УДК 621.74.04:669.14

https://doi.org/10.34185/tpm.1.2021.03

Пройдак Ю.С., Підгорний С.М., Трегубенко Г.М., Поляков Г.А., Підяш Л.А.

Підвищення якості та вдосконалення технології виробництва економнолегованих сталей для енергетичного машинобудування

Proidak Yu., Pidhornyi S., Tregubenko G., Polyakov G., Pidyash L.

Improvement of quality and improvement of technology of production of economic alloyed steels for power engineering

Мета. *Дослідити вплив комплексного мікролегування азотом, титаном і алюмінієм на структуру і властивості литих низьколегованих сталей при підвищених температурах.*
Методика. *Для металографічного аналізу мікроструктури сталей застосовувалися методи оптичної мікроскопії. Механічні властивості при кімнатній і підвищеної температури визначали на статичний розтяг, загин і ударний вигин.*
Результати. *Технологія карбонітридного зміцнення кремніймарганцевих теплостійких сталей пройшла дослідно-промислове опробування. Результати механічних випробувань свідчать про сприятливому комплексному впливі азоту, титану і алюмінію на властивості стали 20ГСЛ в усьому діапазоні робочих температур.*
Наукова новизна. *Вперше досліджено вплив нанодисперсних карбонітридних фаз (TiN, AlN) на механічні властивості низьколегованої кремніймарганцевої сталі типу ГСЛ при підвищених температурах (250-450^{0}С).*
Практична значущість. *Застосування технології карбонітридного зміцнення кремніймарганцевих теплостійкої електросталі забезпечує підвищення експлуатаційної надійності, збільшення терміну служби і зниження металоємності устаткування енергетичного машинобудування.*
Ключові слова: *технологія, електросталь, теплостійкість, карбонітридне зміцнення, мікролегування, сталь 20ГСЛ*

Purpose. *Investigate the effect of complex microalloying with nitrogen, titanium and aluminum on the structure and properties of cast steels at elevated temperatures.*
Methodology. *Methods of optical microscopy were used for metallographic analysis of the microstructure of steels. The mechanical properties at room and elevated temperatures were determined for static tension, crease and impact bending.*
Results. *The technology of carbonitride strengthening of silicon-manganese production steels has passed pilot testing. The results of mechanical tests indicate a favorable complex effect of nitrogen, titanium and aluminum on the properties of 20GSL steel in the entire range of operating temperatures.*
Scientific novelty. *For the first time, the effect of nano-dispersed carbonitride phases (TiN, AlN) on the mechanical properties of low-alloy silicon-manganese steel of the GSL type at elevated temperatures (250-4500C) has been investigated.*
Practical value. *The use of carbonitride technology for strengthening silicon-manganese heat-resistant electric steel provides an increase in operational reliability, an increase in the service life and reduce the metal consumption of equipment for power engineering.*
Keywords: *technology, electric steel, heat resistance, carbonitride reinforcement, microalloying, steel 20GSL.*

Introduction. Nowadays, low-alloy silicon-manganese steels are used for the manufacture of castings of critical-purpose and increased strength parts operating in the temperature range from -40 ° C to + 450 ° C. For example, 20GSL steel is used for the production of parts for hydro, steam and gas turbines, parts for equipment of nuclear power plants, heat supply stations, combined heat and power plants, nuclear reactors and installations, as well as parts of welded-cast structures with a large volume of welding. Accordingly, an increase in the strength of low-alloy silicon-manganese steels provides:

- increased service life and reduced costs and time for repair work;
- increase operational reliability;
- reduce in metal consumption.

Analysis of literature indicates and problem statement.To obtain high strength properties, low-alloy silicon-manganese steels (15GSL [1-4], 20GSL [5-7], 25GSL[8], 30GSL [5]) contain a sufficiently high concentration of silicon, which worsens their impact and plastic characteristics. It should be noted that in foreign analogs of steels of this class (for example on DIN EN 10269) the silicon content is limited to a level of ≤ 0.50%. To mitigate the effect of silicon on brittleness and improve the mechanical and operational properties of low-alloy silicon-manganese steels, we proposed their complex microalloying with nitrogen, titanium and aluminum. Complex microalloying with these elements provides high mechanical properties of low-alloy silicon-manganese steels at room and low temperatures (up to - 60 ° C) due to the refinement of the metal structure[9, 10], whereas at elevated temperatures (250 - 450 ° C), this can be achieved by strengthening the volume of the grains with finely dispersed titanium carbonitride, and their boundaries - aluminum nitride.

The purpose and objectives of the research. To enhance the quality and improve the production technology of economically alloyed steels for power engineering, it is necessary to study the effect of complex microalloying with nitrogen, titanium and aluminum on

Пройдак Юрій Сергійович – д.т.н., проф. НМетАУ

Підгорний Сергій Миколайович – НМетАУ,
Трегубенко Геннадій Миколайович - д.т.н., проф. НМетАУ
Поляков Георгій Анатолійович - НМетАУ,
Підяш Любовь Андріївна – студент НМетАУ.

Projdak Yuri - doctor of engineering's sciences, professor - NMetAU
Podgorniy Sergey - NMetAU
Tregubenko G. - doctor of engineering's sciences, professor - NMetAU
Polyakov G. – NmetAU
Podyash Lyubov - is a student of NMetAU.

the structure, mechanical and operational properties of the metal at elevated temperatures (250-4500C).

To achieve this goal, the following tasks were set:

- to determine the influence of the complex N+Ti+Al on the quality of steels of the GSL type;
- To investigate the effect of heat treatment on the properties of cast silicon-manganese steels microalloyed with nitrogen, titanium and aluminum at elevated temperatures;
- To improve the technology for the production of steels of the GSL type with carbonitride reinforcement.

Materials and research methods. Exploratory and industrial melting was carried out in an IST-0.06 furnace and an electric arc furnace DSP-3. The composition of the metal was determined by chemical and spectral analyzes. Methods of optical microscopy were used for metallographic analysis of the microstructure of steels. Mechanical properties at room and elevated temperatures were determined for static tension, crease and impact bending.

Industrial studies and research are carried out in accordance with modern standards, on instruments and equipment that have passed metrological control, confirms the reliability of the results obtained.

The following materials were used for research: low alloy steel waste, ferrosilicon FS65, iron-silicon-manganese MHC17, ferrotitanium FTi35 and FTi70, aluminum stamp AB-87AB-87, aluminum calcium wire, nitrogen-containing ligatures.

Research results. The study of the effect of complex microalloying with nitrogen, titanium and aluminum on the structure and complex of mechanical and operational properties of steel 20G (S) L was carried out in the conditions of the metallurgical equipment shop of PJSC "Kremenchug Steel Plant" ("KSZ") in an induction furnace IST-0.06 with acid lining. The weight of the heats was ~ 60 kg. In order to approximate the conditions of industrial production, the following materials were used as a charge at the plant: waste steel 20GL, ferrosilicon FS65, iron-silicon-manganese MHC17, ferrotitanium FTi35, aluminum calcium wire. To introduce the required nitrogen content into the steel, we used nitrogen-containing alloys developed and manufactured at NMetAU on the basis of standard ferromanganese FMn78.

After complete melting of the charge and holding for heating the melt, “scrap patch” and a sample for metal analysis were taken, and the necessary amounts of iron-silicon-manganese and ferrosilicon were successively added to the furnace.After a short exposure for the complete assimilation of those alloying, the temperature was measured with a thermocouple. The outlet temperature, which was 1650 ° C, was controlled by holding the metal with the furnace turned on at the rate of its heating ~ 10 ° C / min. The melt was tapped into a preheated ladle with an acidic lining.

In order to improve the assimilation of titanium and nitrogen, the final deoxidation of the metal was carried out in two steps. Immediately before tapping, half of the required amount of aluminum-calcium wire was fed to the bottom of the ladle. Then, after filling ~ 1/3 of the ladles, another aluminum was planted under the stream ferrotitanium and nitrogen-containing ligatures.

The metal was poured into 3 test trial of the "club" type (according to drawing No. 1 GOST 977-88 [5]) according to the accepted technology. In the process of casting, an identification sample was taken, which, after the end of the melting, was sent together with the previous one for analysis. Pursuant to the results obtained, if necessary, adjustments were made to the amount of alloying additions in further heats.

Treatment of "clubs", heat treatment of workpieces, manufacturing and testing of samples were carried out at "KSZ" according to the current instructions. In order to exclude the influence of accidental unaccounted for factors, the heat treatment of the samples was carried out according to two options - in the workshop and laboratory conditions. The chemical composition and test results of the metal are shown in tables 1 and 2.

Table 1. The chemical composition of steel 20GSL is complexly microalloyed with nitrogen, titanium and aluminum and smelted in Ist-0.06

Chemical composition % mass	C	Si	Mn	S	P	Ni	Cu	Cr	N	Ti	Al
Melting № 422	0,19	0,78	1,35	0,035	0,030	0,14	0,13	0,09	0,015	0,012	0,043
Melting № 423	0,17	0,65	1,37	0,030	0,024	0,10	0,10	0,07	0,017	0,013	0,049

Table 2. Mechanical properties of microalloyed steel 20GSL smelted in Ist-0.06

Heat treatment	σ_B H/mm^2	σ_T H/mm^2	δ_5, %	ψ %	KCU^{-60} J/cm^2
№ 1[1)]	630-660	430-460	20-22	37	50-61
№ 2[2)]	620-640	420-425	18-25	35-42	40-63
№ 3[3)]	690-710	555-580	21	47-49	33-61
№ 4[4)]	630-680	530-570	18-19	39-47	31-45

Note: [1)] - normalization in laboratory conditions; [2)] - normalization in the workshop; [3)] - зhardening and high tempering in laboratory conditions; [4)] - quenching and high tempering in the workshop.

Based on the results recommendations were developed for the industrial production of 20GL steel under conditions of "KSZ", containing within the limits of the grade an increased concentration of silicon and complex microalloyed with nitrogen, titanium and aluminum.

Smelting of pilot-industrial smelts of low-alloy heat-resistant silicon-manganese steels complexly modified with titanium nitride and aluminum was carried out under the conditions of AT "Armaprom" in a DSP-3 furnace according to the current technological instructions with changes concerning mainly the addition of microlight elements (N, Ti and Al). As a nitrogen carrier, we used special nitrogen-containing modifiers based on ferro silico manganese or ferrochrome, which were introduced into the furnace before tapping the metal. Aluminum grade AB-87 was fed on a rod to the bottom of the ladle at the beginning of the tapping in the amount of 3.5-5.6 kg / smelt, and ferrotitanium of the FTI-70 grade (1.3-3.0 kg / melt) was fed into the ladle when it was filled by ~ 1/5 of its volume. The chemical composition of pilot-industrial melts of micro-alloy steel 20GSL is shown in Table 3.

Table 3. Chemical composition of standard and complex microalloyed with nitrogen, titanium and aluminum steel 20GSL, smelted in DSP-3

Melting number	Element content, % mass										
	C	Si	Mn	S	P	Ni	Cu	Cr	N	Ti	Al
1-33	0,18	0,76	1,25	0,008	0,011	-	-	-	0,018	0,037	0,06
1-64	0,16	0,62	1,32	0,003	0,025	-	-	-	0,012	0,030	0,03
1-159	0,17	0,58	1,50	0,004	0,019	-	-	-	0,012	0,035	0,10
3-382	0,21	0,75	1,00	0,006	0,030	0,040	0,16	0,29	0,017	0,020	0,05
GOST-R 977-88	0,16-0,22	0,60-0,80	1,00-1,30	≤0,03	≤0,030	≤0,3	≤0,3	≤0,3	н.р.*	н.р.*	н.р.*
Permissible variation	-0,02 +0,01	-0,05 +0,10	-0,12 +0,25	-	-	+0,15	+0,1	+0,1	-	-	-

Note: *n.r. - not regulated.

To obtain the number of samples required for testing, trial ingots of the type "wedge" (according to the drawing №3 GOST 977-88 [5]) were cast which were subjected to heat treatment in three modes:

-normalization at a temperature of 900-950 ° C, air cooling (mode №1);

- quenching at a temperature of 900-950 ° C, cooling in water and further tempering at a temperature690 ^{o}C (mode № 2) i 650^{o}C (mode № 3).

After heat treatment, blanks of specimens for tensile tests were cut from the wedges according to the scheme shown in Fig. 1. therefore, from each part of the workpiece, 2 were obtained (the bottom of the wedge was not used).

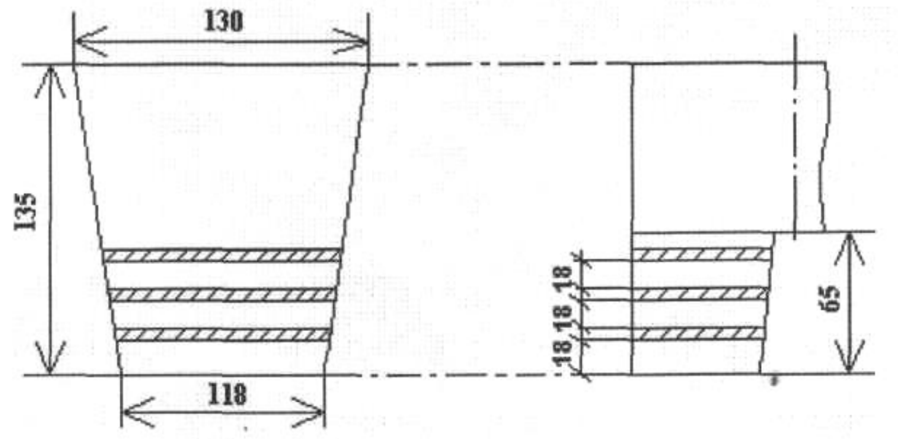

Figure 1. Cutting scheme of blanks

According to the existing normative and technical documentation (for example, [6,7] for steel 20GSL), the quality of cast low-alloy silicon-manganese heat-resistant steels is determined by mechanical properties at room temperature(see Table 4) and by the value of the yield point at operating temperatures(see Table 5).

The study of the heat resistance of research steel in the temperature range provided for steel 20GSL (250-450 ° C with an interval of 50 ° C), was carried out in a certified laboratory of the SE "Scientific and Research Pipe Institute" on a tensile testing machine R - 5 according to GOST 9551-84 and GOST 9651-84. The results of these tests are presented in table 5

Table 4. Mechanical properties of microalloyed steel 20GSL and NTD requirements for the quality of low-alloy steels at room temperature

Steel mark	σ_B, H/mm^2	σ_T, H/mm^2	δ_5, %	ψ, %	KCU^{+20} J/cm^2	KCV^{-60} J/cm^2
20GSL (microalloyed)						
Mode №1	638-646	400-480	18-31	40-65	55-320	undefined
Mode №2	660-690	515-545	21-28	50-82	undefined	25-79
Mode №3	670-715	535-590	20-25	51-80	undefined	25-51
20GSL	≥ 500	≥ 280	≥ 18	≥ 30	≥ 29,4	-
20XMFL 15XIMIFL	≥ 500	320-550	≥ 15	≥ 30	≥ 29,4	-

Table 5. Results of testing samples with micro-alloyed steel 20GSL at elevated temperatures (melting № 3-382)

№ з/п	σ_B, H/mm^2	σ_T, H/mm^2	δ_5, %	ψ, %	Temperature trials, ^{o}C
Mode № 1					
1	553	335	20	58,5	250
2	-	340	24,5	45	300
3	-	332	20	45	350
4	553	358	27	68,5	400
5	487	341	29,5	71,5	450
Mode № 2					
6	589	411	19,5	49,5	250
7	617	369	-	44	300
8	637	413	22	29	350
9	610	398	21,5	41	400
10	493	359	22	54	450
Mode № 3					
11	620	459	-	56	250
12	636	436	-	51	300
13	658	433	17,5	45	350
14	640	487	27	59,5	400
15	525	420	29,5	68	450

Discussion of the results. Table 5 shows that even at the operating temperature (450 ° C), the maximum allowed, microalloyed steel 20GSL has a yield strength level of 170 - 250 MPa higher than that required for the base steel [6,7] for a temperature of 400 ° C. Note that the drop in this indicator is regulated, for standard steel 20GSL from room temperature to 400 ° C is almost 40% relative [6,7], whereas in microalloyed steel, in fact, this drop does not exceed 20-25% of the relative value in the range of the investigated temperatures, which indicates the stability of its properties under thermal influences.

Analysis of the data given in table 5 confirms the advantage of microalloying with nitrogen, titanium and aluminum steel 20GSL and according to OST, it was not regulated 108.961.03 and OST 108.961.02 indicators. So the ultimate tensile strength at 450 ° C for all heat treatment modes is 487-525 MPa,relative elongation ≥ 22% and relative contraction ≥ 54%, which exceeds the level of these properties required by the rest 108.961.03 and OST 108.961.02 in steel 20GSL even at room temperature (see Table 5).

Findings. Complex microalloying with nitrogen, titanium and aluminum of low-alloyed silicon-manganese heat-resistant electric steel significantly increases their yield point at 250-450 ° C and ensures its value is 2.0-2.5 times higher than the required level. At the operating temperatures, the yield and strength limits of microalloyed steel 20GSL remain practically the same, which indicates their stability under thermal influences. The use of carbonitride technology for strengthening silicon-manganese heat-resistant electric steel provides an increase in operational reliability, an increase in the service life and a decrease in the metal consumption of equipment for power mechanical engineering.

Бібліографічний опис

1. ТУ У 27.1-218715-78-002:2008 «Отливки из стали 15ГСЛ для трубопроводной арматуры».
2. Стандарт ЦКБА 005.2 «Арматура трубопроводная. Металлы, применяемые в арматуростроении».
3. Стандарт ЦКБА 014 «Арматура трубопроводная. Отливки стальные. Общие технические условия».

4. Стандарт ЦКБА 025 «Арматура трубопроводная. Сварка и контроль качества сварных соединений. Технические требования.»

5. ГОСТ 977-88 «Отливки стальные». –М.: Изд-во стандартов, 1989г.–57 с.

6. ОСТ 108.961.03-79 «Отливки из углеродистой и легированной стали для фасонных элементов паровых котлов и трубопроводов с гарантированными характеристиками прочности при высоких температурах». – М., 1979. – 20 с.

7. ОСТ 108.961.02-79 «Отливки из углеродистых и легированных сталей для деталей паровых стационарных турбин ». – М., 1979. – 48 с.

8. Марочник сталей и сплавов/ В.Г. Сорокин, А.В. Волосникова, С.А. Вяткин и др.; Под общ. ред. В.Г. Сорокина.-М.: Машиностроение 1989. – 640 с.

9. High-strength heat-treated microalloyed constructional steel for car-building / I.E. Uzlov, A.V. Puchikov, G.N. Tregubenko, G.A. Polyakov // Metallurgical and Mining Industry – 2013. - №2 – p. 51-54

10. Development and fabrication of constructional steel with carbonidridation hardening by means of omplex microalloying with N-Ti-Al / A.V. Rabinovich, G.N. Tregubenko, Yj.A. Bublikov et. al. // Metallofizika I Noveishie Tehnologii. – 2012. - №34, №10. – p. 1385-1396

Reference

1. TU U 27.1-218715-78-002: 2008 "Castings from steel 15GSL for pipeline fittings."

2. Standard TsKBA 005.2 “Pipe fittings. Metals Used in Valve Building ".

3. Standard TsKBA 014 “Pipe fittings. Steel castings. General technical conditions ".

4. Standard TsKBA 025 “Pipe fittings. Welding and quality control of welded joints. Technical requirements."

5. GOST 977-88 "Steel Castings". –M .: Publishing house of standards, 1989. – 57 p.

6. OST 108.961.03-79 "Castings from carbon and alloy steel for shaped elements of steam boilers and pipelines with guaranteed strength characteristics at high temperatures." - M., 1979 .-- 20 p.

7. OST 108.961.02-79 "Castings from carbon and alloy steels for parts of stationary steam turbines". - M., 1979 .-- 48 p.

8. Grade of steels and alloys / V.G. Sorokin, A.V. Volosnikova, S.A. Vyatkin and others; Under total. ed. V.G. Sorokin.-M .: Mechanical Engineering 1989. - 640 p.

9. High-strength heat-treated microalloyed constructional steel for car-building / I.E. Uzlov, A.V. Puchikov, G.N. Tregubenko, G.A. Polyakov // Metallurgical and Mining Industry – 2013. - №2 – p. 51-54

10. Development and fabrication of constructional steel with carbonidridation hardening by means of omplex microalloying with N-Ti-Al / A.V. Rabinovich, G.N. Tregubenko, Yj.A. Bublikov et. al. // Metallofizika I Noveishie Tehnologii. – 2012. - №34, №10. – p. 1385-1396

Отримано/Received: 14.02.2021