# COMBINED ROLLING-EXTRUSION OF RODS FROM ALLOY Al-0.5REM USING BILLET AFTER ELECTROMAGNETIC MOLD

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## ABSTRACT

*The article presents experimental data for obtaining round rods from an Al alloy containing 0.5 % rare earth metals (REM) using combined rolling-extrusion (CRE) from a round billet having Ø 12 mm, obtained in an electromagnetic mold (EMM). The variable parameters were the billet temperature, the degree of deformation, and the deformation rate. With the help of tensometric equipment, experimental data were obtained on the forces acting on the rolls and the die of the unit CRE-200 for combined processing in the process of producing rods with a diameter of 5 and 9 mm. An assessment of the dependence of the mechanical properties of rods on variable factors has been carried out. The highest strength properties are exhibited by a rod obtained by the mode at a temperature 480ºC and a strain rate 0.74 $s^{-1}$. During increasing of the rate of deformation, the plastic properties of the rods increase. The tensile strength of rods obtained by the EMM+CRE method averages 120 - 135 MPa. The plasticity of the deformed products in all modes is at a high level (A = 15 - 25 %), which allows further processing with a minimum number of intermediate annealings. The research was supported by a grant from the Russian Science Foundation No 23-29-00028, https://rscf.ru/project/23-29-00028/.*

Keywords: *aluminum, rare-earth metals, electromagnetic mold, combined rolling-extrusion, mechanical properties, electrical resistivity.*

## INTRODUCTION

One of the actual topics for the development of deep processing of aluminum is the production of longish deformed round rods of small cross-section, wire rod and wire from aluminum and its alloys [1, 2]. Aluminum alloys with the addition of elements such as Ce and La (REM) are often used [3 - 10] for electrical products. Traditional technologies for their production by extrusion cast billets and subsequent drawing are increasingly being replaced by continuous extrusion methods (Conform, CRE) and combined processing (Castex, combined casting with rolling-extrusion, ingotless rolling-extrusion, casting-rolling) [11, 12]. The development of one of these scientific areas related to the creation of technologies for producing wire for electrical purposes from aluminum alloys of various alloying systems by combined processing methods is being carried out by scientists from Siberian Federal University (SFU). They implemented new devices and methods of combined processing for such products, while the laboriousness and costs of energy for manufacture have several times reducing [13].

Obtaining of deformed round longish rods products of small cross-section by classical technologies leads to a high price of these semi-finished products, due to its high laboriousness of production and high energy costs. The authors implemented a technology for producing electrical wire from alloys of the Al-Ce-La system. The technology including a cast round billet from electromagnetic mold (EMM) [14 - 16] and its consistent processing with using combined rolling-extrusion (EMM+CRE) [17, 18].

The EMM casting technology allow obtaining aluminum ingots of various shapes: round solid and hollow ingots of various sizes, as well as flat ingots.

The EMM is designed for the industrial production of ingots of large diameters (80 mm - 500 mm). The use of EMM to obtain ingots of small cross-section (diameter up to 25 mm) requires a change design for the mold, taking into account the features that appear in connection with this.

When casting ingots of small cross-section in EMM, the dimensions of the ingot are commensurate with the metal jet supplied from the dispensing device. Therefore, a pronounced meniscus region, as in the case of casting large ingots, is not observed. In this regard, there is no need for such an element of the mold as an electromagnetic screen. The liquid metal above the inductor is kept from spreading by the elements of the casting equipment.

The aim of the work is investigation possibility of obtaining rods from the Al-0.5%REM alloy and investigation the effect of different production modes on the properties of obtained deformed round rods.

## RESEARCH METHODOLOGY

For research, we used cast billet Ø 12 mm from an Al-0.5 %REM alloy after casting into an electromagnetic mold [19].

The design of an electromagnetic mold used in the metallurgical industry for casting ingots from aluminum alloys is shown in Fig. 1. An electromagnetic mold (EMM) consists of three main elements: an inductor 1, an electromagnetic screen 2 and an annular cooler 3. To create a uniform magnetic field around the perimeter of the liquid zone and reduce the supply voltage in the EMM, mainly single-turn inductors and screens made of copper rectangular tube or copper bus.

The main EMM parameters that determine the characteristics of the casting process and the structure of the resulting ingots are: the air gap between the inductor, the screen and the ingot; the ratio of the height of the inductor to its diameter and the location of the cooling belt relative to the inductor 1.

The principle of operation of the EMM is as follows: liquid metal is fed from the mixer through the casting equipment into the EMM, and falls into a pulsating electromagnetic field created by the inductor 1. Under the action of electromagnetic forces, the liquid metal, which is under some hydrostatic pressure, is compressed in the radial direction and acquires the shape of an inductor in cross section.

The casting process in EMM is reduced to the

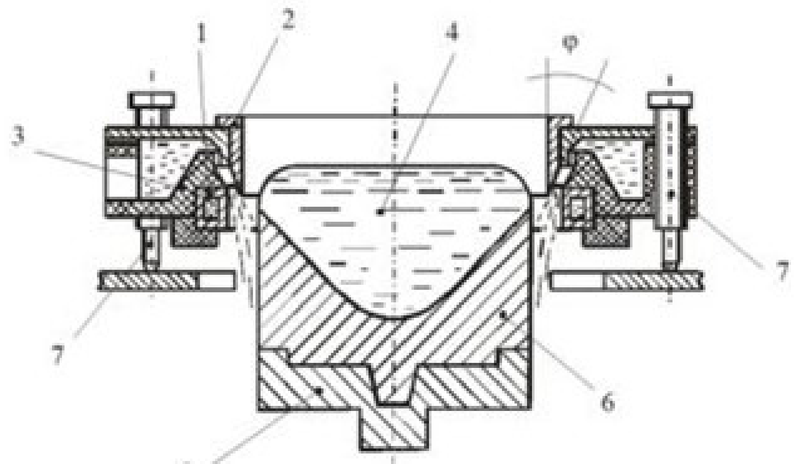


Fig. 1. Scheme of an electromagnetic crystallizer: 1 - inductor, 2 - electromagnetic shield, 3 - ring cooler, 4 - liquid phase, 5 - conductive base, 6 - solid phase, 7 - control supports.

formation of liquid phase 4 having the shape of an ingot in cross section. The liquid metal mass is kept from spreading by an electromagnetic field, the intensity of which is controlled by shield 2. The electromagnetic shield is mounted on control supports 7 in such a way that it can be moved in the vertical direction in order to select the conditions of the casting process. A column of liquid metal formed by a magnetic field rests on a conductive base 5, which is a metal seed, which passes into a crystallizing ingot during the casting process.

To ensure a stable casting process and obtain an ingot of a given geometry, it is necessary the distribution of electromagnetic forces along the liquid height of the zone approach the linear distribution of hydrostatic pressure.

One or more cooling belts located at different vertical levels are used to cool the ingot. The upper belt ensures the initial formation of a crust and complete solidification of the ingot. The lower belt enhances the cooling of the ingot. The amount of coolant depends on the alloy, size and speed of drawing the ingot. Under the action of cooling water entering the side surface of the ingot, the liquid metal mass continuously solidifies turning into an ingot 6, and is taken down. The supply of coolant to the surface of the mucus can be carried out at an acute angle or at an angle close to a right one.

The interface between the solid and liquid regions forms a crystallization front. The crystallization front at the periphery of the ingot is at some distance from the cooling belt. To reduce energy costs and a stable casting process, the boundary of the liquid zone should be in the zone of the highest magnetic field intensity, i.e. approximately at the level of the midline of the inductor.

The chemical composition of the presented Al-Ce alloy is given in Table 1.

To test the studied deformation modes, experimental studies fulfilled on the unit CRE-200 (Fig. 2), manufactured on the basis of a DUO 200 rolling mill according to a previously developed method [11, 20]. Using the same technique, studies were previously carried out to obtain the same alloy using the CRE and CCRE methods [21]. The billet heating temperature was 550°C, the tool was heated up to 100°C. Roll speeds were 4 and 8 rpm. The diameter of the obtained rods was 9 and 5 mm. Technological modes of obtaining rods are presented in Table 2.

Table 1. The chemical composition of the presented alloy

| Alloy | Content, % | | | | | |
|---|---|---|---|---|---|---|
| | Al | REM concentration mass. % | Ni | Fe | B | Ti |
| Al-0.5%REM | balance | 0.5 | 0.2 | 0.15 | 0.001 | 0.001 |

Table 2. Technological regimes of the EMM+CRE modes for the investigated alloy.

| Parameters | EMM+CRE | | | |
|---|---|---|---|---|
| | *T* = 480 ºC | | *T* = 550 ºC | |
| | Rod diameter, mm | | | |
| Strain rate $\xi = 0.74$ s$^{-1}$ ($n = 4$ rpm) | 9 | 5 | 9 | 5 |
| Strain rate $\xi = 1.49$ s$^{-1}$ ($n = 8$ rpm) | 9 | 5 | 9 | 5 |

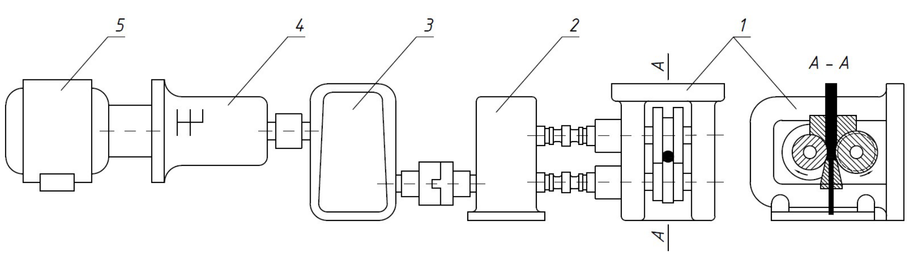


Fig. 2. Unit CRE-200 for combined processing of billet after EMM: 1- working mill, 2 - gear stand, 3 - reducer, 4 - gearbox, 5 – engine.

Mechanical properties were determined on equipment LFM 400 kN and LFM 20 kN in accordance with GOST 1497-84. Electrical resistivity ρ was measured on a "Vitok" ohmmeter according to GOST 7229-76.

The force acting on the instrument (rolls and die) was recorded by tensometric equipment, using a ring mesdoze. As the main recording equipment, a ZET 017-T8 universal strain gauge station with force sensors with a maximum allowable force value of 500 kN and 1 MN was used.

## RESULTS AND DISCUSSION

As can be seen from the experimental data shown in Table 3, the forces on the rolls and on the die higher with an increase in the elongation ratio, which is the result the volume of the deformed metal increases with an increase of deformation degree, and the space between the rolls and the extruding die is filled with metal.

Tensile test samples were cut out of the extruded rods and their tensile strength $R_m$ and relative elongation $A$ were evaluated from the test results.

The results of mechanical tests are shown in Table 4.

Table 4 shows that the change in technological parameters affected the mechanical properties. Plasticity of the round rods is higher with increasing in deformation rate. Plastic characteristics almost do not change with an increase in the temperature of the billet. The tensile strength of products obtained by the EMM+CRE method averages 120 - 135 MPa, and the relative elongation is 15 - 25 %.

Data on the measurement of electrical resistance are listed in Table 5.

Table 5 shows that the heating temperature of the

Table 3. Data for experimental studies of the energy-power parameters of the experimental Al-0.5%REM alloy using the EMM+CRE method.

| Parameters | | *T* = 480 ºC | | *T* = 550 ºC | |
|---|---|---|---|---|---|
| | | Ø 9 mm | Ø 5 mm | Ø 9 mm | Ø 5 mm |
| Strain rate ξ = 0.74 $s^{-1}$ (*n* = 4 rpm) | $P_{roll}$, kN | 192 | 269 | 163 | 204 |
| | $P_{die}$, kN | 151 | 172 | 131 | 133 |
| Strain rate ξ = 1.49 $s^{-1}$ (*n* = 8 rpm) | $P_{roll}$, kN | 168 | 241 | 146 | 194 |
| | $P_{die}$, kN | 123 | 151 | 98 | 126 |

Table 4. Mechanical properties of rods obtained by the EMM+CRE method.

| Parameters | | *T* = 480 ºC | | *T* = 550 ºC | |
|---|---|---|---|---|---|
| | | Ø 9 mm | Ø 5 mm | Ø 9 mm | Ø 5 mm |
| Strain rate ξ = 0.74 $s^{-1}$ (*n* = 4 rpm) | $R_m$, MPa | 126.40 | 139.68 | 128.9 | 137.35 |
| | *A*, % | 18.07 | 15.47 | 23.7 | 14.32 |
| Strain rate ξ = 1.49 $s^{-1}$ (*n* = 8 rpm) | $R_m$, MPa | 123.41 | 128.49 | 126.58 | 123.33 |
| | *A*, % | 26.33 | 25.87 | 24.7 | 25.31 |

Table 5. Measuring results of the electrical resistance of rods made of Al-0.5%REM alloy obtained by the EMM+CRE method.

| Parameters | | EMM+CRE | | | |
|---|---|---|---|---|---|
| | | *T* = 480 ºC | | *T* = 550 ºC | |
| | | Rod diameter, mm | | | |
| | | 9 | 5 | 9 | 5 |
| ρ, Ohm·$mm^2$/m | (*n* = 4 rpm) | 0.0282 | 0.0298 | 0.0295 | 0.0301 |
| | (*n* = 8 rpm) | 0.0271 | 0.0290 | 0.0290 | 0.0286 |

billet affects the electrical resistance insignificantly for 5 mm rod modes. Comparing the modes on a 9 mm rod, for the EMM+CRE method the electrical resistance increases with increasing temperature. Presented data show that with an increase in the strain rate, the electrical resistance decreases.

## CONCLUSIONS

When performing this work, conclusions were drawn and the main results were presented.

• Experimental investigations on the implementation of the EMM+CRE process on electrotechnical alloy of the Al-0.5%REM system from a billet obtained by EMM casting, while varying the processing temperature, speed and degree of deformation.

• An analysis the parameters of power of the EMM+CRE process was carried out. The forces on the rolls do not exceed 269 kN for the EMM+CRE process at a roll speed of 4 rpm and 241 kN at 8 rpm. The forces acting on the extruding die do not exceed 172 kN at a roll speed of 4 rpm and 151 kN at 8 rpm.

• The electrical resistance of round rods after EMM+CRE methods investigated. For almost all rods, the electrical resistance increased uniformly with an increasing the deformation degree.

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