filler in the form of powder of the Rene-142 alloy were developed.

2. It was shown that stable strength of BJ of the JS26NK alloy, produced with application of the NS12 complex brazing alloy, exceeded strength of the JS26VI joints after similar heat treatment. Difference consisted only in the fact that in case of the NK alloy duration of high-temperature ageing was 4–5 h, while in case of the JS26VI alloy — 2 h. Maximal BJ strength value was 1067 MPa, relative elongation — 15–23 %.

3. Application of the complex brazing alloy, in which simultaneously boron and silicon were used as the depressant, allowed producing BJ, characterized by stably high values of ultimate strength and relative elongation in comparison with BJ, produced with application of the #1 + 60 % Rene-142 base brazing alloy.

4. It was found that in case of coincidence of the dendrite growth direction with vector of the applied load, strength of the specimens and their ductility depended upon crystallographic orientation of growth of dendrites in the NK alloy.

5. It was shown that BJ mechanical characteristics of the JS26NK alloy, determined on the specimens cut out both along and across of the dendrite growth direction, are close at room temperature. Yield strength of longitudinal specimens is somewhat higher than that of the cross specimens.

6. Application of the #1 + 20 % NS12 + 60 % Rene-142 complex brazing alloy allowed producing high-strength flawless BJ of the JS26NK alloy with natural gap 400–780 MPa at the brazing temperature 1225 °C (15 min).

7. The weakest place in case of extension of the BJ specimens of the JS26NK alloy is fusion line, in which segregations of carboboride phases and Me_6C carbides of acicular shape was detected. Heat treatment (ageing at 1050 °C, 4–5 h) allows forming BJ structure with uniformly distributed hardening γ'-phase. In case of increase of its volume content growth of yield strength of the BJ metal was registered.

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IMPROVEMENT OF STRUCTURE AND PROPERTIES OF CAST FERRITE-PEARLITE STEELS FOR TRANSPORT MACHINE BUILDING

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Technology for complex modification of casting from low-alloy ferrite-pearlite steels by titanium, aluminium and nitrogen was developed, which ensures increase of the lower level of yield strength in normalized (≥ 380 MPa) and temper hardened (≥ 450 MPa) state, the rest requirements to mechanical properties of the 20GL steel being preserved.

Keywords: steel, casting, carbonitride hardening, titanium, aluminium, nitrogen, grain index, yield strength, impact toughness

Main task of freight railway car building is increase of the car run before the first planned repair from 100–120 to 500 thou km, whereby guaranteed service life of cast elements of the carriage and the car as a whole should be not less than 16 years before the planned repair, its full service life being up to 32 years [1].

An efficient measure for ensuring these requirements, in addition to new design solutions, is improvement 1.2–1.3 times of strength characteristics of metal of the railway car cast elements, first of all yield strength up to ≥ 380 MPa, the rest mechanical properties being not lower than the normative ones (according to the valid standards).

The simplest solution of this task is increase of degree of steel alloying by the elements, which form substitution solution with iron (silicon, manganese, chromium and nickel). Application of the latter is

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connected with significant rise in price of steel and need to make import purchases. Increase of content of just silicon and manganese, alloys of which are comparatively cheap and accessible in Ukraine, without taking additional measures is limited because of reduction of plasticity level, especially impact toughness of steel, and worsening of weldability. As a rule, content of silicon in these steels should not exceed 0.4–0.6 wt.%, its ratio with manganese being not more than 1:2 [2].

For refining of the grain and suppression of its growth during heating, including welding, modification of steel by its microalloying with nitrogen and elements characterized by increased affinity to it — mainly vanadium [3], less often niobium [4], is used. Disadvantage of such solution, in addition to very high cost of the microalloying elements, is relatively low thermodynamic strength of nitrides of these elements, dissociation of which occurs during heating in the process of heat treatment and in the near-weld zone in welding, which reduces effect of the grain refining.

In works of National Metallurgical Academy of Ukraine and the Z.I. Nekrasov Institute of Ferrous Metallurgy of the NAS of Ukraine, which concern production of rolled stock of broad size assortment, efficiency of replacement in steels modified by carbonitrides, of expensive vanadium and niobium by relatively low-cost and less deficient nitride-forming elements — titanium and aluminium [5], is shown, whereby possibility is established of achieving required properties of hot-rolled stock by alloying the carbonitride hardened (CNH) steel just by silicon and manganese without using chromium and nickel.

Adaptation of these principles of microalloying to casting in railway car building allows evaluating possibilities of ensuring requirements, established for cast elements of freight railway cars of new generation.

At present according to OST 32.183–2001, the 20GL steel and its modifications 20GFL, 20GTL and 20KhGNFTL are used for cast components of carriages of 1520 mm gauge double-axle freight railway cars (side frame and the above-spring beam). For achieving maximal strength of cast components of the freight car carriages, the 20GL steel is alloyed by chromium and nickel, which increase solid solution hardening of ferrite, and by vanadium and titanium, carbides of which enable dispersion hardening, whereby regulated level of the 20KhGNFTL cast steel yield strength ($\sigma_y \geq 373$ MPa) anyway remains somewhat lower than that established in new recommendations [1]. In addition, application of this steel is limited by very strict requirements in regard to content of phosphorus and sulfur (≤ 0.02 % for each element), which causes the need of prolonging both oxidation and reduction periods of melting, practically complete removal of phosphorus slag prior to the refining, increase of consumption of deoxidizers, lime and fluxes, and taking other technological measures.

In a number of works [6, 7] possibility of improving properties of the cast metal by its alloying with nitrogen in combination with titanium or aluminium is considered. However, selected level of content of these elements (up to 0.025; 0.150; ≥ 0.100 wt.%) causes significant reduction of the metal plasticity and increases inclination of steel to crack formation in the processes of manufacturing and operation of the castings. That's why we carried out investigations, directed at optimization of composition of the 20GL cast steel, complexly modified by titanium and aluminium nitrides.

Experimental melts were carried out in the IST-0.06 induction furnace with acid lining. The materials, used in melting of the 20GL steel in arc furnaces (wastes of the arc melted 20GL steel, the FS65 ferrosilicon, the MnC17 ferromanganese silicon; the FTi35 ferrotitanium; alumocalcium wire), were used as the charge in order to be closer to conditions of commercial production.

For introducing into the steel required content of nitrogen, the nitrogen-containing ALK master alloy, produced on the basis of the FMn78 standard ferromanganese, was used [8]. Content of the additive nitrogen-containing master alloy varied within 0.83–7.50 kg / t (0.05–0.45 kg per melting). Weight share of titanium, which is jointly with nitrogen one of the main hardening additives, in all experimental melts was increased in comparison with standard 20GL steel, and in majority of cases varied within 0.008–0.025 %. In a number of melts upper limit was increased for investigation purpose up to 0.07–0.11 wt.% [6, 7]. It should be noted that according to valid normative-technical documentation addition of deoxidizers and modifiers without limitation of their kinds and residual contents is allowed in melting of the 20GL steel for transport machine building. Content of the rest alloying elements, carbon and impurities was maintained within requirements of standards on the 20GL steel. Only in two melts content of silicon was somewhat increased (up to 0.72 wt.%) for getting static dependences of silicon content.

For getting comparable results, standard melting of the 20GL steel without addition of nitrogen-containing master alloy and ferrotitanium was carried out in addition to the experimental one.

Charging, which consisted completely of the 20GL steel wastes, was carried out in several stages by means of foundering and settling down of the loaded charge.

After full melting of the charge and soaking for the purpose of the melt preheating a sample was taken for analysis of the metal, and the required amount of ferromanganese silicon and ferrosilicon was consecutively added into the furnace. After a short soaking for full assimilation of the alloying elements, temperature was measured by means of an immersion thermocouple. Tapping temperature (approximately 1650 °C) was adjusted by means of soaking of the metal in the switched on furnace, assuming rate of

Chemical composition and results of tests of commercial 20GL steel modified by nitrides of titanium and aluminium

Series	Number of melts	Consumption of ALK, kg / t	Weight share of elements, %				
			C	Si	Mn	$Ti \cdot 10^4$	$Al \cdot 10^4$
I	1	0.83	0.19	0.53	1.33	46	72
II	11	1.25	0.17–0.22	0.33--0.78	1.18--1.50	8–24	19--52
III	1	2.50	0.20	0.42	1.35	60	60
IV	5	5.00	0.21–0.24	0.35--0.45	1.30--1.44	22--31	21--60
V	1	7.50	0.20	0.47	1.36	110	60
VI	1	–	0.22	0.38	1.29	2	23
Commercial melts	2314	–	0.17–0.24	0.20--0.60	1.05--1.50	≥4	10--82
OST 32.183–2001			0.17–0.25	0.30--0.50	1.10--1.40	--	20–60***

Table (cont.)

Series	Mechanical properties						
	After normalization*				After temper quenching**		
	σ_y, MPa	σ_t, MPa	KCU^{-60}, J / cm^2	Grain index	σ_y, MPa	σ_t, MPa	KCU^{-60}, J / cm^2
I	410 / 380	610 / 580	55–63 / 31–37	9, 10 / 8, 9	560 / 460	740 / 650	44--53 / 53--55
II	405–460 / 360–440	580–660 / 560–640	27–67 / 25–63	8, 9, 10 / 8, 9 (7)	520--580 / 440--530	680--690 / 620--700	40--65 / 31--56
III	410 / 370	610 / 610	37–50 / 36–41	9, 10 / 8	650 / 520	750 / 730	37 / 22--28
IV	415–470 / 390–440	610–660 / 590–630	19–51 / 25–50	10, 9 / 9, 8 (7)	495--540 / 480--510	660--690 / 600--660	45--59 / 27--55
V	440 / 380	640 / 610	19–31 / 19–35	9, 10, 8 / 8, 9	630 / 540	760 / 710	25--37 / 19--22
VI	390 / 370	600 / 580	35–36 / 12–14	8, 9 / 7, 8	520 / 460	660 / 640	26 / 32
Commercial melts	– / 305–400	– / 490–660	– / 10--105	– / 7, 8, 9 (6)	-- / 400--530	-- / 550--700	-- / 25--100
OST 32.183–2001	≥ 343	≥ 490	≥ 24.5	≥ 8***	--	--	--

*In numerator data after heat treatment under laboratory conditions, in denominator ---- under workshop conditions are presented.
**In brackets grain index, registered in some specimens, is shown. ***Requirements, introduced by RZhD since 01.01.2007.

its heating was about 10 °C / min. The melt was tapped into the preliminarily heated ladle with acid lining.

For the purpose of improving assimilation of titanium and nitrogen, deoxidizing of the metal was performed in two stages. Immediately before tapping, half of the required amount of alumocalcium wire was fed on bottom of the ladle. After approximately 1 / 3 of the ladle was filled, the rest aluminium, ferrotitanium and nitrogen-containing master alloy were added under the jet. The metal was cast in three standard test bars (GOST 977–88), which were subjected to heat treatment (normalization at 920–950 °C) or high-temperature temper quenching. Results of the carried out investigations are given in the Table.

As far as it's not chemical and phase composition of steel, which exerts significant influence on structure and properties of the metal in heat treatment in continuous industrial furnaces, but conditions of heating and cooling of the items of big mass, for getting more substantiated conclusions about role of the carbonitride hardening, normalization of the specimens of all experimental melts and hardening of a portion of them were performed in parallel under workshop and laboratory conditions.

One can see from Figure 1 and the Table that irrespective of consumption of the nitrogen-containing master alloy and chemical composition of steel concerning base elements and modifiers, in all melts rather rapid cooling of the billets ensured presence of a finer grain and, respectively, increase of the yield strength level. Size of the grain being the same, the 20GL steel modified by titanium and aluminium nitrides significantly exceeds conventional steel and is characterized by the required level of $\sigma_y \geq 380$ MPa even after heat treatment under industrial conditions. This conclusion is confirmed by processing of the results of commercial and experimental melts concern-

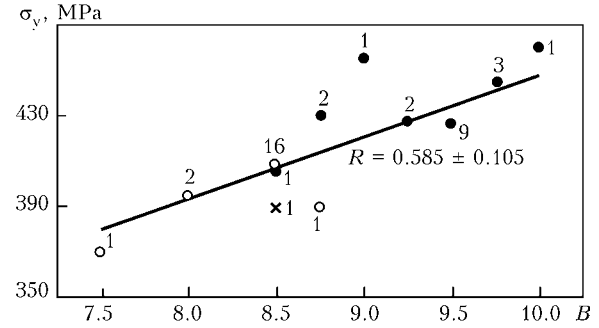

Figure 1. Influence of ferrite grain index B in 20GL steel on its yield strength after normalization under workshop (○) and laboratory (●) conditions: × — melting without CNH; figures near points indicate number of melts; R — correlation factor

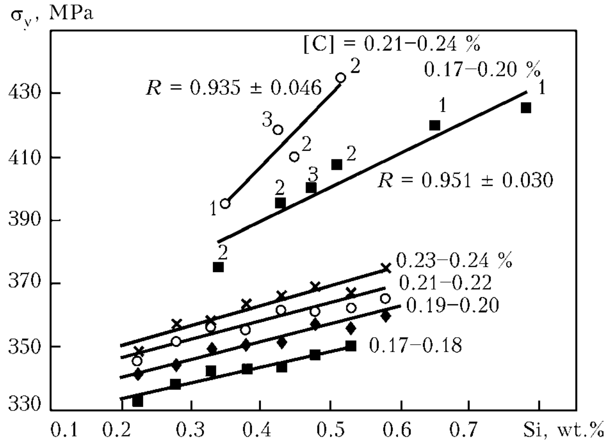

Figure 2. Influence of silicon and carbon on yield strength of commercial (lower curves, 2314 melts) and modified (upper curves) 20GL steel after normalization under industrial conditions (designation of points and figures near points hear and in Figures 3–6 are the same as in Figure 1)

ing function of content of base elements — silicon and carbon (Figure 2). In connection with relatively small number of experimental melts, their processing was carried out only proceeding from two ranges of carbon content.

Similar dependences exist in relation to manganese. That's why for ensuring necessary level of the commercial casting hardness it is recommended in addition to complex modifying of steel by titanium, aluminium and nitrogen to narrow allowable ranges of content of base elements, having increased lower limit for carbon up to 0.2, for silicon up to 0.4 and for manganese up to 1.2 wt.%.

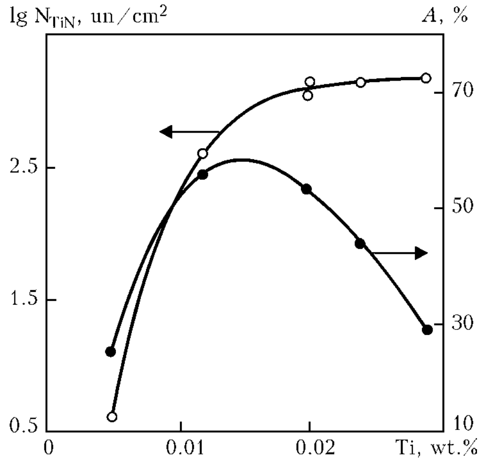

Figure 4. Influence of titanium content on share A of fine carbonitrides in 20GL steel

In contrast to the base elements influence of titanium on mechanical properties of the 20GL steel is of extreme character (Figure 3), which fits well change of content and size of formed titanium carbonitrides (Figure 4). As their content increases up to 0.015 wt.%, share A of fine carbonitrides, which regulate size of the primary grain, grows, and then it starts to fall, thus reducing both dispersion and grain boundary hardening.

Respectively, for sufficiently reliable ensuring required level of mechanical properties of the commercial casting recommended content of titanium in steel with CNH is 0.013–0.035 wt.% (outlined area in Figures 3, 5 and 6).

Extreme character is also registered in consumption of ALK with optimum in the area of 2.0–3.7 kg / t

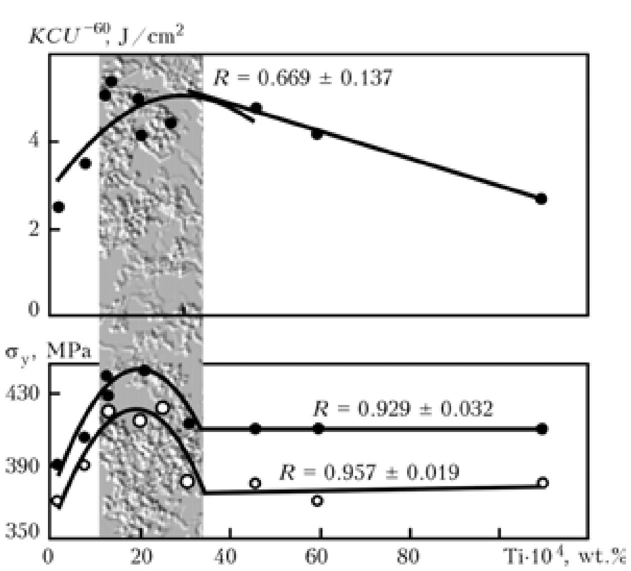

Figure 3. Influence of titanium content on yield strength and impact toughness of 20GL steel with CNH

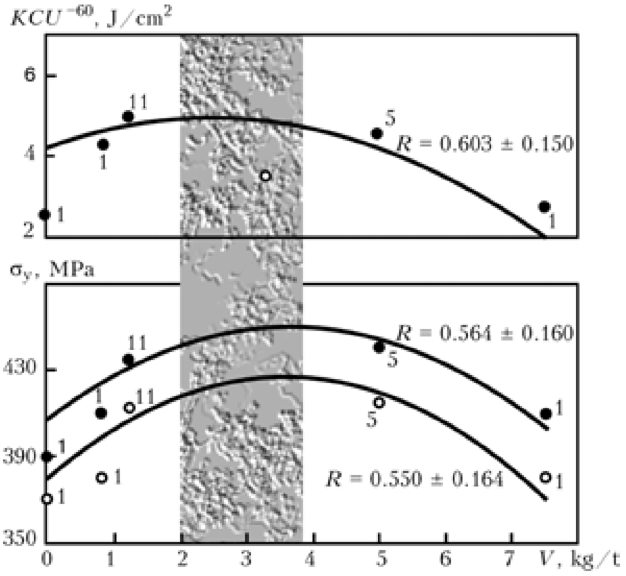

Figure 5. Influence of consumption V of ALK on yield strength and impact toughness of normalized 20GL steel

both for normalized steel (Figure 5) and for high-temperature temper quenched steel (Figure 6).

As it follows from presented in the Figures correlation factors, value of ratio R / σ_y for all experimental dependences exceeds 3, which corresponds to the level of fiduciary probability of the data obtained ($\alpha \geq$ ≥ 0.95) and is rather high value for multifactor investigations. This allows speaking about high statistic reliability of the data obtained and predicting their reproducibility in melting of the 20GL steel with CNH in industrial furnaces.

CONCLUSIONS

1. Modification of the 20GL ferrite-pearlite steel by titanium, aluminium and nitrogen in combination with rather narrow ranges of content of base elements (silicon, manganese and carbon) corresponds to the level of requirements, established for cast elements of freight railway cars of new generation.

2. The results obtained have high statistic reliability and are accepted for industrial application.

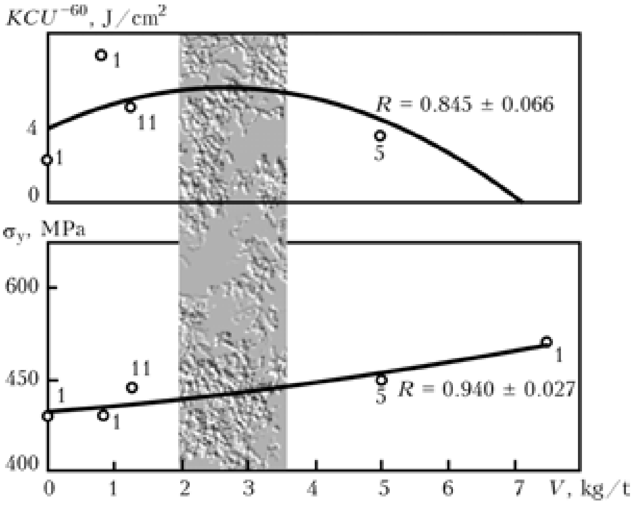

Figure 6. Influence of ALK consumption *V* on yield strength and impact toughness of high-temperature temper quenched 20GL steel

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ANALYSIS OF TECHNOLOGICAL DEVELOPMENT OF FINISH METAL PRODUCT TREATMENT

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Review of existing in the world methods of the rolled metal heat treatment and technological directions of coating application on metal products is made. Results of technological development analysis of finish metal product treatment are presented. The most rational technological schemes of finish metal product treatment are suggested.

Keywords: heat treatment, quality metal product, anticorrosion coatings, controlled rolling

Intensive development of construction and automotive industry within postwar period up to nowadays required high amount of quality metal products.

Improvement of the rolled stock quality is to a significant degree ensured in the process of the fourth metallurgical process stage (heat treatment, heat hardening, and application of protective anticorrosion coatings).

Quality metal product is rather wide idea. One of its components is rolled stock from alloyed, low-alloy, carbon and low-carbon steels, produced by the method of controllable rolling, heat treated in separate units after rolling, subjected to heat treatment in rolling heating, with metal or non-metal coatings. Growth of volume of production of quality steels is presented in Figure 1.

Special attention has to be paid to wish of the metal product consumers to get it in the form, suitable for manufacturing of their products.

That's why metallurgical plants try to produce rolled stock with preset properties — a combination

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