

Technologies of casting and preparation of aluminum alloys using magnetohydrodynamics tools

This article presents some developments of the Physico-technological Institute of Metals and Alloys of the National Academy of Sciences of Ukraine related to the technologies of aluminum alloys, which have been successfully tested in laboratory and production facilities.

Applied magnetohydrodynamics in metallurgy and foundry manufacturing has technological opportunities that are either unattainable or difficult to implement when other physical principles are used. Progress in this area has been slow due to the fact that large non-magnetic gaps are inevitable in metallurgical devices used in metallurgy and foundry. However, due to the improvement of refractory and electro-technical materials, the use of magnetohydrodynamics in metallurgical production of the world is constantly increasing. The following technological developments are described.

Casting under electromagnetic pressure according to the low-pressure casting scheme, in which the pressure of the compressed gas is replaced by electromagnetic influence. As a result, there is no need to seal the crucible with liquid metal and the accuracy of the preset filling mode of the mold is increased.

Casting under electromagnetic pressure with a dispersed gating and feeding system. With this casting method, a high liquid metal utilization rate is achieved, which is unachievable in other casting methods, and the absence of shrinkage defects is ensured.

Electromagnetic stirrer for pulsating effect on liquid metal, which is an alternative to the electromagnetic mixer of traveling magnetic field.

Complex refining of aluminum alloys, including filtration of the melt through a ceramic foam filter and its simultaneous purging with argon. Increased efficiency is achieved by application of electromagnetic factors.

Ключові слова: aluminum alloys, casting, electromagnetic pressure, electromagnetic stirrer, non-metallic inclusions, refining, electromagnetic factors, ceramic foam filter, filtration.

Introduction. Applied magnetohydrodynamics in metallurgy and foundry has both proven and potential technological capabilities that are either inaccessible or difficult to implement when other physical principles are used. For example, the creation of an artificial pressure gradient in a liquid metal that is tens of times higher than the gravitational pressure, non-contact force on the liquid metal, levitation of the liquid metal, wringing the melt from the walls of the mold, etc. [1]. The objectives of the application of magnetohydrodynamics in the field of foundry and metallurgy are to improve existing processes and develop new ones. Progress in this area has been slow, primarily due to the fact that large non-magnetic gaps are inevitable in metallurgical electromagnetic devices. At present, new lining materials with high thermal insulation properties have been developed and continue to be improved, so non-magnetic gaps can be reduced and thereby increase the efficiency of electromagnetic effects on the metal melt. In addition, progress is facilitated by the development of new electrical materials, primarily electrical steels with increased magnetic properties, as well as the use

of modern element base in electrical equipment. An important role is also played by the development of computer programs that can be used to perform complex calculations that allow the optimization of electromagnetic devices and the practical use of theoretical research carried out in recent decades.

The world's generally recognized achievements in applied magnetohydrodynamics relating to aluminum alloys primarily include electromagnetic mixers of running magnetic field for reverberatory melting furnaces and electromagnetic trays for casting the alloy prepared in these furnaces [2]. Another well-known achievement is the technology of semi-continuous casting of ingots with a smooth surface, which is achieved by electromagnetic wringing of the melt from the walls of the mold [3]. Also noteworthy is the use of solenoid pumps for low controlled electromagnetic pressure casting in the Coswoth Process [4]. It is obvious that by now the potential possibilities of using magnetohydrodynamics in foundry and metallurgy are far from being exhausted. Further progress is due not only to new ideas on the use of electromagnetic factors in technology, but also to achievements in materials

science, electrical engineering and theory.

Purpose of the work. The purpose of this work is to present new technologies for casting, preparation and refining of aluminum alloys developed at the Physico-technological Institute of Metals and Alloys of the NAS of Ukraine using a magnetodynamic installation [5] and an electromagnetic stirrer for pulsating effect on a metal melt [6, 7].

Magnetodynamic unit. The magnetodynamic unit is a mixer-doser. It performs the functions of storing molten metal at a given temperature and casting it into casting molds and other metal receivers. Since the unit combines the functions of an electromagnetic pump and an induction channel furnace, it is possible to melt metal in it after filling the channel and sump with liquid metal. However, it is not designed to function as a melting furnace in a production environment, due to the fact that its optimal operating power is only 20-30 kW. At the same time, the melting function can be used when alloying components are introduced into the melt, i. e. in the case of the preparation of special high-quality alloys in the amount of up to 600 kg. In production conditions, this is also acceptable, but only in critical situations. A number of modifications of units with a useful capacity of 160 to 600 kg of aluminum alloy have been developed. In addition to heating the metal and its electromagnetic casting, the unit is able to provide a variety of options for forced convection of the melt in the volume of the liquid metal bath. This factor is very effective in the process of preparation, refining and modification of the resulting aluminum alloy.

Casting under low electromagnetic pressure. Electromagnetic forces have been used not only for the traditional dosing of melt by open jet into molds, but also in the technological scheme of low-pressure casting [8]. On the basis of magnetodynamic installations, two variants of electromagnetic pressure casting (EMPC) have been developed and successfully introduced into production. In the technological scheme of the first variant (Fig. 1), a magnetodynamic unit MDN-6A is used, the feed pipe of which is connected to the cavity of the casting mold. The main difference from the traditional low-pressure casting method is that instead of the pressure of the compressible gas medium (working body of the process), the pressure created by the electromagnetic force (electromagnetic pressure) is used. As a result, the following advantages are achieved: there is no need to seal the crucible with liquid metal to create pressure; porous refractory materials can be used for the manufacture of metal pipelines instead of cast iron, since there are no problems associated with gas seepage through the pores; for melt heating, pressure creation and process control, one type of energy is used — electrical; iron is not added to the melt because it is possible not to use iron-containing parts in contact with the melt; the accuracy of the preset filling mode of the molds is increased, since the electrical processes are practically inertia-free compared to pneumatic ones. The described device is inferior in developed pressure to gas pressure — 0.25 MPa versus 0.6 MPa, but it is technically possible to create an electromagnetic pressure that

exceeds the applied gas pressure. At the same time, it should be noted that the limit of the applied gas pressure is due to safety requirements, while there are no such restrictions for electromagnetic pressure. The described technology was introduced into production to produce castings of parts for the diesel engine of an infantry fighting vehicle at a diesel-building plant in the city of Tokmak, Zaporizhzhia region.

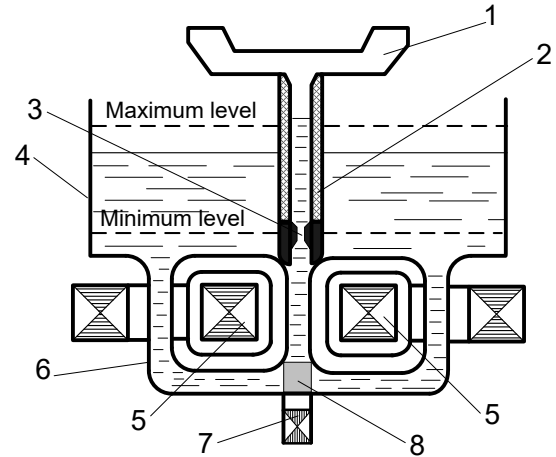


Fig. 1. Diagram of the electromagnetic pressure casting unit: 1 — mold cavity; 2 — metal wire; 3 — throttling constriction at the inlet to the metal pipeline; 4 — crucible; 5 — inductors; 6 — induction channel; 7 — electromagnet; 8 — electromagnetic pressure generation zone

The development of the EMPC method was the casting process, which rationally combines the principles of casting under low electromagnetic pressure and the dispersion of the gating and feeding system [9-12].

The pouring device is a two-chamber unit of a new type, created on the basis of elements of two magnetodynamic installations (Fig. 2). Mold 1 is installed on the gating plate 3, which has gating channels 4 with a diameter of 5-10 mm, located in the zones, the supply of melt to which provides the most rational filling and feeding of the casting. The plate 3 is located on the gating chamber 5 and the melt 8 is always in contact with it. Electromagnetic pressure is generated in the working area 6 and delivers the melt 8 from the metal receiver 7 to the pouring chamber 5 and then through the gating holes 4 to the mold cavity 1. After the casting has solidified, the electromagnetic pressure is reduced to a value at which the melt is set at the level of the sprues 4 in the plate 3. The mold is lifted along with the casting, which is removed from it by pushers.

Described casting method has all the advantages of low electromagnetic pressure casting and additionally optimizes the filling and feeding processes of castings. Due to this, when obtaining a certain range of castings, for example, castings such as frame, ring, lid, glass, a level of quality of cast products and a liquid metal utilization rate are achieved, which are unachievable in traditional low-pressure casting technology. The technology was successfully implemented at the Minsk Bearing Plant in relation to the casting of cages with a diameter of 200 to 500 mm for large-sized spherical bearings (Fig. 3). Other castings were also successfully produced in small batches.

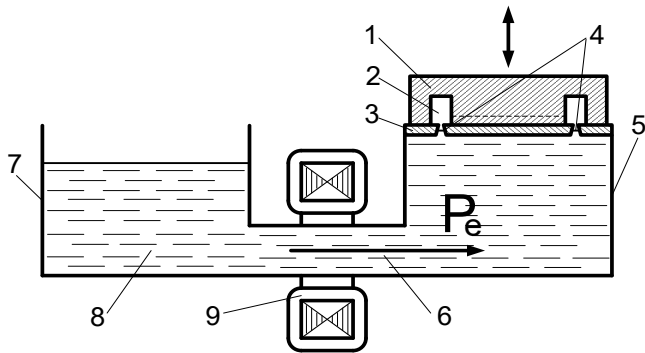


Fig. 2. Diagram of the electromagnetic pressure casting process using a dispersed gating and feeding system: 1 — casting mold; 2 — foundry handicap cavity; 3 — gating slab; 4 — gating channels; 5 — pouring chamber; 6 — electromagnetic pressure generation zone; 7 — metal receiver; 8 — liquid aluminum alloy; 9 — electromagnetic systems

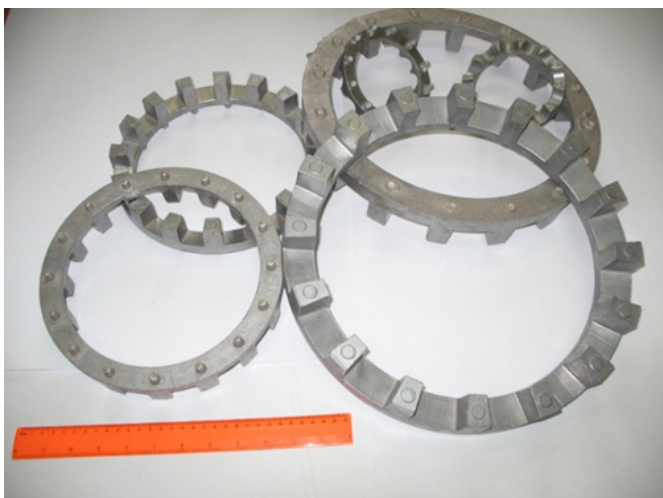


Fig. 3. Cast separator blanks for bearings

Electromagnetic stirrer for pulsating action on liquid metal. Another direction of the Physico-technological Institute of Metals and Alloys of the NAS of Ukraine in the field of magnetohydrodynamics is related to the development of a new type of electromagnetic stirrer (EMS) that creates a pulsating action on liquid metal [6, 7].

The work was carried out despite the fact that electromagnetic stirrers of the traveling magnetic field have been successfully used for more than 20 years for the melting and preparation of aluminum alloys. However, despite their undeniable advantages, they have limited application due to their high cost. Prices for the device are about 150 thousand dollars or more. In connection with this circumstance, the task was set to create a lateral EMS on reverberatory furnaces that is not inferior in efficiency to the known ones, but has a 3-4 times lower cost. To date, an experimental sample mounted on a crucible containing 300 kg of liquid aluminum alloy has been developed and tested. EMS is supposed to be used in reverberatory furnaces according to the scheme (Fig. 4).

The frequency of the magnetic field pulsations is equal to twice the frequency of the supply voltage, i.e. 100 Hz, since the positive and negative parts of the

sinusoidally varying voltage create force pulses of the same magnitude and direction in the liquid metal (Fig. 5). EMS has a repulsive effect on the melt, resulting in a horizontal flooded jet. According to conducted measurements, the melt velocity in the flow core is about 1 m/s, the length of the flow core is 1.2 m, and a range of at least 2 m.

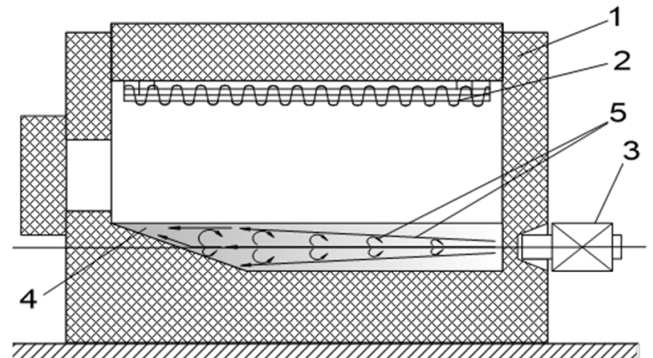


Fig. 4. Scheme of the effect of EMS on the melt in a reverberatory furnace: 1 — reverberatory furnace body; 2 — heating elements; 3 — EMS; 4 — liquid aluminum alloy; 5 — horizontal jet below the melt level created by a stirrer

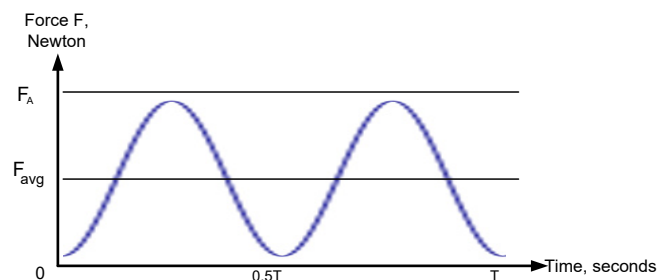


Fig. 5. A graph showing two periods of action of the electromagnetic force on a liquid metal in a melting furnace for one period T of change in supply voltage

Refining of liquid aluminum alloys under the influence of MHD factors. In a magnetodynamic unit, it is easy to implement a variety of melt circulation options and create MHD-influences on the elements that provide degassing and removal of non-metallic inclusions. In this case, to the tuyere through which argon and ceramic foam filter are blown. These capabilities have been used to improve the efficiency and economy of the molten metal refining process.

It is known [13, 14] that one of the most commonly used methods of removing hydrogen from a liquid aluminum alloy in industry is its purging with argon. To do this, a rotating rotor is used to disperse the argon bubbles and distribute them over the volume of the liquid metal bath. Using this technology, it is possible to obtain bubbles with a diameter of about 5 mm. Argon consumption is 20 dm³/min for a melt mass of 500 kg or 0.8 dm³/kg for the entire process of degassing this mass within 20 minutes. The disadvantage of this technology is that it fails to increase the degree of dispersion of bubbles, and the surface of the bath is highly turbulized, as a result of which the oxidation of the metal increases. In addition, since refining is carried out in a furnace and not in a doser, when pouring metal into a ladle before

pouring it into molds, a certain increase in the content of hydrogen and oxide inclusions occurs.

According to the diagram (Fig. 6), the purge and filtration processes are carried out simultaneously in the magnetodynamic unit. An electromagnetic force is generated in the work area, which can be given any direction depending on the task at hand. In this case, on the left mouth of the channel there is a special lance for blowing the melt with argon 9, on the right there is a ceramic foam filter 6, and on the central mouth there is a feed pipe 4. The electromagnetic systems of the unit 7 and 8 are switched to a mode that ensures circulation in the direction indicated by the arrows. The liquid metal enters through the right mouth into the ω -shaped channel through the filter and exits through the left mouth, on which the lance is located, which gives the flow a horizontal direction [15-17]. The argon bubbles are distributed by the flow throughout the volume of the bath. Obviously, the smaller the bubbles, the larger their total surface area, and, accordingly, the higher the efficiency of hydrogen removal. To assess the role of electromagnetic factors in the dispersion of bubbles, the blowdown results were compared with the unit's electromagnetic systems switched off and on. In the first case, bubbles with a diameter of up to 50 mm floated, despite the fact that the blowing was carried out through a porous material with pore sizes of 0.01-0.15 mm. The distribution of bubbles by size was determined according to a specially developed method. Studies have shown the following distribution: 5-2 mm — 10 %; 2-1 mm — 30 %; less than 1 mm — 60 %. In addition, the horizontal flow velocity was measured using a pitot tube. Experiments have shown that the most rational speed of the bottom flow is 0.2-0.3 m/s.

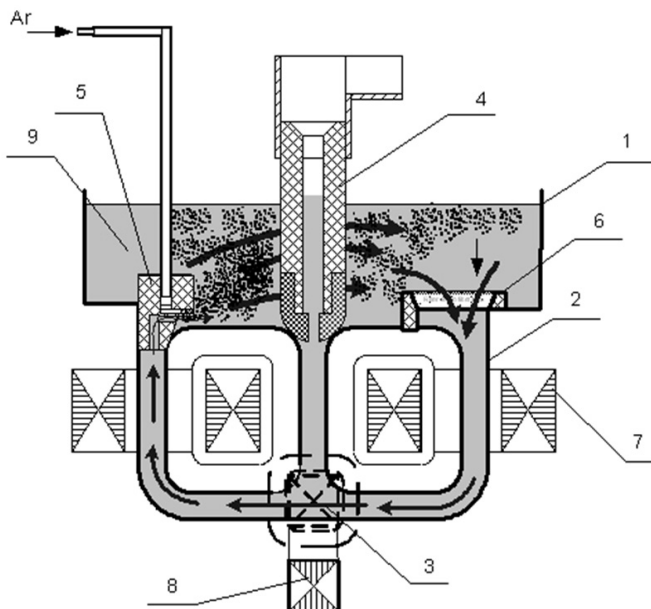


Fig. 6. Diagram of the process of refining aluminum alloys in a magnetodynamic unit before casting into casting molds: 1 — crucible; 2 — ω -shaped channel; 3 — electromagnetic pressure generation zone; 4 — feed pipe; 5 — tuyere; 6 — ceramic foam filter; 7 — inductors; 8 — electromagnet; 9 — liquid aluminum alloy

In industrial technologies for the removal of non-metallic inclusions by filtration, the melt passes through the filter only once. The peculiarity of the developed process is that the melt, after passing through the filter, is mixed with the melt in the crucible and then filtered again. With a capacity of 250 kg, about 3000 kg of melt passes through the filter in 20 minutes. To analyze the effectiveness of this filtration method, the following formula was derived:

$$k(t) = k_0 \exp\left\{-\frac{Q}{M}t\right\},$$

where t is the time, minutes; k_0 is the initial concentration of non-metallic inclusions, pieces/kg; $k(t)$ is the concentration of non-metallic inclusions at time t , pieces/kg; Q is the melt flow rate through the filter, kg/min; M is the mass of the melt to be refined, kg.

The derivation of the formula was carried out under the assumption that the number of particles retained per unit time, the throughput of the filter and the specified melt flow through the filter during filtration are constant. The calculation using the formula showed that 250 kg of melt in 20 minutes is purified from non-metallic inclusions by 96 %, which corresponds to the duration of melt blowing with argon, adopted in production. At the end of the purging, it is necessary to soak the melt for 20 minutes to remove very small bubbles that are formed by any blowing method and float very slowly according to Stokes' formula. At the same time, the filter is not removed and the melt continues to circulate through it, so the actual filtration process lasts 40 minutes.

Samples were cast from refined and modified metal, which were then examined in the laboratory of the Antonov aircraft plant [18]. The table shows the average values of tensile strength and elongation of factory and experimental samples. A 16% increase in strength and 3.5 times in elongation compared to the metal obtained by factory technology (table) is a consequence of effective refining under the influence of electromagnetic factors. An important role is also in the increase in efficiency of the modification by creating forced convection that encompasses the entire melt bath.

Таблиця 2

Comparison of mechanical properties of factory and experimental samples

Facility where the samples were obtained	Strength, σ_B , MPa	Relative extension, δ %
State Enterprise "Antonov"	218.4	4.0
PTIMA NAS of Ukraine	244.8	13.9

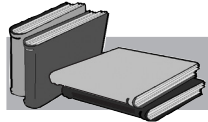
Conclusions

1. The replacement of gas pressure with electromagnetic pressure in low-pressure casting provides benefits related to improved casting quality and metal savings, especially in a process that combines casting under electromagnetic pressure with the principle of dispersion of the sprue system. This conclusion is confirmed by the implementation of developments at industrial enterprise.

2. Laboratory studies have shown that an

electromagnetic stirrer with pulsating action on liquid metal can become a competitive alternative to a stirrer with a traveling magnetic field.

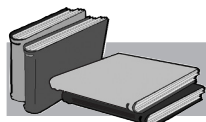
3. The use of electromagnetic forces in the complex refining of aluminum alloys by argon purge and filtration is an effective and promising direction. This conclusion is confirmed by the results of joint research with SE «Antonov».



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Технології лиття та приготування алюмінієвих сплавів за допомогою засобів магнітної гідродинаміки

У статті представлено деякі розробки Фізико-технологічного інституту металів та сплавів Національної академії наук України, пов'язані з технологіями алюмінієвих сплавів, які успішно пройшли випробування в лабораторних та виробничих умовах.

Прикладна магнітна гідродинаміка в металургії та ливарному виробництві має технологічні потенціали, які або недосяжні, або важко реалізуються при використанні інших фізичних принципів. Прогрес у цій галузі був повільним у зв'язку з тим, що в металургійних пристроях, що використовуються в металургії та ливарному виробництві, неминучі великі немагнітні зазори. Однак у зв'язку з удосконаленням вогнетривких і електротехнічних матеріалів використання магнітної гідродинаміки в металургійному виробництві світу постійно зростає. Описані наступні технологічні розробки.

Електромагнітне лиття під тиском за схемою лиття під низьким тиском, при якій тиск стисненого газу замінюється електромагнітною дією. В результаті відпадає необхідність герметизації тигля рідким металом, і підвищується точність заданого режиму заповнення форми.

Електромагнітне лиття під тиском з розосередженою ливниково-живлючої системою. При такому способі лиття досягається високий коефіцієнт використання рідкого металу, що недосяжно при інших способах лиття, і забезпечує відсутність усадочних дефектів.

Електромагнітний перемішувач для пульсуючого впливу на рідкий метал, який є альтернативою електромагнітному перемішувачу магнітного поля, що біжить.

Комплексне рафінування алюмінієвих сплавів, що включає фільтрування розплаву через пінокерамічний фільтр і його продування аргонном. Підвищений коефіцієнт корисної дії (ККД) досягається застосуванням електромагнітних факторів.

Ключові слова

Алюмінієві сплави, лиття, електромагнітний тиск, електромагнітний перемішувач, неметалеві включення, рафінування, електромагнітні фактори, пінокерамічний фільтр, фільтрування.