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NICKEL SCRAP RECYCLING BY ELECTRON BEAM MELTING METHOD

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ABSTRACT

Experimental-production melting of low-grade nickel scrap was conducted to obtain nickel ingots of not lower than NP2 grade, which are furtheron used to produce semi-finished products in the form of hot- and cold-formed seamless pipes, including capillary, thin-walled and particularly thick-walled pipes, rings, squares, hexagons, etc. It is shown that during electron beam melting a significant removal of impurity elements from the nickel scrap occurred, and metal quality began to correspond to nickel grade not lower than NP2. In order to further study the produced ingot quality, comprehensive research work was performed on manufacturing semi-finished products in the form of elongated soft rods of 40 mm diameter and wire of 3 mm diameter. It was determined that mechanical properties of semi-finished products from EBM nickel fully meet the standard requirements. It is shown that electron beam melting is an efficient method of producing nickel ingots from secondary raw materials, as it allows ensuring a high level of the produced material quality, and the semi-finished product quality fully meets the standard requirements by chemical composition, structure and mechanical properties.

KEYWORDS: electron beam melting, electron beam unit, nickel, melting, ingot, scrap, refining

INTRODUCTION

Nickel belongs to the group of heavy nonferrous metals used both in alloyed steel production and in manufacturing high-tech products in the sphere of aircraft construction, medicine and electronics [1]. Wide application of nickel in different industries is due to its unique properties. Nickel addition to alloys increases their strength, wear resistance, corrosion resistance, heat- and electric conductivity, and improves their magnetic and catalytic properties.

In Ukraine proven reserves of nickel ore deposits are small or depleted, new deposits are insufficiently explored, but the need in such kinds of raw materials is due to increased demand and industrial progress [2]. Thus, nickel production in Ukraine has limited development and it largely depends on price situation in the world market.

Today, the proportion of secondary raw materials during nonferrous metal manufacture is continuously growing. Analysis of tendencies in production and consumption of products from nickel and alloys on its base shows that all the Ukrainian enterprises, operating in this market segment, more and more often use metal scrap as the starting raw material. In the long term it should become the main source of producing many nonferrous metals, in particular, nickel, and its efficient recycling will cover the deficit of balance between consumption and own production. Involvement of secondary raw materials into the metallurgical production cycle is of tremendous economic importance, as it allows rational use of non-renewable natural resources, reducing the technogenic load on the environment, producing metal by simpler and less costly methods.

Therefore, under the conditions of unpredictable changes in the world markets of metallurgical products, the manufacturers of structural elements from nickel and alloys on its base are faced with an acute issue of improvement of production efficiency and ensuring output of high-quality competitive products. Further increase of competitiveness of local products from nickel and alloys on its base due to an essential lowering of the material and energy costs for its production is a complex task. The urgency of solving it for Ukraine is determined both by the need of recycling low-grade local metal scrap from nickel, and by the wish to manufacture final products meeting the world standards, as today strict requirements are put forward in the world markets for the quality of products made from recycled raw materials. Therefore, one of the main stages of ensuring the final product quality is producing a high-quality ingot as the initial billet for further processing. Here, in order to ensure the required level of ingot quality, it is necessary to study in greater detail the influence of both the secondary raw material properties and of the technological parameters of conducting the process. Both the yield and the quality of the produced metal depend in many respects on a rational organization of this process. Increase of the quality and lowering of the ingot cost can be achieved due to a detailed study of the processes of crystallization and formation of casting defects. The processes of secondary nickel refining at electron beam melting (EBM), which are still insufficiently studied, have an important role here. This is particularly relevant in production of nickel ingots from low-quality scrap, where impurity content can reach high values.

Therefore, a promising route for development of enterprises using nickel in their manufacturing is creation and introduction of high-efficient technologies of producing cleaned nickel, based on secondary raw materials.

A promising direction of modern metallurgy is application of electron beam heat sources for melting, refining, surface treatment and other technological processes [3].

Investigations of the processes of nickel refining to remove impurities by electron beam melting were considered in works [4–7].

EBM is used to produce high-purity ingots of refractory and highly reactive metals and alloys. As to their quality, EBM ingots are superior to the initial material. At EBM of nickel effective removal of gases and other impurities takes place. High vacuum, drop transfer and overheating of the metal pool surface in electron beam melting create favourable conditions for practically complete removal of such impurities as As, Zn, Se, Cl, Fe, P, Mg, etc. [4].

Ingots of EBM nickel have high ductility and are easily deformed at room temperatures [7].

With the purpose of vacuum refining, EBM is performed in a copper water-cooled mould with a cold hearth by horizontal feeding of the material being remelted. Here, charge materials can have the form of ingots, lump charge, rods and various wastes, for instance pressed chips [3].

INVESTIGATION PROCEDURE

Experimental-production melts of low-grade nickel wastes were conducted in production facilities of SC “SPC “Titan” of the E.O. Paton Electric Welding Institute of the NAS of Ukraine” together with ”DZST” Ltd. Company, in order to produce nickel ingots of not lower than NP2 grade (not lower than 99.5 wt.% nickel content). These ingots are further on used to produce semi-finished products in the form of hot- and cold-rolled seamless pipes (capillary, thin-walled and particularly thick-walled), rings, squares, hexagons, etc.

Used as the initial charge was low-grade scrap with average nickel content of 98 wt.% (Figure 1), which was subjected to double EBR in electron beam unit UE-208M [8].

The technology of producing ingots in electron beam unit included the following: forming the consumable billet; preparation of the equipment and technological fixtures for melting; melting process and control of the produced ingot quality.

Figure 1. Low-grade nickel wastes

Low-grade nickel scrap was cleaned from surface contamination of different origin, compactly packed into a nonconsumable box and loaded into electron beam unit UE-208M (Figure 2).

The technology of cold-hearth EBM with portioned liquid metal feeding into a water-cooled mould (Figure 3) was used to produce ingots of 150 mm diameter (Figure 4).

The following technological parameters were monitored during melting: accelerating voltage of electron beam guns, beam currents, rate of initial charge feeding into the melting zone, speed of the ingot pulling from the mould, and cooling water temperature.

Numerical values of the technological parameters of melting, used at remelting the nickel scrap, are as follows:

Melting speed, kg/h. 50
Height of portions which are poured into the mould at a time, mm. 10
Power, kW
in the mould 25
in the cold hearth 100

Figure 2. Initial charge from low-grade nickel scrap

Figure 3. Process of electron beam remelting of nickel

Figure 4. EBR nickel ingot of 150 mm diameter

At the end of melting, the shrinkage cavity was removed by gradual lowering of the power of heating the ingot upper end face in the mould.

The side surface of the produced ingots after cooling in vacuum to a temperature below 200 °C is clean, and a higher concentration of impurity elements on the surface in the form of an oxidized or alpha layer is absent (Figure 4). The depth of corrugation-type surface defects is 1–3 mm, defects in the form of tears, cracks or discontinuities are absent.

Metal of the produced ingots was studied to assess the depth of refining of low-quality nickel scrap during EBM. Determination of chemical composition of samples taken by their length from the upper, middle and lower parts was conducted by the method of inductively couple plasma optical emission spectrometry (ICP-OES) in ICP-stpectrometer ICAP 6500 DUO. Results of analysis of the produced ingot metal showed that significant removal of impurity elements from nickel scrap occurred during EBM (Table 1), and the metal quality began corresponding to nickel grade not lower than NP2.

Comprehensive research work on manufacturing semi-finished products was conducted at DZST Ltd. for further study of the produced ingot quality. EBM nickel ingots of 150 mm diameter were used to produce soft rods of 40 mm diameter and 3 mm diameter wire (Figure 5).

Produced rods were subjected to heat treatment (HT) by the following mode: heating up to 800 °C temperature in vacuum; soaking for 0.5 h; cooling with the furnace. After HT the rods were machined to the required dimensions. Samples for macrostructural studies were taken from the produced rods. No cracks, delamination, voids, metallic or nonmetallic inclusions were detected in the macrostructure of the produced rods. The macrograin dimensions correspond to 3–4 grain size number to GOST 26492–85.

Mechanical properties of rod metal were determined at the temperature of 20 °C after the conducted heat treatment. Table 2 gives the mechanical properties of drawn soft rods of 40 mm diameter. As one can see from the Table, the mechanical property values of the produced samples fully meet the requirements of GOST 13083–77 [9], which is indicative of the high quality of the metal produced by the developed technology. These data lead to the conclusion that the mechanical properties of semi-finished products from EBM nickel fully meet the standard requirements.

Table 1. Element content in EBR nickel ingot of 150 mm diameter, wt.%

	Not more than								
Metal	As	Bi	C	Cd	Cu	Fe	Mg	Mn	P
After double EBR	0.0001	0.0001	0.015	0.0001	0.01	0.04	0.0012	0.0023	0.0001
Norm by DSTU GOST 492:2007	0.002	0.002	0.1	0.002	0.1	0.1	0.1	0.05	0.002

Table 1 (Cont.)

	Not more than							Not less than
Metal	Pb	S	Sb	Si	Sn	Zn	Co	Ni+Co
After double EBR	0.0001	0.0043	0.0003	0.006	0.0016	0.0001	0.021	99.90
Norm by DSTU GOST 492:2007	0.002	0.005	0.002	0.15	0.002	0.007	0.2	99.5

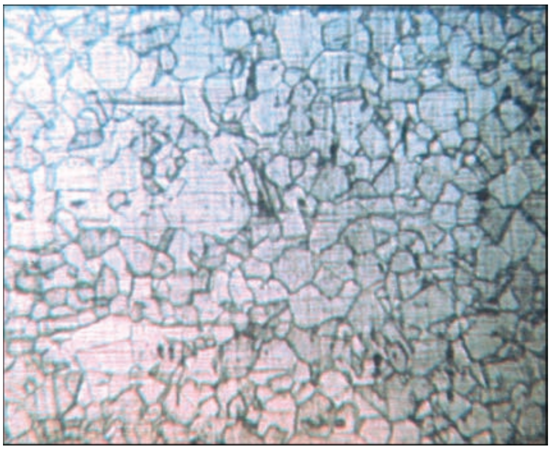

Figure 6. Macrostructure of 40 mm dia rod from EBM nickel of NP2 grade

Table 2. Mechanical characteristics of drawn soft rods of 40 mm diameter

Grade	σ_t, MPa	δ_{10}, %	δ_5, %
EBM nickel NP2	375–390	28–32	37–40
GOST 13083–77	>370	>26	>30

CONCLUSIONS

Thus, by the results of the conducted work, it was shown that electron beam melting is an effective method to produce nickel ingots from secondary raw materials, as it provides a high level of the produced material quality, and the semi-finished product quality fully meets the standard requirements by its chemical composition, structure and mechanical properties.

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Figure 5. Semi-finished products from EBM nickel of NP2 grade: *a* — 3 mm wire; *b* — drawn soft rods of 40 mm diameter

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CONFLICT OF INTEREST

The Authors declare no conflict of interest

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