, little is reported about the modeling of wave in cell with the effect of novel cathode structure.
The innovation cathode structure in aluminum reduction cells have been developed from plat surface to the convex block, where the flow field of molten aluminum shall be divided[6]. It decreases the flow velocity and weakens significantly the effect of electromagnetic force and gravity waves of molten aluminum. Coupled action of electric field, magnetic field, flow field and joule-heat field in aluminum reduction cells has a significant influence on the current efficiency, energy consumption and the cells life[7-8]. So, it is very important in theoretic and practical guideline for improving of the optimization design, engineering analysis and development of new cells with deeper understanding coupled relation of electromagnetic field and flow field in aluminum reduction cells, choosing the appropriate mathematical model of three field, and improving precision of computed result of three field[9-10].

The purpose of present work is to develop a finite element model based on ANSYS platform to examine effect of novel cathode structure[6,11]on the electromagnetic field and interface wave of electrolyte/aluminum melt in aluminum reduction cell.

Mathematical mode

Electromagnetic equations

The Maxwell equation and Lorentz law is:

Ampere law: $$\nabla \times \vec{H} = \vec{J} + \frac{\partial \vec{D}}{\partial t}$$

Faraday law: $$\nabla \times \vec{E} = -\frac{\partial \vec{B}}{\partial t} \tag{1}$$

Gauss law: $$\nabla \cdot \vec{D} = \rho$$

Constitutive equation of magnetic flux is

$$\nabla \cdot \vec{B} = 0 \tag{2}$$

Lorentz law:

$$\vec{F} = \vec{J} \times \vec{B} \tag{3}$$

where $\vec{H}$ is magnetic field intensity; $\vec{J}$ is total current density vector; $\vec{D}$ is electric flux density vector; $\vec{F}$ is Lorentz force; $\vec{B}$ is magnetic flux density; $\vec{E}$ is electric field intensity vector; ρ electric charge density; t is time.

Flow equations:

The three-phase flow in aluminium reduction cells was computed based on the Euler/Euler approach by solving the Navier-Stokers equations which was widely used in large-scale engineering problems for its practicability. In this case, an inhomogeneous equation for conservation of mass can be written as:

$$\frac{\partial}{\partial t}(r_\alpha \rho_\alpha) + \nabla \cdot (r_\alpha \rho_\alpha U_\alpha) = 0 \tag{4}$$

Where U_α , r_α and ρ_α are velocity, volume fraction and density of phase, respectively. The corresponding equation for conservation of momentum is given as:

$$\frac{\partial}{\partial t}(r_\alpha \rho_\alpha U_\alpha) + \nabla \cdot (r_\alpha (\rho_\alpha U_\alpha \times U_\alpha)) = -r_\alpha \nabla p_\alpha + \nabla \cdot (r_\alpha \mu_{\alpha eff} (\nabla U_\alpha + (\nabla U_\alpha)^T)) + S_{M\alpha} + M_\alpha \tag{5}$$

where μ_{aeff} is effective viscosity of pharse, a sum of molecular viscosity μ_T and eddy viscosity μ_α, M_α describes the interfacial forces acting on phase α due to the presence of other phases. Interphase drag force was only considered: $S_{M\alpha}$ describes the momentum sources due to external body force, which mainly include EMFs and buoyancy for this study. In addition, the volume fraction sum to unity:

$$\sum_{\alpha=1}^{3} r_\alpha = 1 \tag{6}$$

For thc bath and metal, the two liquid phase, the terms is Eq.(5) is different. The metal depth is 0.2m. The structure of 300kA aluminum reduction cell is showed in Figure 1. (1.aluminum conduction rod 2.cathode 3.cryolite 4. aluminum melt 5. anode rod 6.bus bar 7. anode 8. cathode collector bar 9. riser bus bar 10. ramming paste 11. steel shell 12. side bus bar.) Four cathode structures is plot m Figure 2.

The commercial package ANSYS 12.0, which is based on the finite element method, is used to analyze the electromagnetic field and the current field system. nodal-based method (Solid117 element type) is used to solve three–dimensional static electromagnetic field. The current amplitude loaded on the upper surface of the guide rod of anode is 300kA with coupled VOLT freedom and the electric potential on the outlet tip of the steel bars is zero. The relative permeability of the conductor is set to 1. The VOF approach, available in CFX, is used to track the position of interface of electrolyte/aluminium melt. The geometry, physical properties and operating conditions are shown in Table 1 and Table 2.

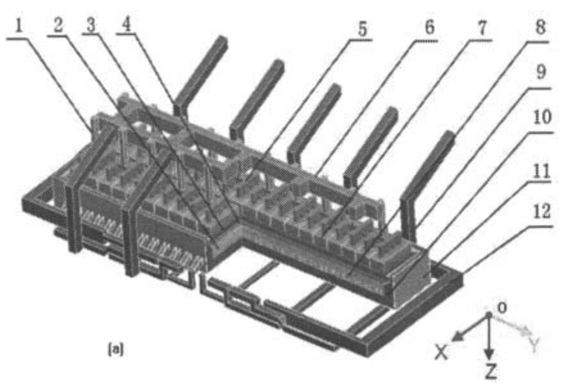

Figure 1 Structure of 300kA aluminum reduction cell

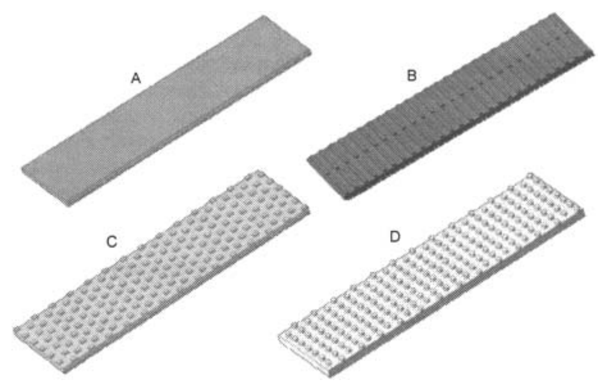

Figure 2 Four cathode structures, A: traditional; B, C, D: novel.

Table1 Geometry and operating parameters of the aluminum reduction cell

Geometry		Parameters	
Chamber, m	14.85×4.20×1.34	Current, kA	300
Anode carbon, m	1.64×0.66×0.55	Voltage, V	4
Cathode, m	3.44×0.51×0.45	Number of bar	26
Cathode Boss, m	1.57×0.18×0.13	Number of boss	26

Table 2 Physical parameters for flow field calculation

Parameter	Aluminium	Electrolyte
Density, $kg \cdot m^{-3}$	2250	2100
Viscosity, $\times 10^{-3} pa \cdot s$	0.883	3.15
Surface tension, $N \cdot m^{-1}$	0.56	
Electrical resisivity, $(\Omega \cdot m)$	2.4×10^{-7}	4.5×10^{-3}

Results and discussion

Numerical simulation are carried out for four aluminium reduction cells with novel cathode structures by following parameters as shown in Table 1 and 2. Figure 3, 4, and 5 are comparison of simulated current density distributions in X, Y, and Z, respectively. It is observed that the current densities in novel cathode structure B, C, and D cells are more than the traditional A cathode structure. Electromagnetic forces in novel cathode structure cells can be calculated by present current densities and induced magnetic flux density.

The flows of aluminium melt and electrolyte are driven by Electromagnetic forces. Figure 6 shows that comparison of flow fields at interface of electrolyte/aluminium for four cathode structures, A is traditional structure, B, C, and D are novel ones. It is seen that the flow velocities in the novel cathode structure cells are reduced, since the ridges and convexes on the cathode have the effect of obstructing.

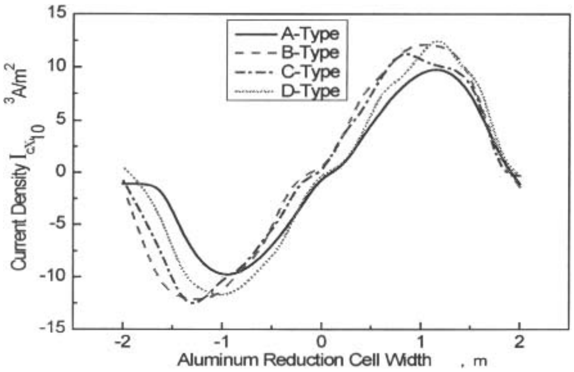

Figure 3 Comparison of simulated current density along x axis in the center of metal pad

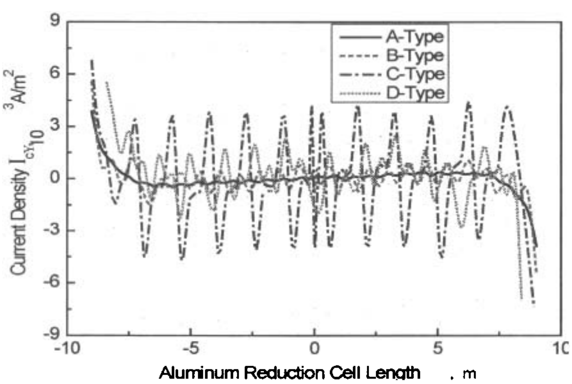

Figure 4 Comparison of simulated current along y axis in the center of metal pad

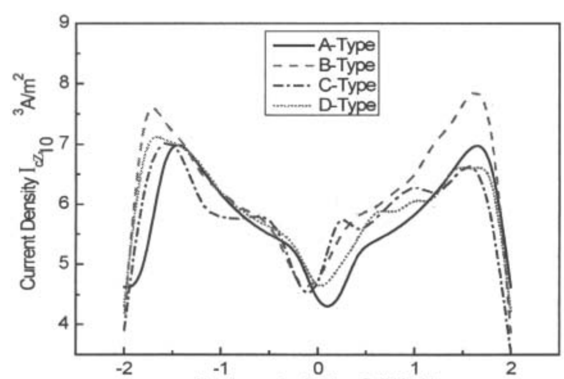

Figure 5 Comparison of simulated current density along x axis in the center of metal pad

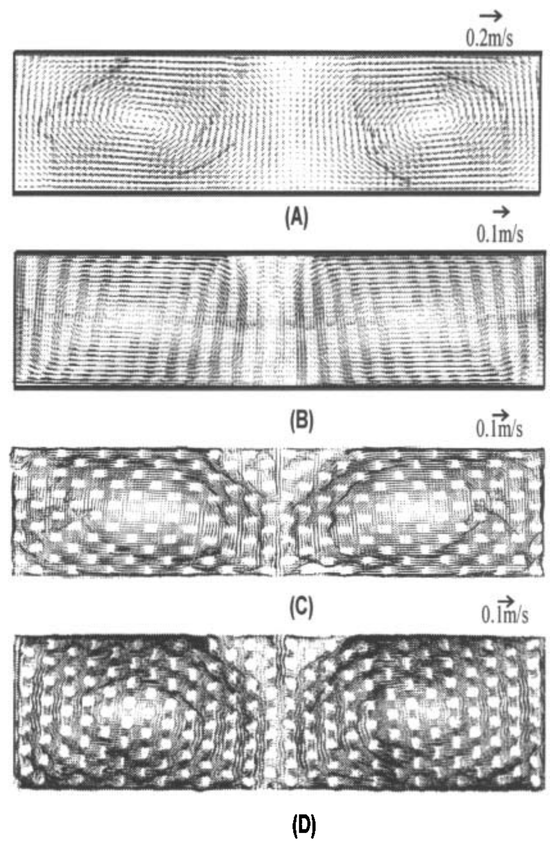

Figure 6 Simulated flow field at interface of electrolyte/aluminium for four cathode structures.

The interface waves of electrolyte/aluminium melt for four structures at its maximum amplitude separately are displayed in Figure 7, it is seen there are two large waves in traditional cathode structure cell. However, a series of small waves are overlapped in two large waves in novel cathode structure cells B, C, and D. these small waves have the effect of suppressing the large waves. Amplitudes of interface waves for four cathode structures are compared as shown in Figure 8, the maximum of amplitudes is traditional A type cathode structure, the minimum is novel B type cathode structure. In conclusion, novel cathode structures, i.e. the ridges and convexes, have the effect of obstructing and can reduce the flow velocities and amplitude of interface waves of electrolyte/aluminium melt in aluminium reduction cells.

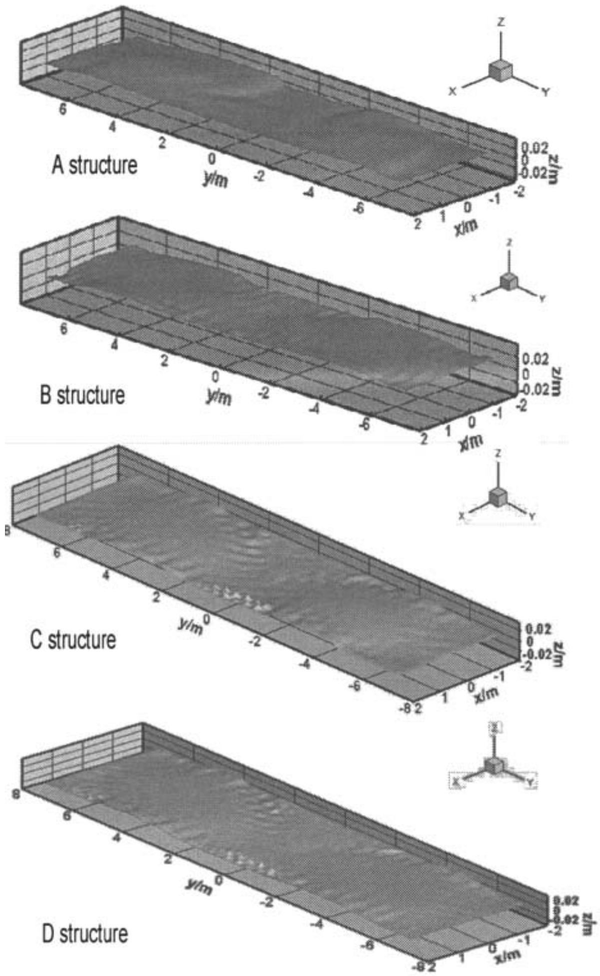

Figure 7 Simulated interface wave of electrolyte/aluminium melt in cells for four cathode structures.

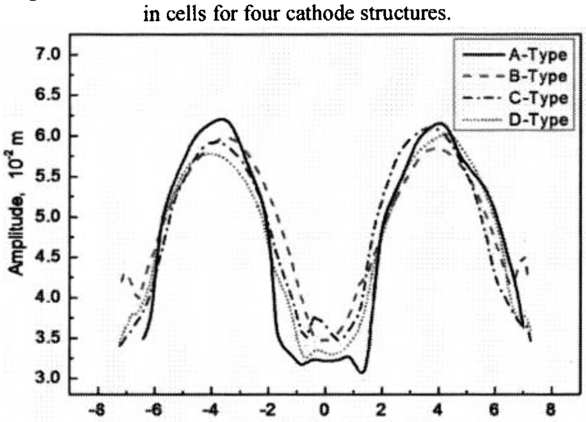

Figure 8 Comparison of amplitude of interface wave of four cathode structures.

Conclusions

(1) Numerical results show that the flow fields in the aluminium reduction cells are composing of two horizontal circulating flows, which are consistent with the traditional structure, but the velocity rates are reduced due to the obstructing of ridges and convexes in novel cathode structures.

(2) The interface waves of electrolyte/aluminium melt in new and traditional aluminium reduction cells are examined, it is found that waves are suppressed and amplitude of waves are reduced with the effect of ridges and convexes in novel cathode structure cells.

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