RECYCLING OF NICKEL ALLOY SCRAP AND WASTE USING THE ESR METHOD IN THE CONDITIONS OF LIMITED RESOURCES OF RAW MATERIALS TO PRESERVE THE CHEMICAL COMPOSITION AND PROPERTIES

YEVHEN PEDCHENKO, YURIY KOSTETSKY, GANNA POLISHKO, VOLODYMYR PETRENKO, VOLODYMYR ZAITSEV

E.O. Paton Electric Welding Institute of NAS of Ukraine

Electroslag remelting (ESR) is an effective method for recycling nickel alloy scrap, enabling the preservation of chemical composition and the production of high-quality ingots with reduced environmental impact and minimized harmful emissions. Modern two-circuit ESR with a current-supply mould offers flexible requirements for electrode geometry and precise thermal control, allowing efficient processing of various nickel alloy scrap and waste into premium-quality ingots.

Key words: electroslag remelting, nickel alloy, electrode, thermal control, recycling

Introduction. The paper considers the current issue of recycling nickel superalloys, which are used in critically loaded parts of aircraft engines, power turbines, chemical and petrochemical industry installations, as well as in defense technology. Such alloys are characterized by high heat resistance, corrosion resistance and stability of properties during long operating cycles at temperatures above 1000 °C. The composition includes scarce and expensive alloying elements, in particular nickel, cobalt, chromium, molybdenum, niobium, tantalum, tungsten, which have limited global reserves and complex production technology.

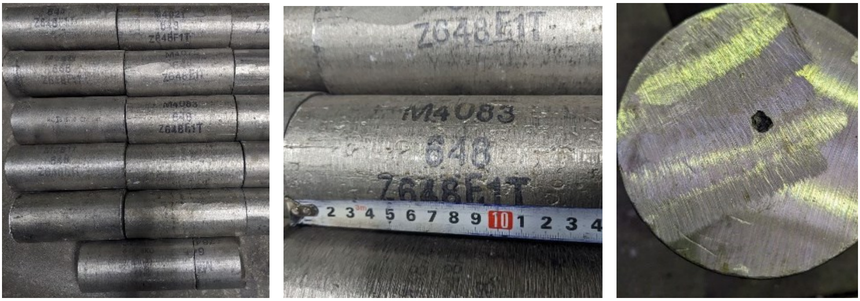
Effective recycling of nickel alloys allows not only to reduce the need for primary ore mining, but also to significantly reduce energy costs and the carbon footprint of metallurgical production. The main sources of waste are:

- production (scraps, cast billets with deviations, shavings after machining);
- operational (parts that have exhausted their resource);
- recycling (decommissioned equipment and units).

According to statistics, about 30,000 tons of special-purpose metals are recycled annually, of which about 1,800 tons are nickel alloys, which are returned to the production cycle after processing. However, the actual share of return was much higher given the introduction of modern technologies, in particular electroslag remelting (ESR), vacuum-induction and plasma remelting, which ensure the purification of the metal from harmful impurities and the preservation of the valuable alloy accordingly.

Further development of methods for recycling nickel alloys is of strategic importance for the metallurgical industry and economic security, as it allows for the creation of closed technological cycles, increased resource efficiency and reduced dependence on imports of critical raw materials.

As an effective recycling technology, electroslag remelting according to a double-circuit scheme (ESR DS) [1-4] using a quasi-passive electrode was proposed. A cycle of laboratory melting of electrodes of variable cross-section (in the shape of a club) formed from scraps of EP648 alloy (Table 1) (round bar d=70 mm (Fig. 1), rings Ø510 mm and Ø370 mm, etc.) was carried out.



a b c

Fig. 1. Billet, round log cut d=70mm. a – General view of the billet, b – Billet with marking and size of the smallest length, c – billet defects.

Table 1. Chemical composition of nickel alloy EP648 according to TU 14-1-4103-86

EP648 TU 14-1-4103-	Al	Ti	Cr	Fe	Ni	Nb	Mo	W
	0.5-1.1	0.5-1.1	32-35	to 4	base	0.5-1.1	2.3-3.3	4.3-5.3

Three samples from different parts of the input material were selected and their chemical analysis was performed on a scanning electron microscope Sem Tescan Vega 3. The actual composition of the nickel alloy EP648 is presented in Table 2, which shows that the input material corresponds to the chemical composition of EP648 according to TU 14-1-4103-86. The material contains chemical liquation of elements, in some cases the values of highly reactive elements, such as Al and Ti, reach the lower level of the grade range. Mo is also at the minimum permissible level.

Table 2. Chemical composition of the incoming nickel alloy EP648 before recycling.

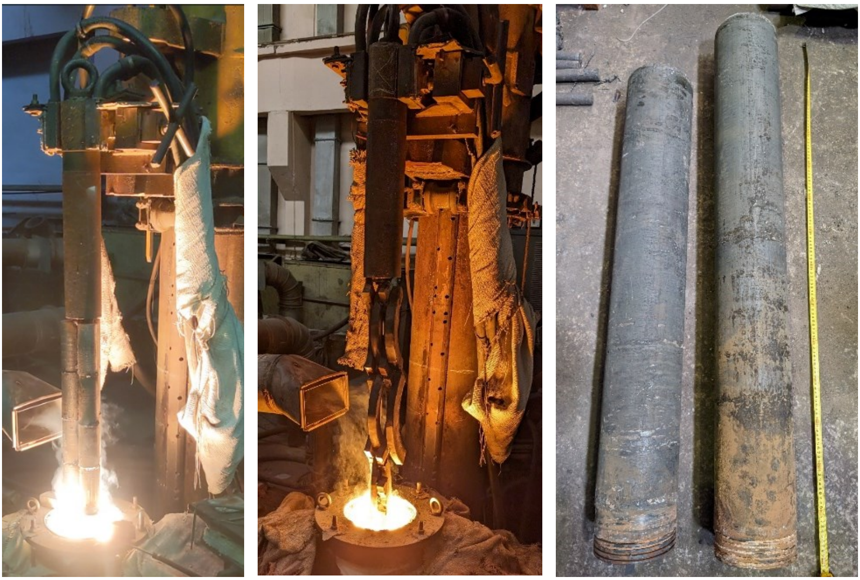
№	Al	Ti	Cr	Fe	Ni	Nb	Mo	W
1	0.61	1.14	35.37	0.75	54.50	1.21	2.37	5.02
2	0.96	1.22	36.46	0.75	55.67	0.83	2.26	5.7
3	0.76	0.97	34.23	0.56	52.75	1.19	1.94	4.13
Average	0.77	1.11	35.35	0.68	54.3	1.07	2.19	4.95

ANF-29 (Table 3) was chosen as the basis of the flux for remelting the nickel alloy. To reduce its melting point and SiO_2 content, it was modified with pure CaF_2 in an amount of 1/10 by weight.

Table 3. Chemical composition of flux ANF-29 according to TU 20.5-00186520-126-2018

SiO_2	Al_2O_3	CaF_2	CaO	MgO	Fe_2O_3
10-15%	13-17%	37-45%	24-30%	2-6%	<0.5%

The remelting of consumable electrodes was carried out by the ESR DS method in a short-extended mould with a forming section d=180mm, liquid start, the total mass of slag for remelting was 6kg, the argon flow rate was 15l/min, deoxidation with Al grains was carried out at a flow rate of 3g/min. The power applied to the electrode was 40-50 kVA, to the current-supply section of the mould was 150 kVA. Each ingot was obtained from several electrodes. The electrodes were replaced without shutting down the power current-supply section of the mould. The remelting rate was an average of 80 kg/h. As a result, ingots with a height of 1100 mm and 1250 mm were obtained (Fig 2).



a b c

Fig. 2. a – Remelting of an electrode from a round billet, b – Remelting of the electrode from cut rings, c – obtained ingots with a diameter of 180mm and a length of 1100 and 1250mm.

A sample was taken from the head of the resulting ingot for chemical composition analysis (Table 4). Chemical liquation of elements was detected

(Table 4), but the overall chemical composition corresponds to the EP648 alloy. The loss of highly reactive elements Al and Ti was 0.1 and 0.15% of the initial metal before recycling.

Further processing (forging, manufacturing of rings) confirmed the proper quality of the metal according to the results of metallographic studies and ultrasound.

Table 4 Chemical composition of the obtained nickel alloy ingot EP648 after recycling

№	Al	Ti	Cr	Fe	Ni	Nb	Mo	W
1	0.56	0.82	32.71	0.47	51.81	0.78	2.18	4.42
2	0.85	1.08	34.59	0.68	53.78	0.49	1.29	5.07
3	0.6	0.98	33.7	0.61	53.04	3.05	3.45	5.39
average	0.67	0.96	33.66	0.58	52.87	1.44	2.3	4.96

Conclusions. It is shown that the use of ESR DS provides effective metal purification, controlled crystallization, uniform chemical composition and obtaining high-quality ingots. The proposed approach demonstrates technical, economic and environmental efficiency, in particular, reducing CO_2 emissions, reducing industrial waste and reducing the need for primary extraction of critical elements. The developed technology can be implemented in closed cycles to obtain high-quality ingots from superalloy scrap.

1. *Pedchenko Y., Kostetsky Y., Polishk G., Petrenko V., Zaitsev V. Recycling of Steel Using the esr method in the conditions of limited resources of raw materials to preserve the chemical composition and properties // Proc. Inter. Young Sci. Conf. on Materials Science and Surface Engineering. – 2023. – P. 47–52. https://doi.org/10.15407/msse2023.047*
2. *Pedchenko Y., Medovar L., Kostetsky Y. Electroslag remelting as a method of recycling non-compact high-speed steel tools //METAL 2022. – 2022. – 18–19 May. https://doi.org/10.37904/metal.2022.4455*
3. *Pedchenko E. O. et al. Recycling of used noncompact tools from high-speed steel by electroslag remelting // Sovremennaâ èlektrometallurgiâ. 2022. – Vol. 2022. – №. 3. – P. 23–28. https://doi.org/10.37434/sem2022.03.04*
4. *Pedchenko Y. O. et al. Electroslag remelting of variable cross-section electrodes using a two-circuit scheme // Welding and Related Technologies. London. – 2025. – P. 25–28. https://doi.org/10.1201/9781003518518-5*