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METALLURGICAL EQUIPMENT

To the Centenary of Metallurgical Plant Electrostal

Implementation and Modification of the Manufacture of High-Quality Ingots in an ALD Vacuum Arc Furnace

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Abstract—The results of producing metal products of the steel and alloy ingots manufactured on an ALD furnace are presented. Remelting with growth rate and drop pulse frequency control is tested. (08–12)Kh18N10T steel is studied to determine the depth of shrinkage and subshrinkage defects in all ingots of all sizes (250, 320, and 500 mm in diameter). The quality of steels and alloys in chemical composition, mechanical properties, long-term strength, macrostructure, and nonmetallic inclusions are analyzed in terms of regulatory documents. The affordability of the implemented remelting process was about 4.4 mln rubles.

Keywords: returnable head, mold, electrical heat schedule, VAR ingot growth rate, drop pulse frequency

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Metallurgical plant Electrostal has radically renovated its production basis as a result of implementation of a modification program. Metallurgical plant Electrostal is now a modern metallurgical works, which includes all processes for the production of high-quality articles in the entire technological cycle from raw materials to the end product.

One of the components of the renovated production basis is an L450 P2.5 vacuum arc remelting (VAR) furnace supplied by the leading Germany Company ALD Vacuum Technologies GmbH.

The L450 P2.5 VAR furnace has a number of advantages over the DSV-3.2 and DSV-6.3 VAR furnaces operating in the plant. First of all, the accuracy of centering an electrode in a mold is increased due to its adjusting along axis *xy*, the computer control system makes it possible to operate in a fully automatic regime, and the device used for weighing electrode and an accurate calculation of the melting rate. Thus furnace allowed us to automate the technological process of VAR and to improve the working environment.

The L450 P2.5 VAR furnace is equipped with three molds 250, 320, and 500 mm in diameter and has two melting stations with a solenoid coil and an inert gas cooling system.

Since the beginning of operation of L450 P2.5 VAR, we developed a program to produce a certain range of products. This program had the following stages:

—mass production technology (current and voltage remelting);

—a new VAR technique, i.e., remelting in the ingot growth rate and the drop pulse frequency (DPF);

—the study of the influence of an ac magnetic field (AMF) on the quality and structure of the deposited metal.

The process of remelting of steels and alloys for the L450 P2.5 VAR furnace was developed by engineers from metallurgical plant Electrostal.

The development of VAR of steels and alloys implied the determination of the optimum I–V characteristics of remelting and melting schedules.

When a mass technology was developed for the furnace produced by ALD Vacuum Technologies GmbH, we performed quality control for steels (08–12)Kh18N10T, ChS4, KhN73MBTYu (EI698), 12Kh21N5T (EI811), 03Kh18K8N5T (EK21), KhN62VMYuT (EP708), and KhN45MVTYuBR (EP718).

For remelting in the L450 P2.5 VAR furnace, we used consumable electrodes with welded returnable heads to form incompletely melted parts no more than 50 mm in height and to increase the ingot-to-product yield of the VAR metal to 100 kg (for remelting in a mold 500 mm in diameter).

Figure 1 shows the appearance of electrodes 250 and 380 mm in diameter with welded returnable heads of 08Kh18N10T steel, which were prepared for FAR.

Table 1. VAR ingot lengths

Electrode diameter, mm	Mold diameter, mm	VAR furnace	Consumable electrode	Ingot length
250	320	VAR L450 P2.5	Forged from 1450-kg ingot	1700–1830
		DSV-3.2	Forged from 1060-kg ingot	1100–1170
		VAR L450 P2.5	Mold cast	930–1100
		DSV-3.2	Mold cast	830–1100
380	500	VAR L450 P2.5	Mold cast	1180–1210
		DSV-6.3	Mold cast	1080–1180

Figure 2 shows the appearance of incompletely melted parts 380 mm in diameter with a welded 03Kh18K8N5T steel returnable head. The masses of the incompletely melted part are 50 and 60 kg and their heights are 40 and 50 mm, respectively. For comparison, Fig. 3 depicts the appearance of the incompletely melted part after the remelting of a consumable electrode of 03Kh18K8N5T steel 380 mm in diameter in a mold 500 mm in diameter in operating DSV-6.3 furnaces (160 kg in mass).

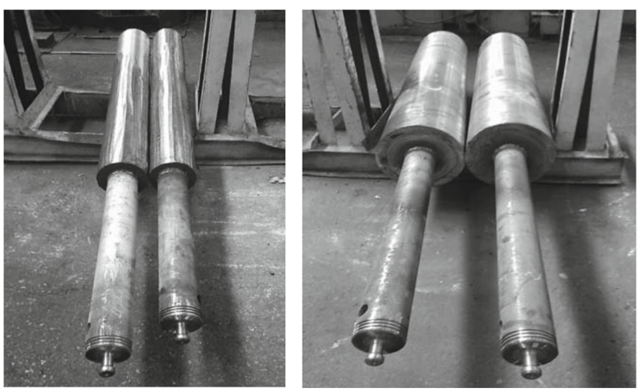

Fig. 1. Appearance of electrodes made of 08Kh18N10T steel 250 and 380 mm in diameter with welded returnable heads.

VAR of the steels noted above was carried out according to a mass technology (in current and voltage) in molds 320 and 500 mm in diameter with and without helium used for additional cooling.

VAR in the L450 P2.5 VAR furnace occurs according to a certain melting schedule loaded in a computer; it consists of three phases, namely, bath formation, melting, and pipe elimination. In turn, these phases are divided into steps programmed individually. The current, the voltage, the melting rate, DPF, the cooling gas consumption, the time, and the ac magnetic field are specified.

VAR and liquid bath formation in the furnace produced by ALD were performed according to a corrected technology without chips to avoid burns and welding of the end face of a VAR ingot to the bottom.

For comparison, Table 1 gives the VAR ingot lengths for the furnace produced by ALD and for DSV furnaces.

Figures 4–6 show the appearance of VAR ingots 250, 320, and 500 mm in diameter made of steels

(a) (b)

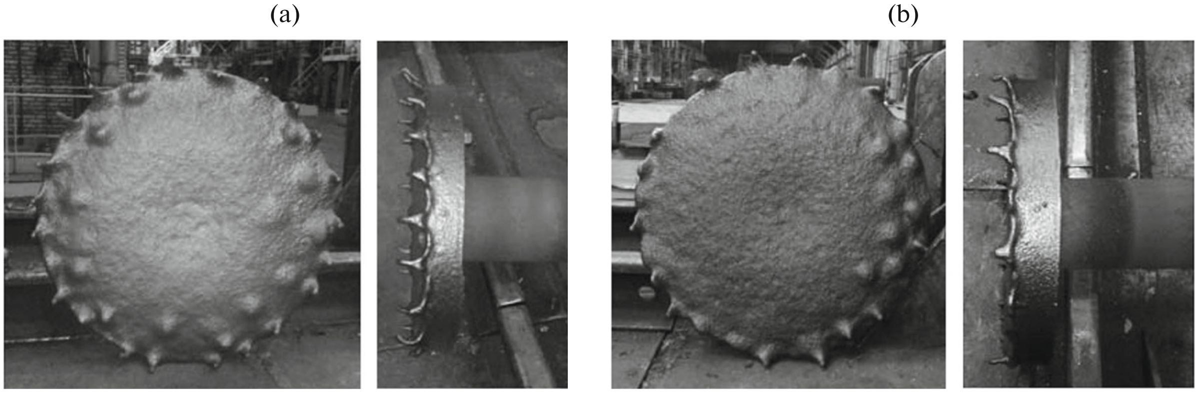

Fig. 2. Retained electrode (incompletely melted part) after VAR of a consumable electrode made of 03Kh18K8N5T steel 380 mm in diameter in the furnace produced by ALD.

Fig. 3. Retained incompletely melted part after VAR of a consumable electrode made of 03Kh18K8N5T steel 380 mm in diameter in a DSV-6.3 furnace.

(a) (b)

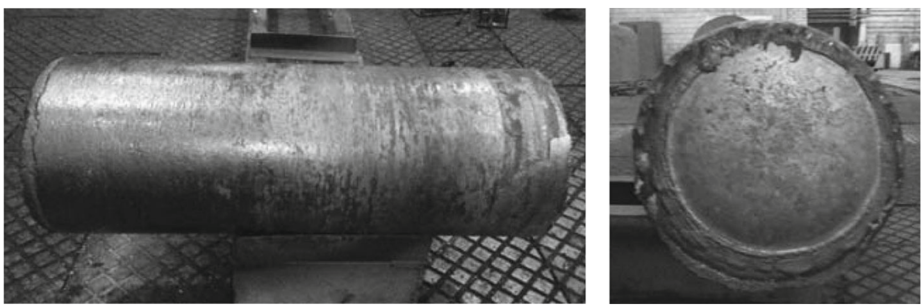

Fig. 4. Appearance of (a) VAR ingot of 03Kh18K8N5T steel 500 mm in diameter and (b) head end.

(a) (b)

Fig. 5. Appearance of VAR ingots of 12Kh18N10T steel (a) 320 and (b) 500 mm in diameter.

(a) (b)

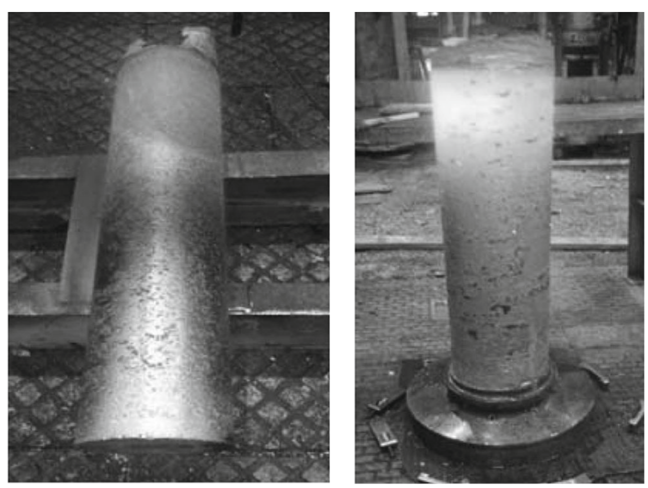

Fig. 6. Appearance of VAR ingots (a) made of KhN73MBTYu alloy 250 mm in diameter and (b) made of KhN62VMYuT alloy 320 mm in diameter.

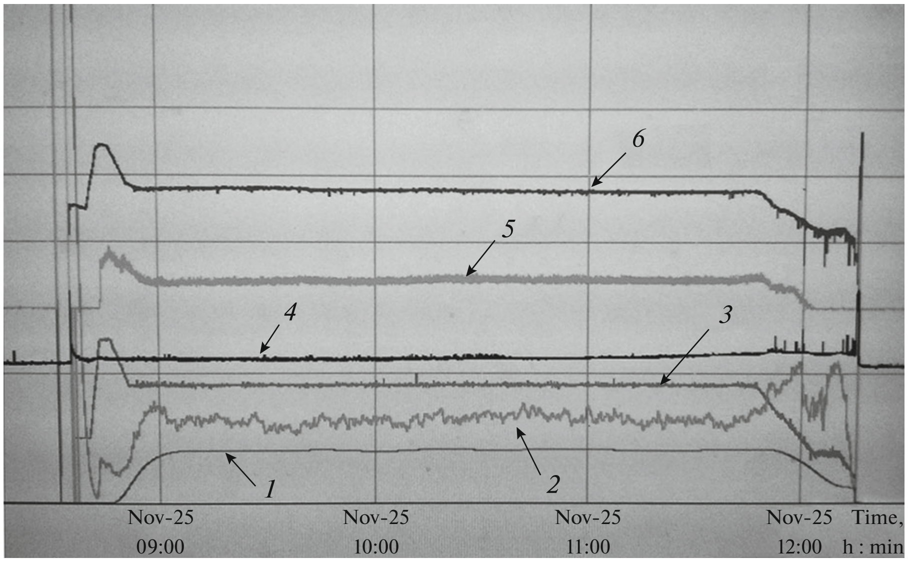

Fig. 7. VAR curves for an ingot made of KhN73MBTYu alloy 250 mm in diameter: (*1*) remelting rate, (*2*) DPF, (*3*) current, (*4*) vacuum, (*5*) electrode position in remelting, and (*6*) voltage.

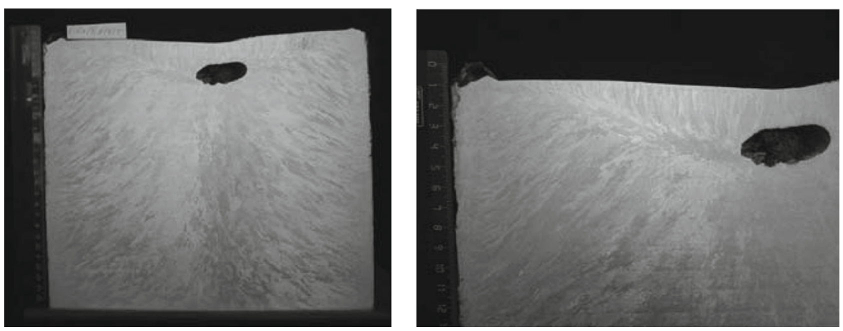

Fig. 8. Macrostructure of the head part of a VAR ingot of 08Kh18N10T steel 320 mm in diameter.

03Kh18K8N5T and 12Kh18N10T and alloys KhN73MBTYu and KhN62VMYuT. The surface quality is close to that of electroslag remelting ingots.

The remelting parameters are stored on a hard disk and are visualized as curves on a monitor in remelting. As an example, Fig. 7 shows the curves recorded during the formation of a VAR ingot of KhN73MBTYu steel 250 mm in diameter according to the existing technology (current and voltage control).

To study the depth of shrinkage and subshrinkage defects in VAR ingots 320 and 500 mm in diameter, we cut off the head part to form templates 250 and 300 mm in height, respectively.

Figures 8 and 9 show the macrostructures of the head parts of VAR ingots of (08–12)Kh18N10T steel 320 and 500 mm in diameter.

As is seen in Figs. 8 and 9, the macrostructure is dense and columnar crystals formed in the ingots. The crystals in the axial zone are directed vertically from bottom to top and the crystals in the region from the axial to the peripheral zone are directed at an angle of ~45°.

The ingots have shrinkage cavities 20 × 45 mm (see Fig. 8) and 19 × 62 mm in size (see Fig. 9) and no more than 50 mm in depth. Subshrinkage defects are absent below the shrinkage cavities.

Quality control of the VAR metal manufactured in the L450 P2.5 VAR furnace showed positive results and compliance with the requirements of regulatory documents in chemical composition, mechanical properties, long-term strength, macrostructure, and nonmetallic inclusions.

The next stage of implementation of remelting in the furnace of ALD Vacuum Technologies GmbH was a new VAR technique, namely, growth rate or DPF control. This technology was put into operation using 12Kh18N10T steel [1].

Consumable electrodes 250 mm in diameter were remelted into a mold 320 mm in diameter using growth rate or DPF control in an automatic regime

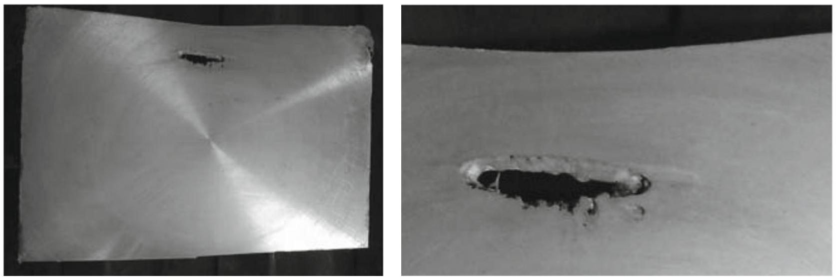

Fig. 9. Macrostructure of the head part of a VAR ingot of 08Kh18N10T steel 500 mm in diameter.

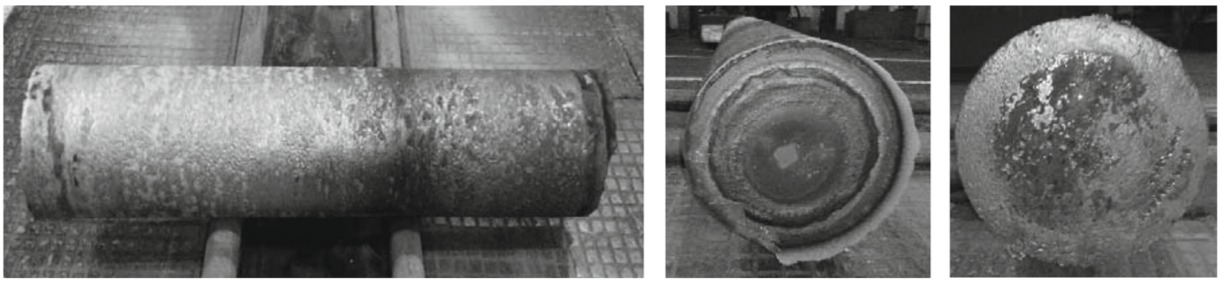

Fig. 10. Appearance of a VAR ingot of 12Kh18N10T steel 320 mm in diameter remelted in an automatic regime with growth rate or DPF control.

using helium. The remelting parameters were chosen using the actual deposition rate and DPF of the 12Kh18N10T steel ingots produced by remelting in the furnace according to the existing technology (current and voltage control).

A bath was formed without chips using current and voltage control. Operating remelting conditions of and pipe formation were achieved automatically using growth rate and DPF control. Remelting was stable without deviations from a heat schedule. The full pipe was brought into the sinkhead.

The ingot surfaces were good: no signs of transition from one heat stage to another were detected on the VAR ingot surfaces. Figure 10 shows the appearance of a VAR ingot of 12Kh18N10T steel 320 mm in diameter.

Figure 11 depicts the curves recorded in making the VAR ingot of 12Kh18N10T steel 320 mm in diameter that was automatically remelted using growth rate or

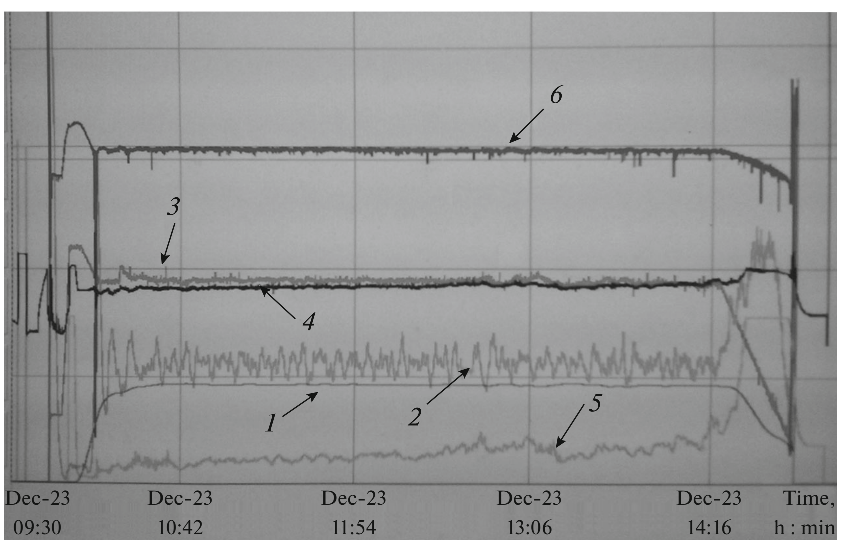

Fig. 11. VAR curves for an ingot made of 12Kh18N10T steel 320 mm in diameter remelted with growth rate or DPF control: (*1*) remelting rate, (*2*) DPF, (*3*) current, (*4*) vacuum, (*5*) helium pressure, and (*6*) voltage.

DPF control (growth rate, DPF, current voltage, vacuum, helium pressure).

Quality control of the VAR 12Kh18N10T steel remelted using growth rate and DPF control demonstrated positive results and complete compliance with the requirements of regulatory documents.

The next step in the implementation of the L450 P2.5 VAR furnace is the development of a remelting technology using an ac magnetic field and the investigation of its influence on the quality of the VAR metal [2, 3].

The affordability of the introduction of the L450 P2.5 VAR furnace into operation in the second half of 2016 was about 4.4 mln rubles due to an increase in the ingot-to-product yield of the VAR metal (decrease in the retained unmelted metal). The retained unmelted metal in DSV-3.2 and DSV-6.3 furnaces depends on the experience, the qualification, and the responsibility of a steelmaker, i.e., the human factor. Apart from the use of consumable electrodes with welded returnable heads, the effect of the human factor in the furnace produced by ALD Vacuum Technologies GmbH is minimized.

We are going to produce a significant part of the range of products made in DSV-3.2 and DSV-6.3 furnaces with allowance for the accumulated experience and putting the L450 P2.5 VAR furnace into operation.

CONCLUSIONS

The following results were obtained during the introduction of VAR in the furnace of ALD Vacuum Technologies GmbH:

(1) Steels and alloys (08–12)Kh18N10T, ChS4, KhN73MBTYu, 12Kh21N5T, 03Kh18K8N5T, KhN62VMYuT, and Kh45MVTYuBR were manufactured by remelting according to the operating technology (current and voltage control) and a developed heat schedule.

(2) Positive results were obtained for remelting with growth rate and DPF control.

(3) The quality of the metal products produced from the VAR metal manufactured in the L450 P2.5 VAR furnace for various types and sizes of molds meets the requirements of regulatory documents and is on the level of mass production metal.

(4) The technologies of remelting using growth rate and DPF control and AMF remelting are being developed.

(5) The affordability of the introduction of the L450 P2.5 VAR furnace into operation in the second half of 2016 was about 2 mln rubles.

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