PROCESSES OF MANUFACTURE OF FERROUS AND NONFERROUS METALS

Technology of Melting of a 12Kh18N10T Alloy in Induction Furnaces

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Abstract—A technology for melting structural cryogenic 12Kh18N10T steel from industrial wastes in an induction unit consisting of two induction core-free 1100-kg FS furnaces has been developed. The paper considers the problems of charge preparation, namely, the fraction composition, the oxidation level, the content of harmful impurities, and the method of its charging, to ensure the resistance of a crucible and a decrease in the melting period ad the problems of the order of introducing alloying and slag forming elements. The results of experimental—industrial heats show a decrease in their contents by 3—5% at a decrease in the metal loss by 2—4% and a specific energy consumption of 570—780 kWh/t. Recommendations on a decrease in the meniscus height on the melt surface are given.

INTRODUCTION

Stainless steel 12Kh18N10T belongs to structural cryogenic steels and is an austenitic steel. It is used to produce parts and instruments operating at temperatures lower than 600°C, welding machines, vessels operating in dilute solutions of nitric, acetic, and phosphoric acids, solutions of alkalis and salts, and also other equipment operating under pressure in the temperature range from −196 to 600°C, but, in the presence of corrosive media, to $T = 350°C$ [1].

The properties of the parts made of this steel are determined by the alloying elements entering in its composition.

Table 1 gives the chemical composition determined by GOST 5632—72.

The high chromium content in 12Kh18N10T steel provides the capacity of the metal to passivation and determines its anticorrosion properties. The presence of nickel transfers the steel to the austenite class, due to which the technological properties of the alloy is combined with an extended set of performance characteristics: the steels are well rolled in a cold and a hot states, have higher corrosion resistance in corrosive media, including sulfur acid as compared to ferritic steels.

High nickel (Ni) and chromium (Cr) contents positively influence the austenite stability in a solid solution as the treatment temperature decreases to 1050—1100°C. For the steel to have a completely austenitic structure at a temperature higher than 900°C, it is sufficient to have 0.1% C, which is due to its strong austenite-forming effect.

Titanium and silicon amplify the ferritic properties of the alloy: titanium (Ti) makes it possible to eliminate the tendency of the steel to the intercrystalline corrosion, since it reacts with carbon and forms refractory carbide TiC, thus preventing a decrease in the chromium (Cr) concentration in the alloys, which also forms carbides.

Silicon (Si) increases the steel density and favors the melt degassing; in addition, this element increases the strength of the steel and the yield strength of parts fabricated from it, but it slightly decreases the ductility, which hampers cold rolling.

Manganese (Mn) decreases the grain growth rate, favoring the formation of a fine-grained structure of the steel and, therefore, the enhancement of the characteristics of metal products.

The phosphorus (P) content in 12Kh18N10T steel cannot be higher than 0.035%. This characteristic has

Table 1. Chemical composition of 12Kh18N10T steel

C	Ti	Cr	Cu	Mn	Ni	P	S	Si	Fe
≤0.12	≤1	17—19	≤0.03	≤2	9—11	≤0.035	≤0.02	≤0.8	For balance

Table 2. Physical properties of 12Kh18N10T steel

t_{test}, °C	$E \times 10^{-4}$, N/mm^2	λ, W/(m K)	$\rho \times 10^6$, Ω/m	C, J/(kg K)
−253	29.0	2.1	−	−
−183	22.5	9.2	−	−
−70	21.2	−	−	−
100	−	16.3	0.80	470
200	−	17.6	0.87	495
300	16.2	18.9	0.94	516
400	−	20.5	0.99	546
500	−	21.8	1.05	571
600	14.0	23.5	1.09	592
700	12.2	24.7	1.14	613
800	9.1	26.4	−	−
900	−	28.5	−	−

t_{test} is the test temperature, °C; E is elastic modulus (18 × 10^{-4} N/mm^2 at 20°C); λ is thermal conductivity, W/(m K); ρ is the electrical resistivity (0.75 × 10^6 Ohm/m at 20°C); and C is the specific heat, J/(kg K).

Table 3. Mechanical properties of the parts made of 12Kh18N10T steel

t_{test}, °C	σ_u, N/mm^2	$\sigma_{0.2}$, N/mm^2	δ_5, %	ψ, %
−253	1790	600	25	−
−196	1610	460	38	56
−70	1130	360	40	64
20	620	280	41	63
300	460	200	31	65
400	450	180	31	65
500	450	180	29	65
600	400	180	25	61
700	280	160	26	59
800	180	100	35	69
900	91	100	36.3	69.6
1000	55	100	43	71.3

σ_u is the rupture ultimate strength, N/mm^2; $\sigma_{0.2}$ is the yield strength at a residual strain of 0.2%, N/mm^2; δ_5 is the relative elongation per fivefold specimen length, %; and ψ is the relative reduction of area, %.

a critical significance, since the parts of this steel are used in cryogenic engineering, and phosphorus adversely affects the mechanical properties of the parts: plastic properties of the steel decrease at low temperatures.

The main advantages of parts from 12Kh18N10T steel are quite a high impact toughness and ductility. The disadvantages are relatively low corrosion resis-

tance in media containing chlorine ions and also sulfuric and hydrochloric [1].

The technical characteristics of 12Kh18N10T steel (GOST 5632−72) are as follows:

(a) density is 7920 kg/m^2;

(b) forging temperature conditions: 1200°C at the beginning and 850°C at the end;

(c) weldability: there are no limits; subsequent heat treatment is desirable;

(d) cutting, only in the quenched state;

(e) high-temperature strength in air: strength group nos. 2−3 at T = 650°C and strength group nos. 4−5 at T = 750°C;

(f) flakes sensitivity is absent.

The best heat treatment of steels of this class is quenching from 1050−1080°C into water, after which parts are characterized by a high toughness and ductility but a low strength and hardness. The properties of the steel (after heat treatment) are given in Tables 2 and 3 [2].

The 12Kh18N10T steel is melted in ESPTs-6 shop at the Electrostal metallurgical plant in an amount of 500 t/year in two 1100-kg induction melting furnaces combined into a unified steelmaking plant consisting of a melting unit, which, in turn, consists of two induction furnaces, a hydraulic drive unit, and the electrical equipment of the furnaces. To provide the service reliability, the rigidity of all the construction, and the possibility of sloping the crucible during metal release, the furnace were placed into a special cage made of a nonmagnetic (stainless) steel, whose fasteners must not form a closed magnetic path. The cage was fixed by asbestos-cement plates at its bottom using stainless-steel angles and bolts.

An induction heater and a crucible are the main elements of the induction unit.

The furnace crucible forms the melting space of the furnace and is a technological process zone, into which a charge is loaded for melting.

The crucible sizes are as follows: the ratio of the mean internal crucible diameter d_0 to its height H, i.e. d_0/H = 0.6−1.0 at the mean wall thickness δ = (0.1−0.25)d_0. To provide the mechanical strength of the crucible filled with metal, the wall thickness is changed with height and the internal surface is cone-shaped with the slope angle α = 2°−4°. The vertical walls are usually connected to the bottom at an angle of 45°−50° or with a smooth transition [3]. The crucible lining can be basic or acid. The durability of acid crucibles is 80−100 heats. The durability of a basic lining is slightly higher and is usually no less than 100 heats (to 150 heats).

During melting, a crucible undergoes thermal, erosive, and corrosive influence of liquid metal, the action of the slag chemical corrosion, a static pressure

of the liquid metal column, mechanical and impact loads during charge loading and during heats.

The performance characteristic of the furnaces entering in the composition of the induction plant in the SPTs-6 shop is presented in [4].

Both the induction crucible furnaces entering in the composition of the induction plant are indented for production of quality and high-quality steels and alloys by remelting industrial wastes. In the production process, usually one furnace is in operation, and packing, drying, and preparing the crucible to heat are carried out in the second furnace.

TECHNOLOGY OF MELTING OF 12Kh18N10T STEEL

The melting of 12Kh18N10T stainless steel in induction furnaces is carried out by remelting of the industrial wastes of stainless steel, which do not contain nitrogen, aluminum, boron, niobium, and, what is desirable, unalloyed with titanium. Induction heating makes it possible to produce an ultrahigh-purity metal in chemical composition (there is no carbonization process, and the metal is insignificantly saturated with nitrogen); in addition this melting method is characterized by smaller metal loss and, particularly, the loss of alloying elements as compared to the alloy production in arc furnaces [3, 5].

There are two limits of sulfur contents in the finished metal: no higher than 0.020% as finished parts are welded, and no higher than 0.030% in all other cases. If the sulfur content in the first sample is low (S ≤ 0.020−0.025%), it is allowed to carry out an accelerated refining of the melt, i.e., under semi-acid slag, which form due to an addition of chamotte powder or breakage. On the other hand, if a ready metal has to meet rigid requirements with respect to the sulfur content (no higher than 0.020%), a heat is carried out under basic quicklime slag. In this case, the refining process is more long-term.

The highest percentage of alloys melted in the workshop is constituted by stainless alloyed corrosion-resistant B26 steels, the charges for which are the industrial wastes of parts from chromium−nickel and chromium−nickel−titanium steels with the following contents of main elements: 8.0−13.0% Ni, 17.0−20.0% Cr, up to 2% Mn, up to 3% Si, and up to 1.2% Ti. The wastes come from steel-making shops in the form of short-runs, pouring gates, and scrap, and from processing plants as crop ends, reject, and chips. In addition, the wastes of processing parts of stainless steels come from consumer plants in the form of chips, rejected products, crop ends, and waste products.

Charge Preparation

When melting 12Kh18N10T steel, a charge should contain no less than 60% steel waste and be cleaned from paint and oils. Scrap should be prepared for heat in granulators and presses: chips should be briquetted and thin steel crop ends should be packed on hydraulic presses; fluxes should pass through crushers, and the coke from a hopper is fed for sieving through screens.

The charge for induction furnaces should be composed using a rational selection of the sizes of the pieces for their dense laying in the crucible. It is known [3, 6] that small charge pieces loaded in the induction furnace generate an insignificant specific power, which increases the melting time and the electric energy consumption; moreover, the lower current frequency, the larger is the depth of its penetration and the lower consumed specific power. Thus, a charge consisting mainly of medium and coarse pieces can be used at a low frequency of the induction heater current.

The charge should not be significantly oxidized, since the oxide film on the piece surface affect the contact to each other and the pieces do not form full-value electric contact, the absence of which lead to the situation as the induced eddy current will be closed in each solo piece, and this fact increases the melting time and the electric energy consumption; in addition, in this case the induction heater current jumps are observed. The practice of servicing induction furnaces [6] showed that the denser charge laying, the faster the heat and the lower electric energy consumption. The charge should be layered most rationally as follows.

Charging and Melting

Because the furnace capacity is small, the charging is carried out by hand, the charging time is 15−20 min, and the time-to-melting is about 20 min. To prevent the damage of the furnace crucible liner by coarse charge fractions, it is recommended to place small-sized charge on the crucible bottom; to prevent the metal against oxidation, it is recommended to pour some slag and some ferromanganese and ferrosilicon. Then, refractory ferroalloys with high melting temperatures are loaded. Such charging system assures the melting of the ferroalloys immediately after the formation of first portions of the liquid metal. Then, the medium and coarse charge pieces are charged up to the crucible top. If the furnace operates with additional charging, refractory materials with lower melting temperatures are used for it.

The crucible should not be charged above the upper induction heater turn, since in this case, the upper layers of metallic charge are not intersected by magnetic field lines and are quite weakly heated due to the contact thermal conductivity from the pieces lying below; in this case, the charge lowering during melting is hampered [2, 6].

Before melting, the crucible is brought into the working state: it is purified from undesired elements presented in the previous heat when needed.
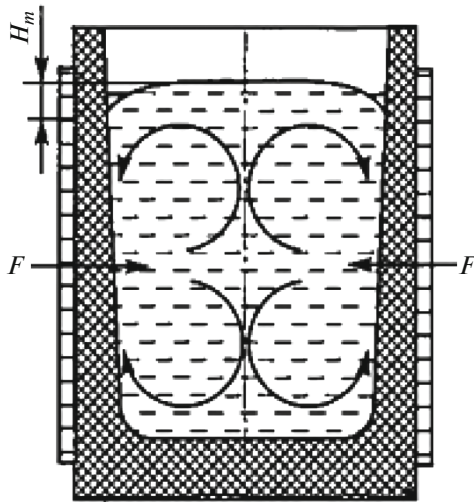
Fig. 1. Scheme of the electrodynamic metal circulation in an induction furnace crucible.

After the furnace is turned on, it is recommended to introduce a decreased power for first 6−8 min up to the moment of ceasing the current jumps in the induction heater. Then, the input power is gradually increased, and the furnace operates at the maximum power up to finishing the melting period, and it is decreased to 30−40% of the maximum power after the complete metal melting. The furnace is additionally charged as the charge level decreases.

As first visible portions of the liquid metal, a slag mixture is added into the crucible; in the case of an acidic furnace, this mixture consists of 10% powdered glass, 65% chamotte, and 25% lime; for steelmaking in a basic crucible, the mixture consists of 60−65% lime, 15−50% magnesite, and 20−25% fluorspar. After melting of the main charge mass (80−95%), it is necessary to take a metal sample for the chemical composition (proximate analysis). After receiving the results of metal analysis, the metal is deoxidized and alloyed. To dilute slag, fluorspar or waste fluxes after electroslag remelting are used, and lime and magnesite powder are used for thickening. During melting and formation of liquid metal, slag forming materials are added in the crucible in the amount sufficient to complete coat the metal mirror with slag.

During melting, the charge hanging and the formation of "bridges" should not be allowed, since these factors can lead to a local overheating of the melt and, as the result, to erosion of the crucible lining or metal emissions during the charge settling; to prevent them, the charge should be settled periodically.

As a result of strong development of convection flows caused by induction current in the melt, the oxidation of impurities containing in it proceeds quite intensively and can be accompanied with the metal foaming, which leads to the melt splash beyond the furnace collar. In order to prevent this process, oxidants should be added by small portions.

During melting the charge, some part (15−20%) of the melt surface is allowed to be free from slag. After the complete charge melting and metal heating, slag is poured off and new slag is prepared from the standard slag mixture for complete coating the metal mirror.

It is known that the peculiarity of the induction method of obtaining liquid metal is the formation of meniscus on melt surface. The interaction of the induction heater current with the current induced in the surface layer of the melt in the crucible leads to the formation of electrodynamic forces, which act on liquid metal and are directed to the crucible axis. These forces cause metal circulation called electrodynamic circulation, whose intensity can be estimated by the height of the convex meniscus (its "camber") H_m formed on the melt surface. An increase in the induction heater current frequency is known to increase the specific power of the furnace and its capacity, but the higher input power the higher meniscus camber [3].

The electromagnetic mixing of a melt along one- or two-contour trajectories leads to equalizing the temperature and chemical composition of the metal over the crucible volume. In this case, the processes of melting of alloying elements and, if required, carbonization occur quicker and more intensive. However, the excess mixing intensity and the formation of the meniscus on the melt surface lead to a distortion of the slag coating continuity, since slag flows down to the crucible walls, and the liquid metal mirror is partially or completely opened. As a result, the metal losses and the dissolution of atmospheric gases in a metal increase; moreover, a gas and a metal can be ejected, and heat loss also increase.

In practice the allowed mixing intensity in the furnaces is provided as the specific input power is no higher than 230−300 kW/t. In this case, the metal flow rate is ~2.5 m/s in the middle part of the crucible and about 4 m/s near its walls [2, 3].

Melt Refining

The moment of slag discharging is considered to be the start of a refining period. New slag is deoxidized using brokalk (a mixture of lime and aluminum oxides) and powder silicon-containing deoxidizers. According to experimental−industrial heats, the silicon assimilation was 45−50%.

Manganese and ferrosilicon are added after slag clarification (approximately within 8−10 min after addition of powder deoxidizers). 6−8 min before metal discharge, metal is deoxidized with a nickel−magnesium master alloy and silicocalcium. Technological addition of titanium is made 3−5 min before metal discharge. According to experimental−industrial heats of 12Kh18N10T steel, the refining period was no less than 20 min.

The metal temperature before tapping was 1540–1580°C.

Pouring of Metal

The metal was poured into a metal mold or ingot molds depending on the type of order. When casting into a ladle, it should be heated; the heating time is at least 1 h. The holding of the metal in the ladle should be no less than 2–3 min.

On casting into molds, it is recommended to protect the metal stream by argon to avoid the ingress of atmospheric gases into the melt.

When unloaded from the molds, the ingots are cooled in wells or preheated thermostats for at least 8 h.

CONCLUSIONS

A technology for melting 12Kh18N10T steel in an FS induction crucible melting furnace by remelting industrial wastes was developed using the dependence the furnace indices on the quality of charge, namely, its surface purity, fraction composition of charge materials, and the order of their charging in a crucible. The experimental–industrial heats showed that the use of a charge with coarse and medium sizes of lump materials leads to a decrease in the melting time by 5–8% as compared to the use of a significant part charge made of small fraction and chips.

A careful selection of the charge in the fraction composition and following the rule of charging, the use of a charging basket instead manual charging leads to an increase in the induction unit performance: the heat time is decreased. In turn, the furnace capacity increases and the energy consumption decreases.

The experimental–industrial heats revealed the dependence of the size of the meniscus camber, which forms on the melt surface, on the charging level in a crucible and the power input in the furnace.

It was found that, to optimize the melting process, it is necessary to select the furnace load introduced into the furnace so as to prevent metal ejection from a furnace and to prevent the liquid metal surface from being opened, and charging should be so that the upper level of the change is no higher the upper turns of the induction heater.

The proposed scheme of charging and the selection of the optimal power input into a furnace led to a decrease in the meniscus camber, which provided a decrease in the metal loss by 4–6% and a decrease in the consumption of slag forming materials.

In the absence of dead times, the following results were obtained:

(a) the furnace capacity for 1030 kg charge was 1.7–1.85 t/h at a specific energy of 570–580 kW/t;

(b) the specific energy consumption decreases by 5–7% as compared to the annual averages (according to melting certificates of furnaces);

(c) the metal loss and the consumption of alloying elements decrease by 4–6% when the upper charge level is below the crucible "collar" or the upper section is turned off during melting;

(d) the consumption of slag-forming materials decreases by 3–5% due to a decrease in the meniscus camber.

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