

APPLICATION OF MODIFICATION OF ANNULAR BILLETS MADE FROM NITROGEN-CONTAINING HIGH-STRENGTH STAINLESS STEELS IN CENTRIFUGAL ELECTROSLAG CASTING

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Abstract:

New technology for production of annular billets including electroslag melting of consumable electrode in the melting crucible, modification of molten metal by refractory particles and its subsequent pouring together with slag into the chill mould is described. The description of equipment for realizing this process is proposed. Influence of dispersed particles of molybdenum and vanadium on the structure and properties of 15Kh12N2MVFAB steel is shown. The results of comparative analysis of cast metal and advantages of modified cast billets are given.
KEYWORDS: ELECTROSLAG CASTING, ANNULAR BILLETS, NITROGEN-CONTAINING STEELS, MODIFICATION, STRUCTURE, PROPERTIES

1. Introduction

Demand for state-of-the-art production of annular billets is very high. They are especially widely used in ship-building, power engineering, chemical and petrochemical industries, aviation and missile technologies. So, for example, in gas-turbine and turbojet engines annular special-purpose parts constitute 25-30 % of general mass of an engine [1].

Choice of the method for production of hollow billets depends upon their designation. For manufacturing such parts casting and mechanical (processing by pressure, cutting on metal-cutting machines) methods are frequently used.

BILLETS produced by open casting methods have significant shortcomings - not sufficiently high quality of metal and difficulty in producing dense castings.

During melting and casting molten metal stays for a long time in contact with refractory brickwork of a furnace, with a ladle, a wiring, a mold, and the atmosphere.

As a result it is saturated with gases and non-metal inclusions. Simultaneous casting of big portions of metal and slow solidification enable occurrence in the casting of shrinkage cavities, zonal and dendrite liquation, and structural inhomogeneity.

That's why mentioned cast billets are mainly used for manufacturing general-purpose parts.

BILLETS for special-purpose structures are produced from solid-section billets using different methods of hot conversion - forging, piercing, pressing, and expanding [1]. Serious shortcomings of this technology consist in high cost of billets stipulated by use of a great number of intermediate operations (forging of ingots, roughing, cutting into billets, piercing of the billets, distribution, calibration), low metal utilization coefficient, and need to use expensive press-forging and rolling equipment. So, application of hot deformation in production of annular billets is a compelled measure, to which one resorts because of low quality of casting. That's why production of cast billets, the shape and size of which maximally approach those of the ready item and quality of which is not inferior to the one of the deformed billets, is an actual task.

Everything mentioned above also relates in full degree to annular billets made from nitrogen-containing steels, in particular steels 15Kh12N2AM, 15Kh12N2MVFAB, etc., which are widely used for manufacturing parts and units of power engineering installations that operate under conditions of increased temperatures and are subjected in the course of their operation to significant loads of different character.

Requirements, established for items manufactured from these steels, may be mainly met only in case of using deformation processing, because properties of cast steels of these grades even after refining remelting and optimum conditions of heat treatment are inferior to those of forged ones. Manufacturing of parts and units of big overall dimensions and mass is accompanied by excessively high consumption of expensive materials and low productivity.

2. Preconditions and means for resolving the problem

High potential for solution of this issue has method of centrifugal electroslag casting (CESC), the essence of which consists in remelting of the metal in the melting unit (a crucible), which enables accumulation of the molten metal and slag in necessary amounts and their subsequent casting into a rotating mould, whereby efficient refining and reliable protection of accumulated in the crucible metal against action of the atmosphere is ensured, and melting loss of the alloying elements significantly reduces. An important advantage of the process, in comparison with traditional ones, is simplicity of the equipment and the fitting-out.

At the same time, as showed investigations, level of mechanical properties of cast billets, produced by the method of electroslag casting from high-alloy steels and alloys, solidification of which is accompanied by significant development of dendrite chemical inhomogeneity because of presence in their composition of strongly sweating elements, is, all the same, lower than that of forged billets [2]. Reduced level of mechanical, and especially ductility properties, have also cast billets, produced from steel 15Kh12N2MVFAB. One of the ways of solving this issue is development of the methods of structure control of the electroslag casting metal and, therefore, of its mechanical properties, because the latter ones are structurally sensitive.

3. The solution of the problem in question

For this purpose complex volumetric modifying of nitrogen-containing chrome-nickel steel 15Kh12N2MVFAB in electroslag casting of billets of «flange» type, having mass up to 50 kg and thickness of walls up to 30 mm, was investigated. The modifier was used, composition of which includes molybdenum, vanadium, and nickel. The modifier was selected proceeding from the following ideas. Dispersed particles of molybdenum with high melt point are inoculators - centers of nucleation. Vanadium has crystal lattice, which is similar to that of molybdenum and small difference with the latter in electronegativity and atomic diameter, which stipulates formation of continuous rows of solid solutions between them [3].

Due to the known principle «a similar one is wetted (adsorbed) by a similar one» [4], atoms of vanadium after introduction of the modifier into the melt are selectively adsorbed by surface of molybdenum particles. High affinity of vanadium to nitrogen should increase nucleation activity of molybdenum particles. Nickel ensures isolation of the inoculator (molybdenum) particles from each other, thus preventing their coalescing and coagulation at the stage of the modifier introduction into the melt.

The modifier was produced by mixing of powder components, having dispersity 0.5 - 1.0 mm, with their subsequent pressing at specific pressure 500-700 MPa into the briquette-pellet of 30 mm diameter and 10 mm thickness

In the course of pressing mutual movement of particles relative each other takes place, due to which oxide film on surface of the pellet is destroyed. Size of the pellets is selected proceeding from their sufficiently quick dissolution in molten metal (30-60 s) and to ensure conditions that one pellet to be per 10 kg of the melt subject to

processing. Such pellets have significant density, which stipulates their quick passage through molten slag that ensures high degree of assimilation of the modifiers by the metal pool.

The modifier was introduced into the melt at the temperature 1750 °C for 2-3 min before casting the melt into the metal mould. Ratio and number of particles of inoculators and the activating additive were selected experimentally in order to achieve maximum refining of the cast metal structure.

Experiments were carried out on the A-550U installation complete with copper skull water-cooled melting unit, a centrifugal device, and a metal mould.

The metal to be remelted was represented by the rods of respective steel.

As far as rate of the metal solidification in the zone of an item formation is high in CESC, composition of used flux is of great importance. The latter should have low melting point, wide range of solidification, significant yield at high cooling rate, and ensure stability of skull layer over the whole surface of a billet. That's why flux of the $\text{CaF}_2\text{-CaO-Al}_2\text{O}_3$ system was used with addition up to 10 % SiO_2 , which allowed increasing forming properties of the flux and its ductility in solid state [2].

4. The results and discussion

Data of chemical analysis performed on the ARGOMET-930 SP optical-emission analyzer (Table 1) prove that metal composition of the casting, produced by electroslag casting with application of mentioned flux, changes insignificantly concerning majority of the main alloying elements and remains within the grade composition.

Table 1. Chemical composition of steel 15Kh12N2MVFAB

Metal type	Weight share of elements, %									
	C	Cr	Ni	Mo	W	V	Nb	S	P	N
Electrode	0,16	12,34	1,96	1,48	0,87	0,25	0,32	0,006	0,009	0,05
CESC without modifying	0,15	12,17	1,95	1,41	0,84	0,18	0,25	0,003	0,007	0,06
CESC with modifying	0,15	12,21	1,95	1,46	0,85	0,23	0,28	0,003	0,007	0,07
TU 14-1-1161-75	0,13-0,18	11,0-12,5	1,4-2,1	1,35-1,65	0,65-1,0	0,18-0,30	0,2-0,35	$\leq 0,05$	$\leq 0,030$	0,02-0,08

Metallographic investigations showed that cast non-modified metal has a directed transcrystalline structure with high length of primary dendrite axes (Figure 1, a). Microstructure of such metal represents coarse-needled martensite, plates of which have characteristic orientation and are mainly arranged at the angle 60° (Figure 1, b). Results of mechanical tests of such metal on specimens, cut out in tangential direction, at normal temperature (Table 2) showed that its ductility properties are significantly inferior to those of a deformed metal and do not meet technical requirements.

Table 2. Mechanical properties of steel 15Kh12N2MVFAB

Металл	σ_s	σ_{02}	δ	ψ	KCU	Heat treatment
	MPa		%		MJ/m ²	
CESC without modifying	1067	838	11	27	0,32	Normalizing at 1130 °C, annealing 750 °C, oil quenching from 1120 °C, annealing at 700 °C
CESC with modifying	1056	862	18	59	0,68	
TU 14-1-1161-75	≥ 1030	≥ 830	≥ 14	≥ 55	$\geq 0,59$	

It was established in investigation of the fracture surface of impact specimens after the tests that microfractures are of semi- and brittle character (Figure 1, c). Micrographic investigations showed that the fracture represents a trans-crystalline spalling with characteristic «river pattern» (Figure 1, d).

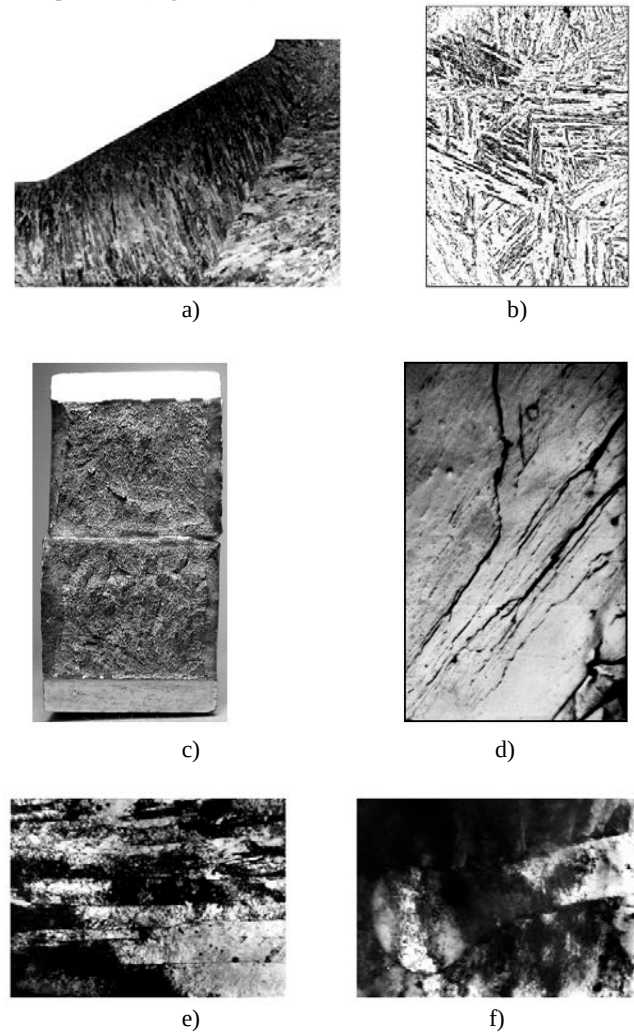


Figure 1. Structure of cast annular billet produced by electroslag melting from non-modified steel 15Kh12N2MVFAB: a - macrostructure; b - microstructure, $\times 500$; c - fracture relief; d - fracture microfractography, $\times 5000$; e - fine structure of α -martensite crystals, $\times 22000$; f - β -ferrite in martensite matrix, $\times 27000$

Electron-microscopic investigations showed that the main structural component is BCC – α -martensite, crystals of which form packages of plane-parallel plates (Figure 1, e). Residual austenite was not discovered.

At the same time in martensite matrix there is a certain amount of structurally free β -ferrite, which was discovered in the form of inclusions, located both inside and over boundaries of former austenite grains (Figure 1, f). Evidently, exactly this causes significant worsening of the cast metal ductility. Similar influence of β -ferrite on impact toughness and heat resistance of stainless steels was noted in [5, 6].

Introduction of a modifier into the metal causes significant change of produced structure and properties of the cast metal. Structure and mechanical properties achieve the best state at ratio of the particles of inoculators and the activation additive 1:2 and mass of the modifier 0.5-0.8 %. Transcrystallization zones are removed in the annular casts, size of dendrites drastically reduces and they acquire favorable shape all over the volume of the crystallized metal (Figure 2, a).

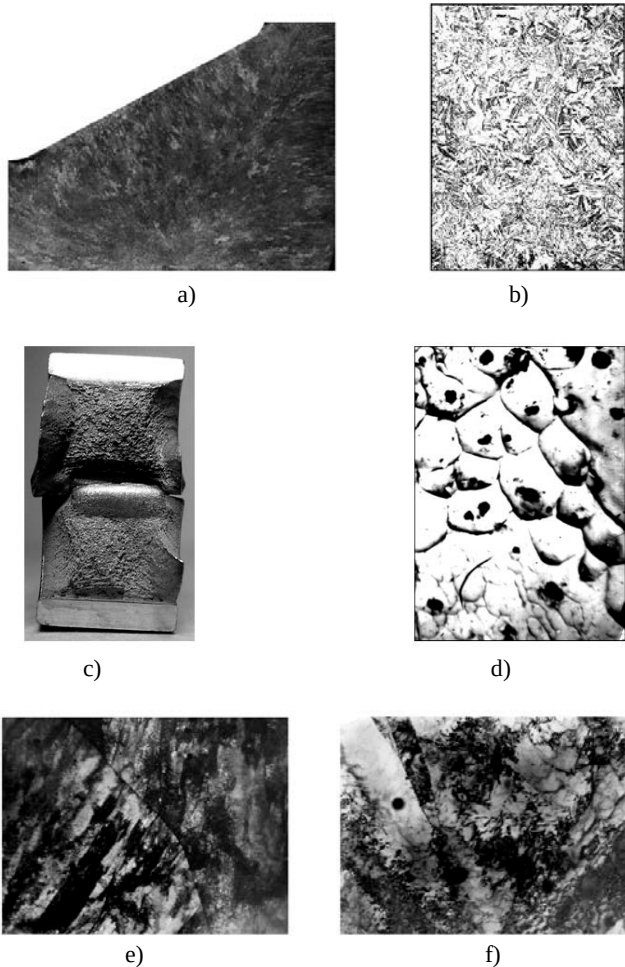


Figure 2. Structure of cast annular billet produced by electroslag melting from modified steel 15Kh12N2MVFB:

- a - macrostructure; b - microstructure, $\times 500$; c - fracture relief; d - fracture microfractography, $\times 5000$; e - fine structure of α -martensite with interlayers of residual austenite, $\times 22000$; f - oxycarbonitrides, $\times 50000$

Plates of α -martensite do not have preferential orientation (Figure 2, b). Mechanical tests showed that all characteristics of the modified metal are higher than those of non-modified metal and are at the level of the deformed metal properties.

It was established in investigation of the impact specimens that all failure zones (central, side, and additionally broken zones) have practically the same, characteristic of tough fracture, relief (Figure 2, c). The main micrographic characteristic of failure is a hole-like fracture (Figure 2, d).

Significant precipitations of β -ferrite were not detected in microstructure of such metal. At the same time in addition to martensite residual austenite occurs, located mainly between martensite crystals in the package in the form of thin interlayers (Figure 2, e). Boundaries between adjacent α -crystals are, as a rule, located at a small angle.

In addition, in all places of the structure dispersed particles, evidently of oxycarbonitrides, were detected, which looked like orbicular black inclusions of different size (Figure 2, f).

5. Conclusion

Presented data allow drawing conclusion that used modifier is optimal for formation of the metal structure of electroslag castings, which determines ductility characteristics of nitrogen-containing martensite and martensite-ageing steels. Occurrence of residual austenite and absence of β -ferrite, evidently, determine higher ductility properties of the modified cast steel 15Kh12N2MVFB.

As a result of the investigations technology for casting annular billets from high-strength nitrogen-containing steels was developed.

So, properties of annular billets, produced by CESC method with application of the metal modifying by dispersed inoculators, are not inferior to those of hot-deformed billets. At the same time they are less labor-consuming and cheaper.

6. Literature

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