

From the Editors. Nitrogen is used as an alloying element in steels for various applications. In austenitic corrosion-resistant steels it is an austenite-forming element and it reduces the amount of nickel required, which is in short supply; the solid solution is also strengthened. Generally, the nitrogen content of austenitic corrosion-resistant steels depends on its solubility in the liquid steel at normal atmospheric pressure. In contrast to existing practice, research is being conducted at the Scientific-Research Institute of Ferrous Metallurgy (TsNIChERMET) and the E. O. Paton Institute of Electric Welding on the effect of nitrogen on the structure and properties of corrosion-resistant steels at concentrations far exceeding the solubility of nitrogen in a given steel. These steels are produced by means of special plasma arc remelting. Another method of adding nitrogen to corrosion-resistant steels in amounts larger than the limit solubility is so-called counterpressure casting in a nitrogen atmosphere (the Balevskii-Dumov method, Bulgaria). Steels containing nitrogen in amounts larger than its normal solubility are new materials in principle with high strength and special characteristics, which are partially described in the following articles.

STRUCTURE AND PROPERTIES OF HIGH-NITROGEN
CORROSION-RESISTANT AUSTENITIC STEELS

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We investigated the effect of heat treatment on the structure and properties of three steels with high nitrogen concentrations melted in a commercial plasma arc furnace with high nitrogen pressure in the melting chamber (Table 1).

The steels were tested after hot deformation of rounds 80 mm in diameter and plates 8 mm thick.

The temperature dependence of the nitrogen solubility in the liquid metal was calculated by using the equation given in [1].

TABLE 1

Steel	Composition, %										Solubility polytherm	Solubility of nitrogen at 1600°C, %
	C	Si	Mn	S	P	Cr	Ni	N	Mo			
03Kh19N-10G6AM2	0,023	0,25	7,67	0,006	0,018	20,2	6,70	0,54 0,60 0,75 0,77 0,81	2,27		$\frac{2697}{T} - 1,843$	0,387
09Kh25N-16G7AR	0,090	0,36	6,16	0,007	0,014	24,73	15,73	0,85	—		$\frac{2657}{T} - 1,835$	0,365
04Kh20-G2AN5	0,043	0,27	1,55	0,008	0,009	20,52	4,74	0,52	—		$\frac{2287}{T} - 1,75$	0,295

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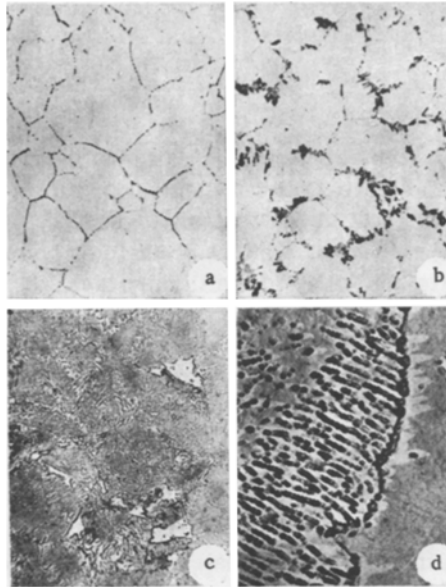


Fig. 1. Microstructure of steel 09Kh25N16G7AR after heating to 1250° and cooling in water (a), in air (b), and in the furnace (c, d). a-c) 300 ×; d) 7000 ×.

As can be seen from the data in Table 1, the nitrogen content of the steels is 50-100% higher than the solubility limit of nitrogen in the liquid metal.

Samples were heat-treated at 950-1250°C, with cooling in water, in air, and in the furnace. Some samples water-quenched from 1150° were tempered at 850-650° for 1, 10, and 100 h, with cooling in water and in air.

After water quenching from 1150° no nitride phase was precipitated in steels 04Kh20G2AN5 or 03Kh19N10G6AM2. In steel 09Kh25N16G7AR, containing the largest amount of nitrogen and carbon, precipitates of excess phase were observed even after quenching from 1250° (see Fig. 1).

With quenching from 1000° or lower the supersaturated solid solution decomposes in all steels. Precipitation of excess phase begins at places most favorable for the formation of nuclei — in the boundaries of grains, blocks, and twins. Decomposition of the solid solution may occur not only with decreasing quenching temperatures but also with decreasing cooling rates. Comparison of the microstructure of steel 09Kh25N16G7AR cooled at different rates indicates that with rapid cooling precipitates of excess phase are found only in grain boundaries (Fig. 1a). With cooling in air the transformation extends some distance from the grain boundaries (Fig. 1b).

TABLE 2

Steel	Quenching temp., °C	Cooling medium	N, %		N _{nitride} / N _{tot} %
			total (N _{tot})	in solid soln.	
03Kh19N10-G6AM2	1050	Water	0,787	0,703	7,75
	1100		0,803	0,749	1,62
	1150		0,790	0,757	1,77
	1200		0,793	0,767	0,75
	1250		0,802	0,771	0,50
	1300		0,793	0,774	0,51
09Kh25N16-G7AR	1150	Air	0,841	0,503	37,8
		Water	0,670	0,541	16,5
	1200	Air	0,844	0,539	35,9
		Water	0,745	0,724	2,3



Fig. 2. Microstructure of steel 03Kh19N10G6AM2 after tempering at 750° for 10 h (300 ×).

With furnace cooling a structure similar to pearlite is formed in carbon steels and has been called "false nitrogenous pearlite" [2], alternating with sections of pearlite and nitride platelets (Fig. 1c), the nitrogenous pearlite occupying almost the entire area.

At small magnifications nitrogenous pearlite has the form of platelets; in the electron microscope it can be seen that these platelets are colonies of finely dispersed nitride precipitates (Fig. 1d).

Examination of the microstructure after tempering at 850–650° showed that the lower temperature limit for the formation of nitrogenous pearlite is above 650° for all three steels heated ~ 1 h.

At lower temperatures and shorter heating times the dispersity of the structure increases. The distance between particles becomes indistinguishable in a light microscope and nitrogenous pearlite appears to be a solid mass (Fig. 2). The formation of this structure is similar to the formation of sorbite during high-temperature tempering of quenched carbon steels.

Tempering of the steels at 650° for 1, 10, and 100 h leads to precipitation of nitride phase only in grain boundaries, which was determined from their increase in thickness.

The distribution of nitrogen between the solid solution and nitrides in the high-nitrogen steel after different heat treatments was determined by electrolytic solution of the samples by the method given in [3].

With rising quenching temperatures the amount of nitrogen in nitrides decreases and its concentration in the solid solution increases (Table 2). With air hardening the quantity of nitrides increases sharply, which is also confirmed by metallographic analysis.

The x-ray analysis of residues showed that the excess phase consists of Cr_{23}C_6 and Cr_2N particles. This agrees with data in [4] on chromium nitrides in Fe–Cr–N alloys, where it was shown that chromium forms two nitrides with nitrogen — CrN and Cr_2N , and CrN forming in steels with < 13% Cr.

Tensile tests at room temperature of steel 03Kh19N10G6AM2 with 0.54–0.81% N showed that the strength of the steel increases proportionately with the nitrogen content (Fig. 3).

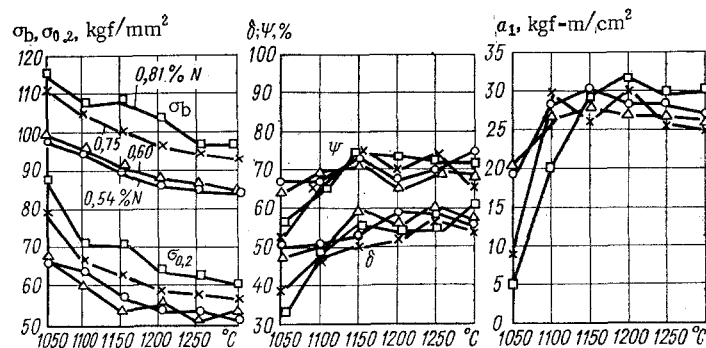


Fig. 3. Mechanical properties (at 20°) of steel 03Kh19-N10G6AM2 with different amounts of nitrogen (indicated on the curves) in relation to quenching temperature.

The quenching temperature is of considerable importance in this case. The optimal temperature for high-nitrogen steels may be 1150°, where with some reduction of the strength due to solution of nitride phases and an increase of the grain size the ductility of the steel is high.

The mechanical properties and lattice constants of austenite in steel 03Kh19N10G6AM2 with different amounts of nitrogen were determined on samples water-quenched from 1200°, when practically all the nitrogen is found in the solid solution. With 0.54% N the lattice constant of austenite is 3.5998 Å, and the strength characteristics increase correspondingly.

The corrosion resistance of Cr—Ni austenitic steels, stabilized and especially unstabilized, is highest after quenching from the temperature at which the solution of chromium carbides is most complete or at which carbon is most completely combined in titanium or niobium carbide. As much as 0.25% N has no noticeable effect on the corrosion resistance of these steels [5].

Intercrystalline corrosion tests (ICC) of high-nitrogen steels showed that the steels are not susceptible to ICC in the quenched condition (tests by the AM method, GOST 6032-58).

Sensitizing of steel 03Kh19N10G6AM2 with 0.54 and 0.8% N at 650° for 10 and 100 h did not induce susceptibility to ICC in the steel with 0.54% N but did induce ICC in the steel with a higher nitrogen content after 100 h. This is due to the formation of a dense network of finely dispersed nitrides in the grain boundaries after prolonged tempering.

CONCLUSIONS

1. Alloying of austenitic stainless steels with as much as 0.8% N makes it possible to raise the ultimate strength to 100 kgf/mm² and the yield strength to 70 kgf/mm².
2. With slow cooling from 1250° the structure of these steels is of the nitrogenous pearlite type.
3. High-nitrogen austenitic Cr—Ni stainless steels and Cr—Ni—Mn steels are not susceptible to ICC after quenching (tests by the AM method, GOST 6032-58). Sensitizing of the steel with > 0.54% N induces susceptibility to ICC.

LITERATURE CITED

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