

МАГНІТОГІДРОДИНАМІЧНІ ПРОЦЕСИ УПРАВЛІННЯ ПРОЦЕСАМИ РОЗЛИВАННЯ І ТВЕРДІННЯ МЕТАЛІВ ТА СПЛАВІВ

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Prerequisites for the use of electromagnetic forces in technologies for refining aluminum alloys from non-metallic inclusions

In the production of aluminum castings, the problem of removing non-metallic inclusions (NMIs) is very relevant. A modern efficient way of refining aluminum alloys is filtration through ceramic foam filters. However, their capabilities for retaining small NMIs are limited, since the dimensions of the smallest cells are much larger than the dimensions of the NMIs to be retained. The retention of such particles occurs due to their coagulation and adhesion inside the filter. To enhance the role of these two processes, additional effects on the melt passing through the filter are required. An analysis of current trends shows that at present the most promising application of electromagnetic factors is to create physical conditions in the filter cells, under which the role of coagulation and adhesion will significantly increase. The article describes the main electromagnetic phenomena, using which the task can be solved and specific ways can be outlined to create a technology for the separation of NMIs in aluminum alloys using electromagnetic factors. The basis of electromagnetic influences is the interaction of electric current with a magnetic field. Electric current can interact with both its own and external magnetic field. In both cases, the Lorentz force arises, which creates a pressure gradient in the liquid metal. The direction of the vector of this gradient can be chosen arbitrarily. In a particular case, it may coincide with the direction of the gravitational gradient or be opposite to it. A force opposite to the direction of the vector of the artificial pressure gradient will act on the NMIs located in the pores of the filter. As a result of this factor, it is possible to control the direction of movement of the NMIs. For example, if the pressure gradient vector is directed away from the pore walls, then the role of NMIs adhesion to the filter material will increase and favorable conditions will be created for their coagulation. As a result, an increase in the probability of retaining NMIs, which are much smaller than the pore sizes of the filter, is expected.

Keywords: aluminum alloys, non-metallic inclusions, refining, electromagnetic force, pressure gradient, ceramic foam filter, filtration, coagulation, adhesion.

Non-metallic inclusions (NMIs) have a negative impact on the properties of aluminum alloys starting from their pouring into casting molds, especially into chill molds. A melt containing a lot of inclusions fills casting molds worse than a refined one, which increases the rejection of underfilling. It also increases the tendency of castings to hot crack. In finished products, due to the presence of non-metallic inclusions in them, mechanical

properties, including fatigue strength, are reduced. In addition, in the obtained products, as a rule, corrosion resistance decreases. This is especially true for high-strength alloys of the Al-Cu system. In metallurgical practice, the main methods for refining the melt from NMIs are purging with argon, processing with special fluxes, and filtering. Despite the successes achieved, technologists still have a serious need to improve the efficiency of refining

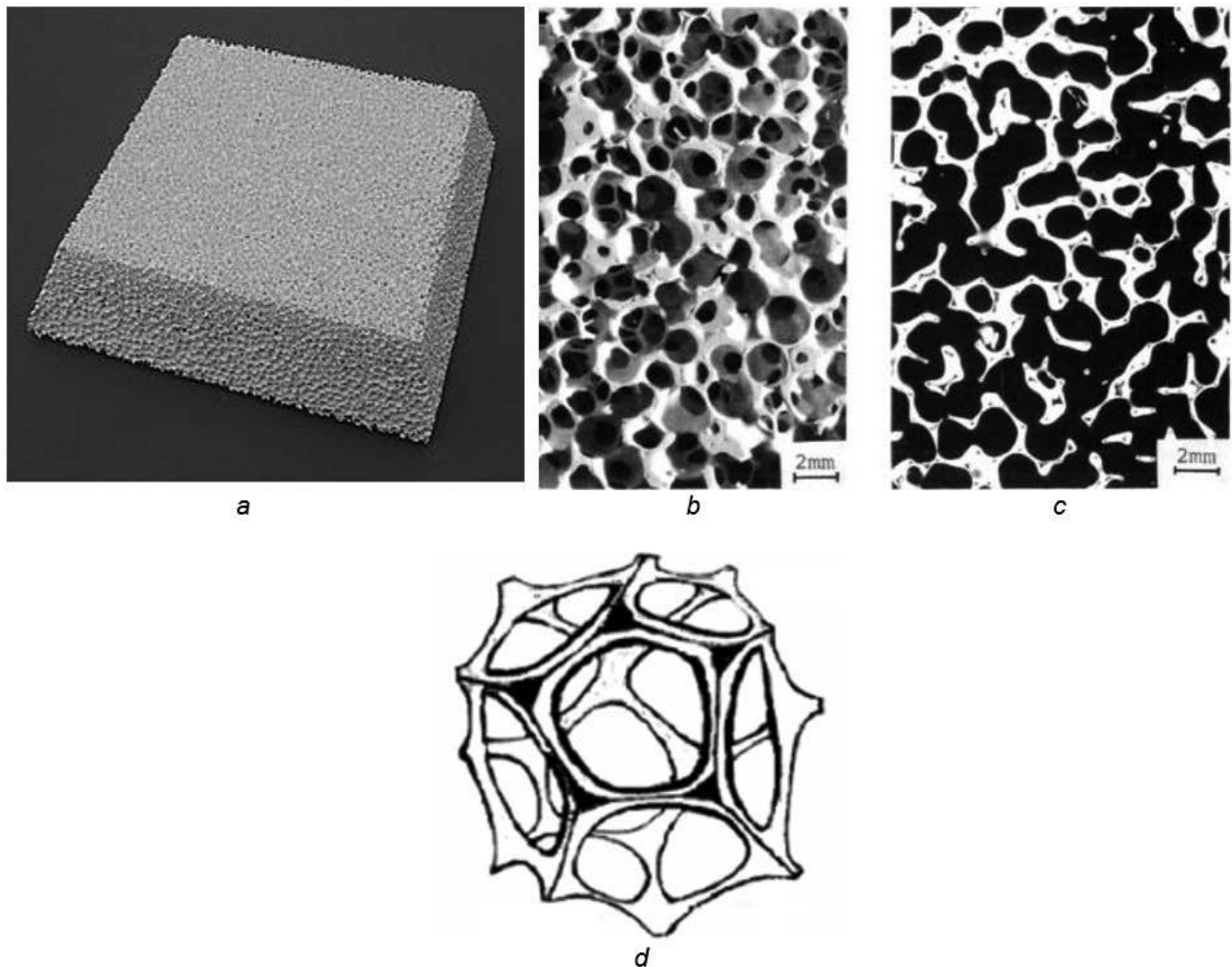


Fig. 1. Typical ceramic foam filter with dimensions 180×180×50 mm (a), photo of the surface (b) and flat section of this filter (c) [1]. The geometric shape of the elementary cell of the filter (d) [2]

technologies. First of all, it is necessary to increase the completeness of the removal of NMIs, especially those with dimensions less than 20 μm . Currently, refining by filtration through ceramic foam filters is most often used in production. Usually they are square slabs with a side from 180 to 660 mm and a thickness of 50 mm (Fig. 1a). They are made by introducing a polymeric cellular foam into a liquid ceramic pulp. This foam is then dried and fired to burn out the polymer base. As a result, a ceramic replica of the original organic foam structure is obtained (Fig. 1b, c) [1]. Each pore is an elementary cell of the filter. In an idealized form, its geometric shape is shown in Fig. 1d [2].

To trap small particles, it is necessary to use filters with a small mesh size. However, firstly, the smaller the filter cells, the lower its throughput, and secondly, the smallest cells have dimensions many times larger than the dimensions of the small NMIs to be retained. It is possible to detain such particles due to adhesion. However, the probability that a fine particle will be retained in one pass through the filter is small. Most of the inclusions will pass through the filter unhindered, so it is necessary to use additional control factors to increase the probability of retaining small particles. At present, such factors can provide the means of magnetohydrodynamics.

There are a number of experimental and theoretical works on the study of the behavior of non-metallic particles under the action of bulk electromagnetic forces. Their appearance was due to the fact that in induction channel furnaces and electromagnetic pumps, the process of overgrowing of channels with deposits consisting of NMIs is observed. In [3], a theoretical analysis of this process was carried out. The substance that is deposited on the walls of the channels looks like a gray powder formed from non-metallic particles. This phenomenon has long been the basis for the conclusion that induction channel furnaces and electromagnetic pumps to a certain extent perform the function of refining aluminum alloys from non-metallic inclusions. In other words, they are electromagnetic devices that detain some of the non-metallic inclusions in the alloy. This fact served as the basis for the work on the creation of electromagnetic filters. Unfortunately, it has not yet been possible to create an effective electromagnetic filter, so ideas have appeared, the essence of which is that electromagnetic influences are superimposed on a ceramic filter through which a metal melt flows, for example, [4] (Fig. 2). The essence of the idea is that the liquid metal is poured into the receiving funnel 6, from where it enters the electromagnetic force creation zone 4, including the ceramic fil-

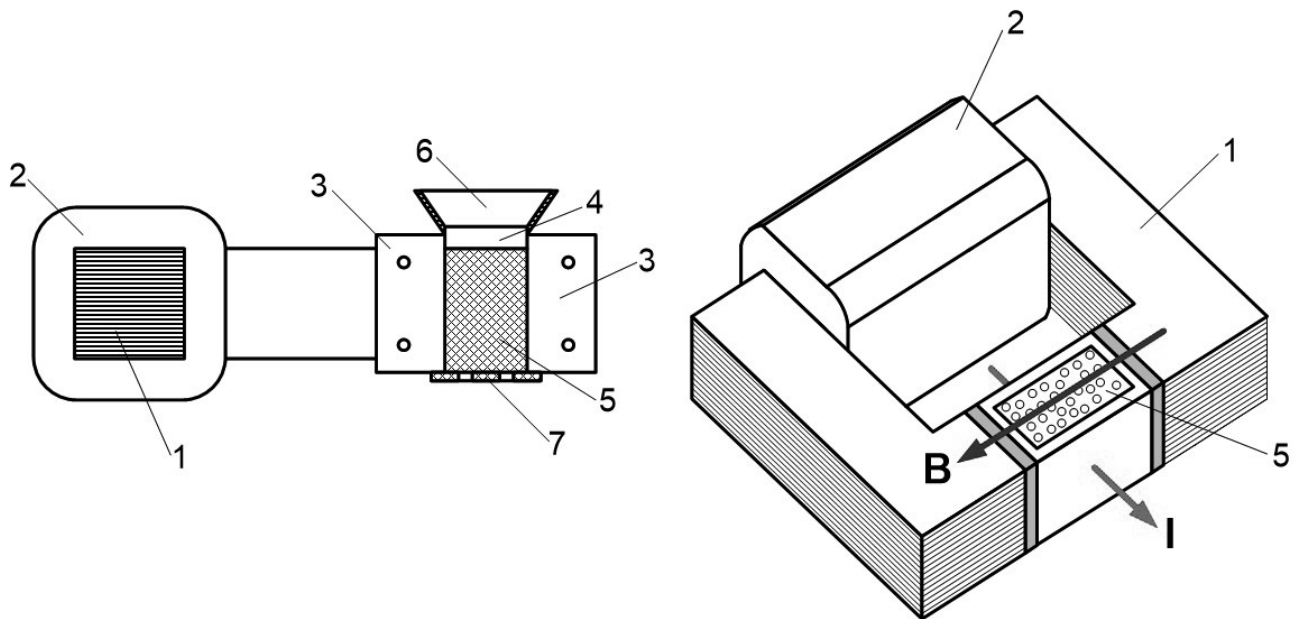


Fig. 2. Scheme of an electromagnetic device for separating non-metallic inclusions from a metal melt [4]: 1 – C-shaped magnetic circuit; 2 – coil; 3 – electrodes supplying electric current; 4 – zone of creation of electromagnetic force; 5 – ceramic filter; 6 – receiving funnel; 7 – perforated refractory plate

ter 5 location zone. The electromagnetic force is created by the interaction of an electric current supplied by electrodes 3 with a magnetic field directed perpendicular to the plane drawing. According to the rule of the left hand, the force will be directed either down or up.

The obvious disadvantages of this device are that it uses a conductive supply of electric current, and the electromagnetic force acts only along the melt flow. That is, it either speeds it up or slows it down. In recent years, in a number of European countries and the People's Republic of China, studies have been carried out on the effect of the magnetic field created by the solenoid on increasing the efficiency of NMIs separation in a ceramic foam filter installed inside the solenoid [5, 6]. A device based on this principle has been tested at Giant (PRC) in semi-continuous casting of wrought alloys. Encouraging results have been obtained, but further development is still required.

The Physico-technological Institute of Metals and Alloys of the National Academy of Sciences of Ukraine (PTIMA NASU) also carried out experimental work on filtering aluminum alloys through a ceramic foam filter with the imposition of electromagnetic effects on it, however, a fundamentally different technological scheme was used (Fig. 3), since the process was carried out in a magnetodynamic installation [7]. The refining of the AK7 grade alloy obtained from the Antonov State Enterprise serial plant was carried out in the form of defective castings.

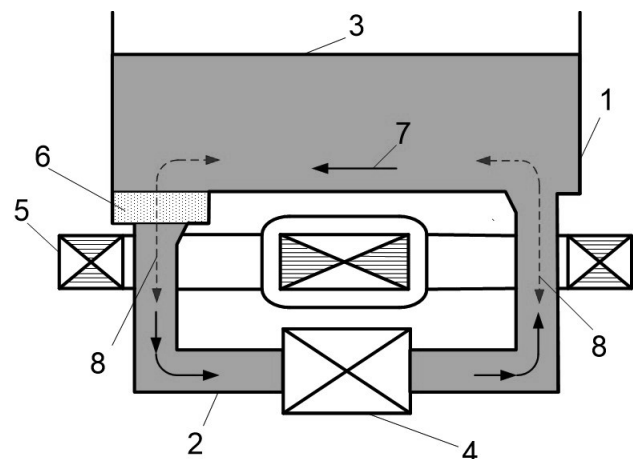


Fig. 3. Schematic diagram of the removal of non-metallic inclusions from aluminum melt, built on the basis of a magnetodynamic unit [7]: 1 – crucible; 2 – canal; 3 – liquid metal bath; 4 – electromagnetic pump; 5 – inductor; 6 – ceramic foam filter; 7 – liquid aluminum alloy stream; 8 – alternating electric current 50 Hz

The melt circulated under the action of an electromagnetic pump 4 along the contour shown by arrows 7: "bath 3 – ceramic foam filter 6 – channel 2 – electromagnetic pump 4 – channel 2 – bath 3". An alternating electric current passes through channel 2 and bath 3 and filter 6, which is induced by inductor 5. The studies of cast samples obtained from the alloy according to the technologi-

Table

Comparison of mechanical properties of factory and experimental samples

Facility where the samples were obtained	Strength, σ_T , MPa	Relative extention, δ , %
State Enterprise "Antonov"	218.4	4.0
PTIMA NASU	244.8	13.9

cal scheme (Fig. 3) were carried out in the laboratory of the State Enterprise "Antonov". The results of the study, shown in the table, showed that the quality of the metal has improved significantly compared to the samples obtained at the factory.

Aluminum alloys always contain non-metallic inclusions, the presence of which impairs their performance properties. The most typical among them are oxide Al_2O_3 , MgO , Al_2MgO_4 , SiO_2 and non-oxide Al_4C_3 , SiC , AlN . Compact inclusions are 5–100 μm in size, and oxide films are up to 5 mm in size [8]. The density of these inclusions is higher than the density of liquid aluminum alloy, but they settle very slowly due to their small size. In addition, convective currents prevent their settling. The overwhelming majority of NMIs are not electrically conductive. Some of them, for example, SiC particles, are still electrically conductive, but their electrical resistance is much higher than the resistance of liquid aluminum alloy, so when an electric current is passed through the melt, they behave almost the same as dielectric particles.

The forces of Archimedes, Stokes and Magnus act predominantly on non-metallic particles in liquid metal [9].

The Archimedes force is due to the static pressure gradient created by gravity.

The Stokes force is mathematically expressed by the dependence of the rate of its settling or floating on the difference between the densities of the liquid and the particle, the viscosity of the liquid and the size of the particle.

The Magnus force arises from a combination of translational and rotational motions of a particle.

The electromagnetic force (Lorentz force) causes a change in the pressure gradient in the electrically conductive medium and acts on the metal melt, and not on the non-conductive particle. In order for a particle whose density is greater than the density of the melt to float, it is necessary to increase the static pressure gradient. This can be achieved by creating a bulk electromagnetic force in the liquid metal, the direction of action of which coincides with the direction of gravity. There is an effect of an apparent increase in the density of the liquid at a constant density of the particle. When an electromagnetic force of the opposite direction is created, the effect of an apparent decrease in the density of the liquid occurs, so a particle having a lower density than the liquid will sink in it [10]. To create an electromagnetic force, an electric current must flow through the melt, and a magnetic field must pass perpendicular to the direction of the current. The magnitude of the electromagnetic force that acts on the elementary volume and its direction are determined by the vector product:

$$\mathbf{F} = [\mathbf{j}\mathbf{B}], \quad (1)$$

where $\mathbf{F}$ is the electromagnetic force vector, Newton, $\mathbf{j}$ is the electric current density vector Amp/m^2 , $\mathbf{B}$ is the magnetic induction vector, Tesla.

Let us agree to consider the direction of the electromagnetic force as positive if it coincides with the direction of gravity. According to [10], the apparent specific gravity of the elementary volume of the melt, provided

that the magnetic field and electric current are homogeneous, is determined by the equation:

$$\gamma = \rho g \pm jB = \pm \text{grad } p, \quad (2)$$

where γ is the apparent specific gravity of the melt, j is the electric current density, B – magnetic induction, $\text{grad } p$ – pressure gradient, Pascal/m.

The pressure gradient in a liquid metal also arises under the action of two types of pinch effect, which manifest themselves as axial compression of the conductor [11]. In both cases, the electric current interacts with its own magnetic field.

The first type, the linear pinch effect, occurs when a direct or alternating electric current passes through a liquid conductor. If the conductor is round and has a radius r , then the pressure p on the axis of the conductor is determined by the equation:

$$p = -\frac{\mu\mu_0}{4} \cdot j^2 \cdot r^2 + p_c, \quad (3)$$

where μ is the magnetic permeability of the liquid metal (dimensionless value), μ_0 – magnetic constant equal to $4\pi \cdot 10^{-7} \text{ H/m}$, j – current density A/m^2 , r is the radius of the conductor m , p_c is the static pressure in the melt when no electric current flows through it, Pa.

The minus sign on the right side of the equation means that the pinch effect creates a pressure opposite to the gravitational metallostatic pressure p_c . Metallostatic pressure presses the melt against the walls of the channel in which the melt is located, and electromagnetic forces tend to squeeze the melt away from the walls. The particles will then move towards the walls. It follows from equation (3) that the melt will move away from the walls when the absolute value of the negative term becomes greater than p_c .

The second type is the θ -pinch effect, which operates in a liquid conductor placed in an alternating current solenoid. With direct current, the effect does not appear. The pressure p on the axis of the conductor is:

$$p = -\frac{(\mu\mu_0 j)^2}{2\mu} + p_c. \quad (4)$$

When an electric current flows through a solenoid, an axial compressive force acts on the liquid rod. The particles will then move in the direction of the walls. If the current strength in the solenoid is increased, then the liquid metal will be squeezed out from the walls as soon as the absolute value of the negative term exceeds the value of p_c .

In industrial practice, a linear pinch effect occurs in induction channel furnaces, since the electric current flows along the channel and causes melt compression. As a result, a static pressure gradient appears, directed towards the longitudinal axis of the channel. The above example shows that as a result of the action of electromagnetic forces on a liquid metal, it is possible to create

a movement of non-metallic particles in a given direction using a linear pinch effect. It should be noted that in the technological scheme (Fig. 3) a linear pinch effect operates in the volume of the ceramic foam filter.

The idea of using the θ -pinch effect to remove non-metallic particles is reflected in a number of theoretical works. For example, in [11], the separation of non-conducting particles in a channel passing through the field of a current ring (solenoid) was considered. A formula is obtained for calculating the required magnetic field induction for given particle sizes to be removed.

In [10, 12], a theoretical analysis of the use of a magnetohydrodynamic (MHD) machine in general and its various modifications in particular as a separator of non-conductive particles in a liquid metal is carried out. There are also experimental works on electromagnetic effects on liquid metals to improve the efficiency of refining from NMLs, for example [13, 14].

Thus, over the past decades, various researchers have created a solid theoretical basis for the electromagnetic separation of NMLs from liquid metals. Promising practical results have also been achieved in the refining of aluminum alloys from NMLs using electromagnetic factors, including the development of the PTIMA NAS of Ukraine.

Conclusions and research perspectives

Many years of production experience in the operation of induction channel furnaces and electromagnetic pumps has shown that MHD factors create conditions in the liquid metal under which the NMLs move to the channel walls.

Theoretical works of many researchers have revealed the physical nature of the forces acting on non-conductive NMLs and have shown that using electromagnetic forces it is possible to control the process of movement of non-metallic particles in metal melts.

Ceramic foam filters widely used in production do not retain small non-metallic inclusions, the dimensions of

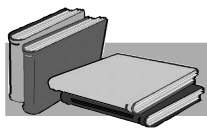
which are many times smaller than the pores of a ceramic foam filter with the smallest cells. For their retention, additional external influences are required that promote the coagulation of NMLs and enhance the role of adhesion.

To date, specialists in the field of applied magnetohydrodynamics have not been able to create an effective electromagnetic filter due to the influence of scaling factors. The problem can be solved if an additional functional element is used, which divides the total melt flow into many small jets. In each such jet, it is possible to effectively carry out an electromagnetic effect on the melt due to a decrease in the influence of scale factors. Such an element can be a ceramic product with many channels, for example, a ceramic foam filter.

In the development of the above concept, it is advisable to continue the research and development of the technology developed in the PTIMA NAS of Ukraine using the magnetodynamic pump (MDP) according to the scheme (Fig. 3). In MDP, it is easy to create conditions under which an electric current passes through the ceramic foam filter; therefore, at the first stage of research, it is necessary to focus on studying the influence of this factor.

To develop a filtering technology in crossed magnetic and electric fields, it is necessary to create an autonomous filter box designed for two use cases. The first option is the pouring of the melt into the mold from an electromagnetic filter box, into which the melt enters from the MDP, which is switched on in the mode of controlled electromagnetic pouring. The second variant assumes the use of a circulation circuit: "MDP – filter box – MDP". The filtration process continues for a predetermined time, and then the refined alloy is electromagnetically poured into the mold.

Studies of the quality of the metal after refining should be carried out using a set of modern technological samples presented in [15].

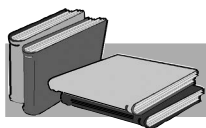


ЛІТЕРАТУРА

1. Otsuka R. Molten Metal Processing. Handbook of Aluminum, 2003. Vol. 1.
2. Бэтхерс У., Якович А., Екабсон Н., Маджулис И., Наке Б. Теоретические исследования условий возникновения отложений в индукционных канальных печах. *Магнитная гидродинамика*. 1994. Т. 30. № 2. С. 247–258.
3. Безденежных И.С., Матыгуллина Е.В., Шумков А.А. Выбор элементарной ячейки для моделирования структуры пенокерамического фильтра. *Вестник Пермского национального исследовательского политехнического университета. Машиностроение, материаловедение*. 2020. Т. 22. № 1. С. 95–101. DOI: <https://doi.org/10.15593/2224-9877/2020.1.11>
4. А. с. 452604 СССР, М. Кл. С21с 7/00. Устройство для очистки металлических расплавов / Г.А. Демин, Н.П. Сабадырь, В.И. Королёв, Е.И. Зарецкий; Оpubл. 05.12.74. Бюл. № 45.
5. Fritsch R., Kennedy M.W., Akbarnejad S., Aune R.E. Effect of Electromagnetic Fields on the Priming of High Grade Ceramic Foam Filters (CFF) with Liquid Aluminum. In: Hyland M. (eds.) *Light Metals*. 2015. Springer, Cham. DOI: https://doi.org/10.1007/978-3-319-48248-4_156
6. Zhang Z.T., Guo Q.T., Yu F.Y., Li J., Zhang J., Li T.J. Motion behavior of non-metallic particles under high frequency magnetic field. *Transactions of Nonferrous Metals Society of China*. 2009. Vol. 19. Iss. 3. P. 674–680. DOI: [https://doi.org/10.1016/S1003-6326\(08\)60332-5](https://doi.org/10.1016/S1003-6326(08)60332-5)

7. Fikssen V. Increasing the efficiency of refining and modification of aluminum alloys when using electromagnetic factors. *Magnetohydrodynamics*. 2022. Vol. 58. Iss. 1–2. P. 151–156.
8. Bernd Friedrich. Understanding of Inclusions – Characterization, Interactions and Boundaries of Removability with Special Focus on Aluminum melts. Presentation Werkstoffwoche, Dresden 14.09.2015. URL: https://aluminium-guide.com/wp-content/uploads/2019/09/Understanding_of_Inclusions_Freidrich.pdf
9. Новиков И.М., Горн Р.К. МГД воздействие на неметаллические включения в каналах МДН / Магнитодинамические установки для плавки, обработки и заливки литейных сплавов: Сб. науч. тр. АН УССР. Киев: Ин-т пробл. литья, 1989. С. 19–28.
10. Повх И.Л., Чекин Б.В. Магнитогидродинамическая сепарация. Киев: Наукова думка, 1978. 148 с.
11. Шерклиф Дж. Курс магнитной гидродинамики. Москва: Мир, 1967. 320 с.
12. Кирко И.М. МГД-машина как сепаратор для непроводящих включений в жидком металле / Применение магнитной гидродинамики в металлургии: Сб. статей. АН СССР – Уральский научный центр. Свердловск, 1977. С. 3–15.
13. Taniguchi S., Yoshikawa N., Takahachi K. Application of EMP to the separation of inclusion particles from liquid metal. Proc. of the Joint 15th Riga and 6th PAMIR Intern. conf. “Fundamental and Applied MHD” (Riga, June 27–July 1, 2005). Riga, 2005. P. 55–63.
14. Higuchi M., Ambai H., Shimasaki S. et al. Electromagnetic separation of inclusions from molten copper by alternating electromagnetic field. Proc. of the 6th Intern. conf. on Electromagnetic proc. of materials EMP 2009 (Oct. 19–23, 2009, Dresden, Germany). Dresden, 2010. P. 86–89.
15. Djurdjević M., Odanović Z., Pavlović-Krstić J. Melt quality control at aluminum casting plants. *MJoM*. 2010. Vol. 16 (1). P. 63–76.

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REFERENCES

1. Otsuka, R. (2003). Molten Metal Processing. Handbook of Aluminum, vol. 1.
2. Bathers, W., Yakovich, A., Ekabson, N., Majulis, I., Nake, B. (1994). Theoretical studies of the conditions for the occurrence of deposits in induction channel furnaces. *Magnetohydrodynamics*, vol. 30, no. 2, pp. 247–258 [in Russian].
3. Bezdeneznykh, I.S., Matygullina, E.V., Shumkov, A.A. (2020). The choice of unit cell for modeling the structure of the ceramic foam filter. *Bulletin PNRPU. Mechanical engineering, materials science*, vol. 22, no. 1, pp. 95–101, doi: <https://doi.org/10.15593/2224-9877/2020.1.11> [in Russian].
4. A. s. 452604 USSR, M. Kl. C21c 7/00. Device for cleaning metal melts. G.A. Demin, N.P. Sabadyr, V.I. Korolev, E.I. Zaretsky; publ. 12/05/74. Bull. no. 45 [in Russian].
5. Fritsch, R., Kennedy, M.W., Akbarnejad, S., Aune, R.E. (2015). Effect of Electromagnetic Fields on the Priming of High Grade Ceramic Foam Filters (CFF) with Liquid Aluminum. In: Hyland M. (eds.) *Light Metals*. Springer, Cham., doi: https://doi.org/10.1007/978-3-319-48248-4_156
6. Zhang, Z.T., Guo, Q.T., Yu, F.Y., Li, J., Zhang, J., Li, T.J. (2009). Motion behavior of non-metallic particles under high frequency magnetic field. *Transactions of Nonferrous Metals Society of China*, vol. 19, iss. 3, pp. 674–680, doi: [https://doi.org/10.1016/S1003-6326\(08\)60332-5](https://doi.org/10.1016/S1003-6326(08)60332-5)
7. Fikssen, V. (2022). Increasing the efficiency of refining and modification of aluminum alloys when using electromagnetic factors. *Magnetohydrodynamics*, vol. 58, iss. 1–2, pp. 151–156.
8. Bernd Friedrich. Understanding of Inclusions – Characterization, Interactions and Boundaries of Removability with Special Focus on Aluminum melts. Presentation Werkstoffwoche, Dresden 14.09.2015. URL: https://aluminium-guide.com/wp-content/uploads/2019/09/Understanding_of_Inclusions_Freidrich.pdf
9. Novikov, I.M., Gorn, R.K. (1989). MHD impact on non-metallic inclusions in channels MDN / Magnetodynamic installations for melting, processing and pouring cast alloys: Collection of scientific papers. AN Ukrainian SSR. Kyiv: Institute for Problems of Casting, pp. 19–28 [in Russian].
10. Povkh, I.L., Chekin, B.V. (1978). Magnetohydrodynamic separation. Kyiv: Naukova dumka, 148 p. [in Russian].
11. Shercliff, J. (1967). A textbook of magnetohydrodynamics. Moscow: Mir, 320 p. [in Russian].
12. Kirko, I.M. (1977). MHD-machine as a separator for non-conductive inclusions in liquid metal. Application of magnetohydrodynamics in metallurgy: Collection of articles. USSR Academy of Sciences – Ural Scientific Center. Sverdlovsk, pp. 3–15 [in Russian].
13. Taniguchi, S., Yoshikawa, N., Takahachi, K. (2005). Application of EMP to the separation of inclusion particles from liquid metal. Proc. of the Joint 15th Riga and 6th PAMIR Intern. conf. “Fundamental and Applied MHD” (Riga, June 27–July 1, 2005). Riga, pp. 55–63.

14. Higuchi, M., Ambai, H., Shimasaki, S. et al. (2010). Electromagnetic separation of inclusions from molten copper by alternating electromagnetic field. Proc. of the 6th Intern. conf. on Electromagnetic proc. of materials EMP 2009 (Oct. 19–23, 2009, Dresden, Germany). Dresden, pp. 86–89.
15. Djurdjević, M., Odanović, Z., Pavlović-Krstić, J. (2010). Melt quality control at aluminum casting plants. *MJoM*, vol. 16 (1), pp. 63–76.

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Передумови використання електромагнітних сил у технологіях рафінування алюмінієвих сплавів від неметалевих включень

У виробництві алюмінієвого лиття дуже актуальною є проблема видалення неметалевих включень (НВ). Сучасним ефективним способом рафінування алюмінієвих сплавів є фільтрування через пінокерамічні фільтри. Однак для затримання дрібних НВ їх можливості обмежені, оскільки розміри найменших комірок значно більші, ніж розміри НВ, які необхідно затримати. Затримання таких частинок відбувається внаслідок їхньої коагуляції та адгезії всередині фільтра. Для посилення ролі цих двох процесів необхідні додаткові впливи на розплав, що проходять через фільтр. Аналіз сучасних тенденцій показує, що в даний час найбільш перспективним є застосування електромагнітних факторів для створення в комірках фільтра фізичних умов, за яких істотно зростає роль коагуляції та адгезії. У статті описуються основні електромагнітні явища, при використанні яких поставлене завдання може бути вирішено та намічено конкретні шляхи створення технології сепарації НВ в алюмінієвих сплавах із застосуванням електромагнітних факторів. Основою електромагнітних впливів є взаємодія електричного струму з магнітним полем. Електричний струм може взаємодіяти як із власним, так і із зовнішнім магнітним полем. В обох випадках виникає сила Лоренца, що створює у рідкому металі градієнт тиску. Напрямок вектора цього градієнта можна вибрати довільно. В окремому випадку він може збігатися з напрямком гравітаційного градієнта або бути протилежним йому. На НВ, що знаходяться в порах фільтра, діятиме сила, протилежна напрямку вектора штучного градієнта тиску. Внаслідок дії цього фактора можна керувати напрямком руху НВ. Наприклад, якщо вектор градієнта тиску спрямований від стінок пор, то посилюється роль адгезії НВ до матеріалу фільтра, і створюються сприятливі умови для їхньої коагуляції. В результаті очікується підвищення ймовірності затримання НВ, розміри яких набагато менші, ніж розміри пор фільтра.

Ключові слова

Алюмінієві сплави, неметалеві включення, рафінування, електромагнітна сила, градієнт тиску, пінокерамічний фільтр, фільтрування, коагуляція, адгезія.