THERMOMECHANICAL STRENGTHENING AND STABILITY OF AUSTENITIC Cr18Ni10N STEEL

ТЕРМОМЕХАНИЧЕСКОЕ УПРОЧНЕНИЕ И СТАБИЛЬНОСТЬ АУСТЕНИТНОЙ СТАЛИ Х18АН10

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Abstract: *The hardening and austenite stability as a result of nitrogen alloying steel type of Cr18Ni10 in the temperature range, which is usual for the application of such steels as corrosion-resistant structural heat-resistant and/or cryogenic ones was studied. It is shown that the nitrogen alloying is perspective for strengthening and increasing of stability of austenitic stainless steels. Additional strengthening due to the preliminary cold or warm deformation hardening increases a tendency to the martensite formation under load, which limits the operating temperature of these steels. High-strength non-magnetic nitrogen-alloyed steels on the base of Cr18Ni10 steels containing up to 0.22 % of nitrogen are suitable for cryogenic application of non-deformed articles only. Otherwise, a strain-induced martensite will always form in them at temperatures below -70 °C. High strength, ductility and toughness of these steels can be achieved simultaneously only as a result of the TRIP-effect or fine-grained structure formation.*

KEYWORDS: AUSTENITIC STEEL, CRYOGENIC STEEL, CORROSION RESISTANCE, HEAT RESISTANCE, ALLOYING BY NITROGEN, THERMAL STABILITY, THERMOMECHANICAL STRENGTHENING.

1. Introduction

Alloying by the nitrogen, using in the past years, is effective for stability, strength and corrosion resistance of austenitic steels [1–7].

Nitrogen-alloyed stable chrome-nickel and chrome-manganese austenitic steels often are strengthened by a cold plastic deformation and ageing.

The nitrogen reduces the temperature of the start of the martensite transformation during cooling, but it can increase the tendency to the formation of deformation-induced martensite due to the stack fault energy reducing.

The thermomechanical treatment is effective for nitrogen-containing austenitic steels and the range of controlled parameters for such steels can be extended.

Alloying steels with nitrogen increases resistance to local corrosion and intergranular corrosion [6, 7]. However, corrosion resistance sensitive to the structural state of steels, so when thermo-mechanical hardening of nitrogen-containing steels is also a need for a clear choice of regulated parameters of structures and more strict observance of technology of smelting and processing.

Thus, due to changes in the processes of structure formation with the adding to the steel even a small amount of nitrogen, it is necessary to strictly control the chemical composition, to adjust such parameters of thermal and thermomechanical treatment as temperature, degree of deformation, duration and conditions of subsequent cooling and aging, depending on the applications of the steel. In particular, it is necessary to take into account the specific temperature of formation and dissolution of nitrides, which can be estimated by thermodynamic calculations, for example, using phase diagrams. The change in the stability of austenite under and without loading can be evaluated only experimentally.

The aim of this work was to study both strengthening and stability of austenite resulted from the nitrogen alloying of Cr18Ni10-type steel in the temperature range usual for the application of such steels as structural corrosion-resistant heat-resistant and/or cryogenic.

2. Material and Experiment

Steels of Cr18Ni10-type with content of nitrogen varied from usual for contaminants (less than 0.01 %) to 0.22 % for specially alloyed by the nitrogen with application of traditional technologies of melt of corrosion-resistant chrome-nickel ones were studied. Chemical composition of steels is given in the Table 1.

Investigated steel were received and pre-processed in the following way. Steel 1 (Cr18Ni10Ti) was industrial melting and hot rolled.

Nitrogen-alloyed steels were produced in laboratory conditions using component of the charge of various purity by impurities. Steels 2 and 3 (Cr18Ni10N) were melted in the induction furnace from nitrogen-free steel of similar chemical composition with addition of pure charge components to the required composition. Steel 4 (Cr18Ni10N) was produced from pure materials: technical iron, electrolytic nickel, electrolytic manganese, pure chrome, nitrogenized ferrochrome, granulated aluminum in vacuum induction furnace. Ingots with the weight of 12.5 kg were forged in the temperature range 1160–820°C up to the general deformation of 80 % and cooled by air.

The final treatments were: 1) quenching on solid solution from the temperature of 1050 °C in the water or in the air; 2) high-temperature thermomechanical treatment, including hot multipass longitudinal rolling at the temperature 1070 °C with degrees of compression ε=35, 50 and 80 %, and the cooling from the temperature of rolling finish in the water or in the air.

The structure, phase composition and mechanical properties of steels after different schemes of heat and thermomechanical treatments, as well as their mechanical behavior in conditions of hot and warm deformation were studied.

Qualitative analysis of the microstructure was carried out using optical microscopy. Phase composition and the lattice period of austenite was studied using x-ray analysis.

Vickers hardness, mechanical properties (both tensile and impact bending tests) was is measured defined for all steels at room

Table 1. Chemical composition of investigated steels

No.	Steel	Chemical composition, wt. %								
		C	Cr	Ni	Mn	Mo	S	P	Al	N
1	Cr18Ni10Ti	0.10	17.7	9.5	1.19	0.10	0.007	0.027	0.11	<0.01
2	Cr18Ni10N (N=0.135 %)	0.05	18.0	10.3	1.04	–	0.015	0.023	0.10	0.135
3	Cr18Ni10N (N=0.186 %)	0.05	18.1	9.6	0.82	<0.10	0.018	0.025	0.12	0.186
4	Cr18Ni10N (impurity free, N=0.220 %)	0.007	19.1	9.3	1.42	0.012	0.004	0.002	0.035	0.220

* – base is Fe.

temperature (+20 °C), and for steel 4 (Cr18Ni10N) at the temperature -163 °C too. Samples in the initial state and after mechanical testing were studied for the presence of ferromagnetic phase using ferritometer.

3. Results and Discussion

All investigated steels are austenitic at the room temperature: they are non-magnetic and α-phases are not discovered using X-ray method. This fact consequents to their position on Shaeffler diagram (fig. 1).

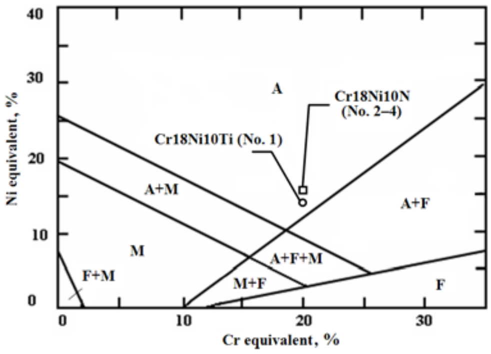

Fig. 1. *Positions of studied steels on Shaeffler diagram*

A formula taking into account only the actual chemical composition [8]:

$$M_S = 500 - 25(Ni + 0{,}8Cr + 1{,}2Mn - 8) - 12{,}5Mo - , \quad (1)$$
$$- 29{,}4Ti - 35Nb - 32{,}6Cu - 254(C + N)$$

evaluates the temperature of the martensite transformation (Table 2). Values M_S are in the range of +23 °C (steel 1 (Cr18Ni10Ti)) to -15 °C (steel 4 (Cr18Ni10N)).

Table 2. Evaluated temperatures M_S and M_{d30}

No.	Steel	M_S, °C	M_{d30}, °C
1	Cr18Ni10Ti	23	-1
2	Cr18Ni10N (N=0.135 %)	-14	-54
3	Cr18Ni10N (N=0.186 %)	-7	-66
4	Cr18Ni10N (impurity free, N=0.220 %)	-15	-71

Fig. 2 presents polythermal section of phase diagram for alloys with the content of alloying elements corresponding to steels (Table 1), and the nitrogen content from 0 to 1 %. The diagram was built by the Thermo-Calc program on the basis of the thermodynamic database TCFE6. It is seen that the temperatures of hot processing and heating for quenching correspond to the austenitic region. So, after the complete dissolution of excess phases neither δ-ferrite nor martensite in the studied steels should not be.

Mechanical properties of the studied steels are given in Table 3. Hardness values in all the investigated steels are similar and typical for austenitic steels.

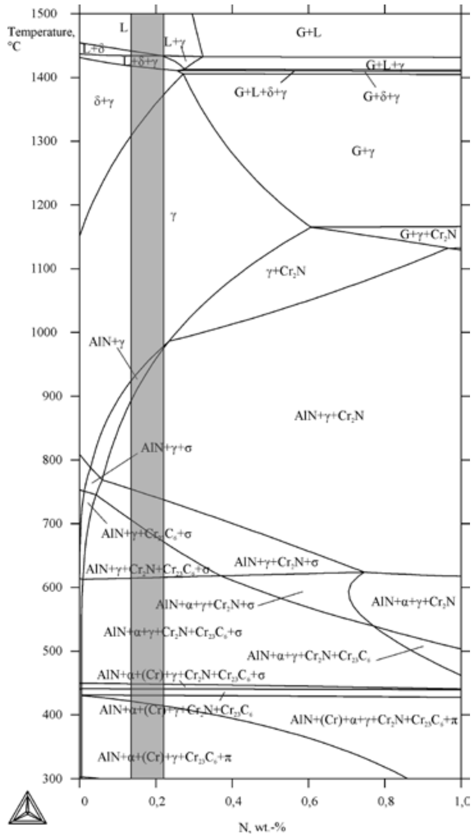

Fig. 2. *Phase diagram for steels Cr18Ni10N (steels 2, 3, and 4)*

When the tensile tests at 20 °C all nitrogen-containing steels discovered a behavior typical for austenitic ones as a stable high-plastic materials. Deformation curves are smooth, without a serration, except steel 4 (Cr18Ni10N). The deformation pattern of this steel demonstrated high plasticity and hardly noticeable aliasing (with a small amount of peaks) in the deformation range of 30–40 %. After the test samples of this steel were poor magnetic (Table 4). That is connected with formation of a small number of deformation-induced martensite (α-martensite). Other steels in the field of uniform deformation and after tensile up to failure at room temperature remained non-magnetic. After the tensile test at -163 °C the steel 4 (Cr18Ni10N) was strongly magnetic (see table 4), suggesting a relatively large part of the α-martensite.

The strength of steels increases according to the nitrogen content in steels 1–4 (Table 3), and the resistance to the small plastic deformation YS increases more actively. Characteristics of strength at the temperature -163 °C are, naturally, higher than at room temperature.

Evaluation of the tendency to formation of deformation-induced martensite is carried out through the M_{d30} temperature at which 50 % of martensite formed under the influence of 30 %

Table 3. Mechanical properties of the investigated steels

No.	Steel	Processing	T_{test}, °C	HV, MPa	UTS, MPa	YS, MPa	El_U/El*, %	RA, %	KCU (KCV), MJ/m^2
1	Cr18Ni10Ti	hardening, air	+20	210	515	230	47	51	(2.2)
		HTMT 80 %, air	+20	310	700	440	26	54	(0.9)
2	Cr18Ni10N (N=0.135 %)	hardening, water	+20	255	530	315	29	63	(2.2)
		HTMT 50 %, water	+20	260	670	370	42	71	(1.9)
3	Cr18Ni10N (N=0.186 %)	hardening, water	+20	240	715	355	25	67	(1.7)
		HTMT 50 %, water	+20	255	690	345	27	74	(1.3)
4	Cr18Ni10N (impurity free, N=0.220 %)	HTMT 35 %, water	+20	240	750	400	63/44	84	3.9
			-163	–	1065	645	39/31	78	2.5

* – El_U – uniform elongation, El – total elongation.

Table 4. Assessments of stability of austenite at mechanical tests of steel 4 (Cr18Ni10N)

T_{test}, °C	Tensile test			Tests for impact bend		
	El_U*, %	magnetization during the uniform deformation	magnetization in the neck	magnetization away from the area of destruction	magnetization in the field of fracture	mass part of austenite**, %
+20	44	poor magnetic	poor magnetic	non-magnetic	non-magnetic	100
-163	31	strongly magnetic	strongly magnetic	weakly magnetic	medium magnetic	96

* – designation corresponds to table 3; ** – the part of austenite in the non-deformed samples was measured by x-ray analysis

deformation, according to the equation of T. Gladman, J. Hammond, F. Marsh [9]:

$$M_{d30} = 497 - 462(C+N) - 9{,}2Si - 8{,}1Mn - 13{,}7Cr - 20Ni - 18{,}5Mo \quad (2)$$

This equation, in general, reflect the influence of the composition of the steel (see table 2) after final processing for solid solution. Real data may be different, because here, as in the evaluation of M_S points, also not taken into account any differences in the structural state of the steels or conditions of deformation. M_S of steels can be decreased by grinding the grain down to 10 microns in preprocessing. This preprocessing don't significantly effect on M_{d30} [10].

All steel under tension at room temperature have high characteristics of plasticity: El is from 26 to 63 %; reduction of area RA is from 51 to 84 % (see Table 3). The clean steel 4 (Cr18Ni10N) with the highest content of nitrogen among the steels demonstrate higher plasticity, minimal stability during deformation and the highest strength. It is possible to note that quite high plasticity of the steel at temperature -163 °C El=39 %, RA=78 % is resulted from the TRIP-effect.

On the diagrams of deformation during testing at the temperature -163 °C of steel 4 (Cr18Ni10N) appeared aliasing was also found under strain over 10 %.

Intensive formation of deformation-induced martensite in nitrogen-containing steels of the Cr18Ni10N-type leads to their strong deformation hardening and retaining high plasticity provides high level of relations UTS/YS.

Tests at room and low temperatures showed good reproducibility of results and a very small spread of absolute values of all characteristics of strength and plasticity, which reflects the stability of the mechanical behavior of all investigated steels.

The results of impact tests showed naturally high values and for steels with nitrogen at room temperature: $KCU_{+20°C}$=1,7–3,9 MJ/m^2; maximum value of impact strength is for steel 4 (Cr18Ni10N).

The impact strength at the test temperature -163 °C for steel 4 (Cr18Ni10N) is also quite high: 2.5 MJ/m^2. In the area of plastic deformation and fracture of this steel 4 (Cr18Ni10N) α-martensite was found: alloy became magnetic near the zone of destruction (see Table 4). This suggests that even at such high speed of loading (~10 m/s) quite big plastic deformation takes place due to the the TRIP-effect.

The final structure and properties of strongly hot-deformed austenite are the only determined by the conditions of hot deformation and cooling cycle in thermo-mechanical processing.

The warm deformation of austenitic steels was carried out at the temperature of maximum effect of aging – 410 °C. The maximal hardening thus achieved when processing scheme was hot deformation → warm deformation. So the warm deformation of steel 2 (Cr18Ni10N) at 410 °C by the compression up the true reduction e = 0,08 with the speed of 0.01 s^{-1} in vacuum after the hot compression at temperature 1050°C up e=0.27 with the speed of 1 s^{-1} and rapid cooling to of 410 °C leads to additional strengthening on near 170 MPa. Resistance to deformation at e=0.08 (close to the steady-state stage) reached 436 MPa.

Patterns of warm deformation have normal view, explicit serration not revealed. The average value of austenitic grain during warm deformation does not change. Resistance to warm deformation is defined by both a composition of steel and hot-deformed structure of austenite, i.e. it depends from the modes hot deformation of each steel. The addition of nitrogen significantly increases the resistance to the small (YS) and large (UTS) degrees of warm deformation. The small grain increases the effect of increasing the resistance to large deformations.

All steel remained austenitic after cooling to room temperature. Their hardness noticeably increased. For example, for steel 2 (Cr18Ni10N) it increased up to 260 HV compared to 245 HV for hot-deformed and 200 HV for the non-deformed state.

4. Conclusion

Alloying of austenitic stainless steels, used as heat-resistant and cryogenic, by nitrogen is perspective for strengthening and increasing of stability.

Both strength and thermal stability of austenite increase with increasing of the nitrogen content. Additional strengthening due to the preliminary cold or warm hammering, usually used for austenitic steels, increases the tendency to the formation of martensite under load, especially near and below M_S. This effect limits the working temperature of these steels.

High strength non-magnetic nitrogen-containing Cr18Ni10N-based steels with the nitrogen concentration not more then 0.22 % are applicable as cryogenic for non-deforming products. Otherwise, the deformation-induced martensite will form at temperatures below -70 °C. High strength, ductility and toughness (especially in the case of the raised cleanliness of detrimental impurities) for these steels can be achieved only through the TRIP-effect or grain refining.

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