# ELECTRON-BEAM REMELTING OF Ni-Cr-Al-Y ALLOYS FOR MANUFACTURING OF CATHODES FOR ION-PLASMA COATING

Prof., Dr. Hrechaniuk M.[2], Ph. Dr. Khomenko O.[1],. Prof., Dr. Sc. Bagliuk G.[1], Eng. Smashniuk Y. [2], Eng. Klochykhyn V. [3]

[1] Institute for Problems of Materials Science, NAS of Ukraine, Kyiv, Ukraine
[2] Research Association «ELTEHMASH», Vinnitsa, Ukraine
[3]Joint-stock company «Motor –Sich», Zaporozhye, Ukraine

E-mail: gbag@ukr.net

***Abstract:*** *An experimental electron-beam technology for obtaining tube billets from NiCrAlY alloys used as cathodes for the deposition of heat-resistant coatings by the ion-plasma method has been developed. It is established that coatings applied to gas turbine blades of aircraft engines using cathodes of electron beam melting meet the requirements of Motor-Sich JSC TU for this type of products.*

***Keywords:*** *ELECTRON-BEAM MELTING, HEAT-RESISTANT ALLOYS, COATINGS ON GAS TURBINE BLADES, ION-PLASMA COATING.*

## *1. Introduction*

NiCrAlY materials are used to protect high-temperature nickel-based heat-resistant alloys from high-temperature oxidation, in particular, they are widely used as an internal bonding metal layer in thermal barrier coatings on gas turbine engine (GTE) blades, performing not only protective functions, but also reducing the difference in coefficient of thermal expansion between base and ceramic outer layer. Rigid conditions for the operation of gas turbine blades, associated with the multiple change of the thermal regime under the influence of gas streams saturated with combustion products of the fuel, give rise to special requirements for the quality of coatings on the base material. The search for optimal technologies for the formation of a qualitative layer applied to the blade material, begun as early as the late 1980s. last century, showed the high efficiency of the ion-plasma method with the use of cathode-cast tube castings made of high-purity NiCrAlY alloys [VIAM RF, is available by https://viam.ru/review/2725].

In most cases cast billets are subjected to rolling, drawing, mechanical and other types of processing for the subsequent manufacture of tubular products. Naturally, the use of multiple technological redistribution leads to a significant increase in the cost of products, and therefore the development of technologies that allow to obtain blanks with subsequent minimal mechanical, thermal and other treatments remains the main problem of their production. System studies on the development of technologies for the production of tube billets from copper, zirconium, titanium and other alloys are held at the Paton Institute of Electric Welding. NAS of Ukraine, Physical and Technological Institute of Metals and Alloys, International Campain "ANTARES", etc. [1-3].

A promising direction in the development of this technology is the use of electron beam melting (EBM), widely used to produce ingots (slabs) of metals and high purity alloys [4]. However, obtaining high-quality pipe billets from heat-resistant nickel-base alloys is a rather complicated technical problem due to the substantial difference in the physico-chemical characteristics of the alloy components and technological difficulties in obtaining hollow articles from these alloys [5, 6].

Therefore, at the initial stage of the introduction of ion-plasma equipment in 1981 (the MAP-1 unit with a vacuum-arc evaporation method - the development of the Institute of Aviation Materials (Russian Federation), ingots of the appropriate alloys were used for the production of cathodes, which were subjected to drilling and subsequent machining of the inner and outer parts hollow billets to the required geometric dimensions.

This technology is extremely time-consuming and costly, especially in the manufacture of cathodes made from alloys МЗП 6 and СДП 2 (Ni-basis; 18-24 % Cr , 10-14% Al; 0.4-1% Y; % by weight), with increased hardness and brittlene ss [7, 8]. About 50% of the metal goes to waste, re-melted. To optimize the technological process, the Institute of Aviation Materials proposed a method for producing cast pipe products from nickel and / or cobalt-based alloys, including melting the charge materials and casting the melt in a vacuum into a preheated casting mold in the form of a ceramic shell with a sprue-feeding system or a mold of casting graphite with a casting bowl (fig. 1), and subsequent machining of the workpiece [9].

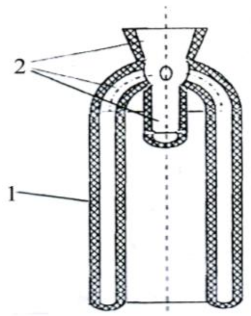



***Fig. 1.*** *The design of the ceramic shell mold for casting of tube billets: 1- tubular shell part; 2 - gating system with molding cup [9]*

In the technological process, a two-chamber induction furnace with a melting and casting chamber and a charging chamber is used, which are separated by a vacuum gate providing a vacuum of 0,6 Pa in the melting chamber. Form before pouring it is necessary to warm up to a temperature of 950-1000 $^{o}$C. The casting in the mold is carried out at a melt temperature of 1420-1600 °C at a speed of 20-50 kg / min. Cooling of the casting to a temperature equal to or less than ½ the melting point of the alloy is carried out in a vacuum, the subsequent - in the air. It should be noted that the use of vacuum induction melting in the manufacture of blanks has a number of significant drawbacks.

Among them:

- degree of refining of liquid metal is lower in comparison with electron-beam melting;
- need to produce single shell molds, as well as sprue-feeding systems and pouring bowls;
- need to heat and maintain the required temperature of the ceramic or graphite shell shape;
- interaction of molten metal with a ceramic or graphite material, leading to contamination of the casting;- the difficulty of providing and maintaining high melt overheating;- the difficulty of ensuring a high rate of pouring liquid metal.

Reducing the casting speed leads to the formation of foundry defects of the "non-braze" type, due to the high rate of crystallization on the walls of the metal jet shape, the oxidation of its surface, which does not allow obtaining a reliable metallurgical connection between the primary casting and the crystallized icicle of the primary metal on the inner surface of the mold.

These shortcomings are not inherent in the EBM method, which, as is known, is the most promising method of metal refining and degassing in vacuum [1, 4]. Therefore, in Research Association "ELTEHMASH" (Vinnitsa, Ukraine) together with the Frantsevich

Institute for Problems of Materials Science of National Academy of Sciences of Ukraine mastered the experimental production of tubular cathodes for ion-plasma spraying of NiAlCrY alloy coatings. An important role in the development of the technology of manufacturing tubular type cathodes was played by the urgent need in Ukraine for import substitution of similar products from the Russian Federation.

## *2. Materials and experimental procedure*

The melting of tubular billets from МЗП 6 and МЗП 7 alloys was carried out in 2 stages on an electron beam installation L-4, developed and manufactured by SA "ELTEHMASH" [10]. The unit is equipped with 4 gas-discharge electron guns with a cold cathode of 100 kV each. In the first stage, according to [8], ingots of alloys (table 1) were prepared in the form of cylindrical billets with a diameter of 100 mm and a length of 250 ... 300 mm.

Table 1

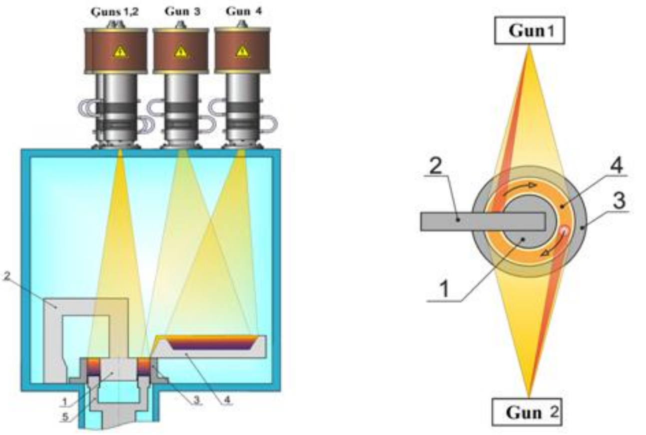
Chemical composition of ingots after electron-beam remelting

| Alloys | Content of elements, % (wt.) | | | |
|---|---|---|---|---|
| | Cr | Al | Y | Ni |
| МЗП 6 | 18...24 | 11...14 | 0,4...1 | basis |
| МЗП 7 | 18....24 | 4...6 | 0,4...1 | basis |

In the working chamber of the installation L-4, a crucible was installed to melt the tube-type blanks (Fig. 2). The necessary number of ingots of a given chemical composition was placed in the chamber of the horizontal feeder of the charge into the melting zone (not shown in Fig. 2). Before the start of the process (step 2), the water-cooled rod with seed was transferred to a copper water-cooled cylindrical mold at a height of 10 ... 15 mm from its upper edge. In this case, the rod was fixed in such a way that there was no gap between it and the crystallizer, as well as a copper water-cooled cylindrical mandrel arranged coaxially with the crystallizer and fixed by means of a special traverse through which water is circulated.

Otherwise, it is possible to shed liquid metal, which makes it impossible to carry out the technological process. The diameter of the mandrel in the lower part is slightly less than in the upper part, which excludes jamming and deformation of the mandrel walls when it is removed from the cast preform. This ensures the production of cylindrical metal tubular castings of different chemical composition, since during crystallization of the alloy, subsequent cooling of the casting and its thermal shrinkage, its jamming and deformation of the mandrel walls are excluded. The preforms of the nickel alloy are alloyed into an intermediate vessel - the liquid metal is gradually merged through the spout of the intermediate capacity into the crystallizer. The height of the filling is 9 ... 11 mm. In connection with the presence of a traverse, which serves to fix the copper mandrel and the supply of cooling water to it to prevent its destruction under the action of an electron beam, heating of the metal surface in the crystallizer is carried out by means of two electron guns **1, 2** (**Fig. 1, b**). The beams of the guns are scanned according to the program (scanning frequency 50 Hz, current for each gun 0.8 ... 1 A), forming two heating zones in the form of osculating semirings (**Fig. 2, b**). When the power control of electron beam heaters is separately controlled, a significant temperature gradient can occur in the heating zones, which under certain conditions leads to cracking and jamming of the casting in the crystallizer.

Therefore, during the formation of the pipe blank, synchronous regulation of the gun power is performed to maintain the material surface in the crystallizer in a liquid state at approximately the same temperature. After holding the first portion of the filled metal in the crystallizer for 6-8 seconds, the workpiece is pulled at a speed of 1 mm / s, while simultaneously filling the next portion of the metal and controlling its height by the sensor to 9...11 mm, the total yield of the crystallized part of the casting from the crystallizer.




*a* *b*

***Fig.2.*** *Scheme of the crystallizer design for the manufacturing of tube billets by ELF (a) method and the heating scheme of the melt bath by two electron guns with sweeps of rays in the form of semirings (b - top view): 1 - water cooled mandrel, 2 - traverse; 3 - water-cooled crucible; 4 - intermediate capacity; 5 - water-cooled rod with seeding*

## *3. The results and discussion*

Thus, the tubular blank with outer and inner diameters outside 198 mm, and inside 114 mm and length L = 358...360 mm is formed during 240...250 min. It is completely drawn out of the crystallizer and cooled in a vacuum to a temperature of 300 °C. After cooling to room temperature, the workpiece is machined to diameters outside 180 mm and inside 140 mm and L = 348...352 mm. The chips after chemical cleaning, drying and compacting are reused as a starting material for melting the tube-type blanks. The appearance of the billet after melting and machining is shown in fig. 3.

*a* *b*

***Fig. 3.*** *General view of the tube billet produced by electron-beam remelting (a) and those after machining (b)*

The chemical composition of pipe billets fully meets the specifications for cathodes according to TU U 27.4-200113410.002-2001 [8] and TU U 1-92-113-87 [11]. Visual inspection and control of geometric dimensions confirms the compliance of cathodes with the requirements of the drawing in accordance with TU 6823-21-38 (JSC "Motor Sich", Ukraine).The phase composition of the materials of the tube billets was determined on a DRON-4 diffractometer by shooting in $K_{Cu}$ filtered radiation in the range of angles 2θ = 20-100 deg with silicon as a reference. Recording of diffractograms was carried out with scanning in steps of 0.05 deg. According to the analysis results for the cast material from the МЗП 7 alloy, the formation of a solid solution based on nickel is characteristic. The phase composition of the МЗП 6 alloy is more complicated. The main constituents of the material are the heat-resistant β (NiAl) and γ' ($Ni_3Al$) phases, as well as the α-solid solution based on chromium (fig. 4). A typical microstructure of cast billets from МЗП 7 (a) and МЗП 6 (b) alloys is shown in fig. 5.

Portion filling and rapid crystallization of the melt lead to the formation of a dispersed structure. At approximately the same content of Ni, Cr, and Y in alloys, the dispersion of structural elements increases with increasing aluminum content from 4-6 % by weight (МЗП 7) to 10-14 % by weight (МЗП 6), which contributes to the formation of new phases. It should be noted that МЗП 7 alloy is characterized by a smooth transition from a fine-grained structure in the zones adjacent to the cooled surfaces of the mandrel and crystallizer to a coarse-grained structure formed in the central regions of the casting. For casts of alloy МЗП 6, this phenomenon is less pronounced.

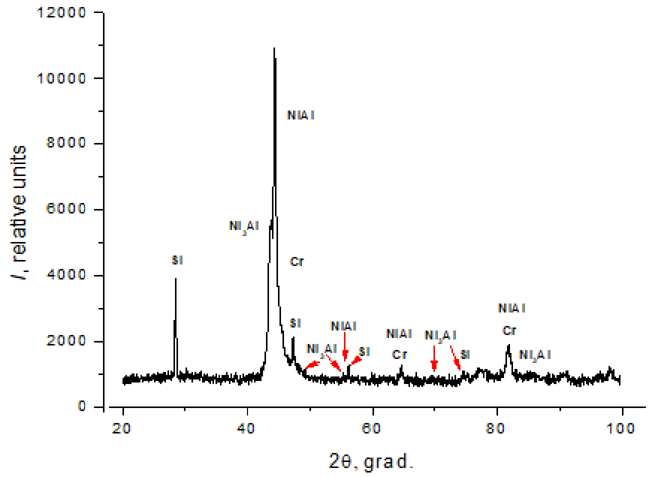
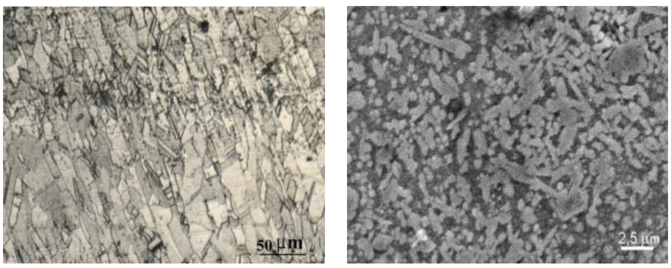



*Fig. 4. Phase composition of the alloy tube billet from МЗП 6*




*a* *b*

***Fig. 5.** Microstructure of cast billets from alloys МЗП 7 (a) and МЗП 6 (b)*

Experimental work was carried out to evaluate the possibility of using experimental cathodes in Joint-stock company “Motor-Sich” joint-stock company. In comparative studies on the application of coatings on the surface of the blades, two castings of the production of the Research Association "ELTEHMASH" from the МЗП-6 alloy and one serial sample of the same composition from the СДП 2 alloy (batch production RF) were used. Coating was carried out on the АПН-250. The installation with an experimental cathode worked stably, all technological parameters corresponded to the parameters of the serial technology. On the coated blades, a roughness control was performed, which showed that the roughness was $R_a$ = 1.63 ... 2.88 per shear, and $R_a$ = 0.67 ... 3.2 - on the flow surfaces of the shelves. ЛЮМ-10В control of blades with a coating showed that they meet the requirements of TU-222-TU-20 of Joint-stock company “Motor-Sich”. The conducted studies confirmed that the structure and thickness of the test coatings correspond to coatings obtained using serial cathodes.

## *Conclusions*

1) An experimental electron-beam technology for the production of tubular cathodes for ion-plasma coatings has been developed.

2) The performance characteristics of coatings on blades obtained by spraying experimental cathodes correspond to the characteristics of standard coatings.

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