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OPTIMIZATION OF NICKEL CONTENT IN AISI 316 STEEL ALLOYED WITH NITROGEN

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ABSTRACT
This work deals with possibility of nickel content reduction in austenite stainless steel AISI 316. Optimal nitrogen contents that are able to replace up to 3% of nickel are determined, with retaining steel properties in accordance with current standards. Nitrogen alloying effect, i.e. possibility of replacing small nickel part content in alloying system is determined on the base of results of mechanical testing and testing of deformability. Mechanisms in microstructure that are in interaction with tested properties are determined by metallographic testing.
Keywords: steel, mechanical properties, microstructure, deformability, corrosion stability

1. INTRODUCTION
Austenitic stainless steel grade AISI 316 is widely used due to its exceptional technological and exploitation properties and for a long time it is object of research. Studying of nitrogen alloying possibility, that is able to replace part of nickel content while preserving the stability of austenite, and at the same time increasing strength properties, is very important [1]. The reduction of nickel content has economic justification and increasing of yield strength and ultimate tensile strength is permanent requirement for structural parts working under high loads and in aggressive atmosphere [2, 3]. Austenitic stainless steel grades 18/8 i 18/12 alloyed with nitrogen are already standardized, but mainly in steels with low carbon content. Steel grade AISI 316, with higher carbon content up to 0,08%, has limited use due to possibility of intercrystalline corrosion.

2. AUSTENITIC STAINLESS STEEL AISI 316
Basic alloying elements, chromium and nickel have greatest influence on forming AISI 316 steel grade microstructure. Their ratio ensures forming of mostly austenite structure after quick cooling (quenching). Smaller changes in content of the alloying elements could cause formation other phases in structure, mostly delta ferrite. Besides alloying elements, the changes in solubility of carbon and nitrogen in solid solution with temperature changes causing precipitation of carbonitrides and undesired intermetallic compounds, has influence on austenite stability. The precipitation occurs at grain boundaries and within grains, at dual lamellas and at phase boundary austenit-delta ferrite, in temperature interval 700°-1100° C. Substitutional and interstitial atoms of alloying elements strengthen austenitic matrix, but interstitial solute atoms of carbon and nitrogen shows a significantly

larger strengthening effect due to stronger deformation of austenite lattice. Other microstructure characteristics as grain size, number of twins and content of delta ferrite also have effect on strengthening. High values of yield strength can be obtained by combination of interstitial solid solution strengthening and grain refining. Possibility of achieving austenite structure due to high austenite stabilization abilities of nitrogen is reason why it is possible to replace part of nickel with nitrogen in this steel grades.
Deformability of steel AISI 316 on all temperatures is mainly connected to influence of the alloying elements on delta ferrite forming and to ability of forming low melting eutectic compositions at grain boundary. Primary trans-crystal macrostructure, segregations and undesirable phase formed during solidification have essential importance for assessment of deformability. Nitrogen with content up to 0,1% improves deformability by reduction of delta ferrite, and at the same time in this amounts nitrogen does not dominantly affects on reduction of dynamic recovery speed and does not lead to forming soluble eutectic compounds.
The main characteristic of steel grade AISI 316 is intercrystalline corrosion resistance. Chromium provides intercrystalline corrosion resistance. Nickel and molybdenum additionally improves this resistance. According to intercrystalline corrosion genesis theory, carbides and carbonitrides at grain boundaries, through binding chromium, reduce chromium content in surrounding austenite matrix below critical (resistant) limit of 14% which provides intergranular corrosion resistance [4].

3. RESULTS OF EXPERIMENTAL RESEARCH

Research is performed on experimental heats with different content of nitrogen and nickel. Six heats were made with three nitrogen content varieties and constant content of other alloying elements. Carbon contents were 0.07 or 0,08%. For each nitrogen alloying variety, two heats with nickel content of 10,5 and 13,5% were made. After forging and before final testing two varieties of het treatments were made by quenching in water from temperature of 950°C and 1100°C. Results of testing (chemical, metallographic and mechanical) are presented in Table 1.

Table 1. Chemical composition, microstructure and mechanical properties of experimental heats

No.	Element content , %					Microstructure					Mechanical properties			
						Quenching 950°C		Quenching 1100°C			Quenching 950°C		Quenching 1100°C	
	Cr	Ni	Mo	C	N	Struc-ture	Grain size ASTM	Struc-ture	Grain size ASTM	Fd QTM	Rp_{02} MPa	Rm MPa	Rp_{02} MPa	Rp_{02} MPa
1	16.5	10.5	2.33	0.07	0.032	A+K+Fd	5	A+Fd	4	2.15	380	655	270	580
3	16.4	10.1	2.31	0.08	0.063	A+K+Fd	6	A+Fd	5	1.45	410	670	315	635
5	17.5	10.6	2.27	0.08	0.12	A+K_N+Fd	7	A+Fd	6	0.75	465	695	340	650
2	15.8	13.2	2.33	0.07	0.029	A+K_N+Fd	5	A+Fd	4	0.65	325	610	250	555
4	15.9	13.1	2.32	0.07	0.057	A+K_N+Fd	7	A+Fd	5	0.50	330	635	285	580
6	16.7	13.7	2.16	0.07	0.12	A+K_N+Fd	8	A+Fd	6	0.35	420	700	325	635

Notes: A – austenite, F - delta ferrite, K - carbide, K_N - carbonitride,
QTM- measured content of delta ferrite, ASTM- grain size

3.1. Mechanical properties

Figure 1. presents values for yield strength and ultimate tensile strength (Table 1.), depending on nitrogen and nickel content, after quenching from temperatures of 950°C and 1100° C. Increase in nitrogen content causes increase of yield strength and ultimate tensile strength. The values of these properties are higher after quenching from 950°C related to corresponding values after quenching from 1100°C.

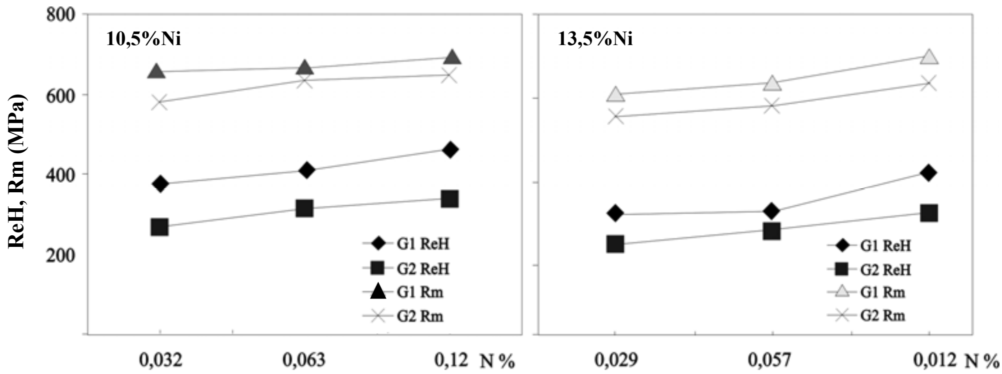

Figure 1. Yield strenght and ultimate tensile strenght depending on nickel and nitrogen content after quenching from 950°C (G1) and 1100° C (G2)

3.2. Delta ferrite and deformability

Revised Schaeffer diagram (Table 2. and Figure 2.) is used for estimation of the delta ferrite content. Real content of delta ferrite is determined on quantitative microscope QTM. All heats (2, 4, 6) with higher content of nickel and one heat (5) with lower content of nickel in combination with nitrogen content of 0,12% are located in the austenite area without delta ferrite. Heats (1 and 3) with lower content of nickel and nitrogen can contain delta ferrite. However, presence of very small quantity of delta ferrite is determined by testing on QTM microscope in all heats (Fd in Table1.).

Process of deformation in temperate range 1150-850°C is simulated by testing on plastometer through determining the number of twist to the brake (Table 2.).

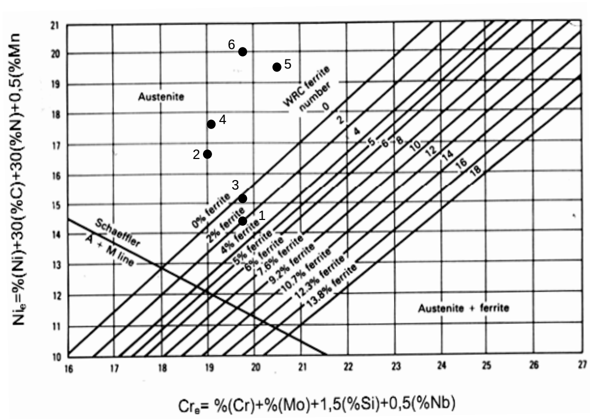

Figure 2. Revised Schaeffler diagram [1]

Table 2. Equivalent of chromium and nickel and number of twist to the brake

No.	Cr_{eq}	Ni_{eq}	Number of twist on the temperature			
			850 °C	950 °C	1050 °C	1150 °C
1	19,8	14,3	11	12	12	15
3	19,7	15,1	9	13	8	14
5	20,7	19,7	8	13	9	10
2	19,0	16,7	9	13	13	16
4	19,2	17,6	10	9	10	15
6	19,7	20,1	6	11	11	11

Note: No. is in accordance with Table 1.

The increasing content of nitrogen causes the reducing number of twist to the brake, i.e. the decreasing of the steel plasticity. It was not determined clear connection between content of delta ferrite and deformability due to very low content of delta ferrite. Generally, taking into account all results it can be concluded that content of nitrogen up to 0,12% has not major effect on deformability of the steel. The main reason for this is related to the fact that nitrogen very effectively stabilizes austenite structure, which is characterized with good plasticity. Additionally, relatively small amount of nitrogen cannot have significant effect on the resistance to deformation or significant effect on recrystallization processes.

3.3 Microstructure

Tasting of microstructure was performed on optical microscope and scanning (SEM) and transmission electron microscope (TEM). Structure of the heats with 0,12% nitrogen, after quenching from 950°C, consists of austenite matrix, carbonitrides (Figure 3.) and small amount of delta ferrite. It was observed a presence intermetallic μ-phase also. Considering ability of the intercrystalline corrosion development an application of the steel in this state is limited because of it was approved that presence of mentioned phases and delta ferrite reduce chromium content in surrounding matrix below resistant content. After quenching from 1100°C, in all heats, it was not confirmed the presence of the carbonitrides and intermetallic μ-phase in structure. Configuration and morphology analysis of the phases and delta ferrite are performed on scanning electron microscope, and by x-ray diffraction on transmission electron microscope and by electrochemical analysis of the isolates. Present carbides are $M_{23}C_6$ type, which depending on temperature pass into $(Cr,Mo,Fe)_{23}(C,N)_6$. Intermetallic μ-phase is Fe_2Mo type. There are some differences in configuration and chemical composition between phases precipitated in grain, grain boundary and at dual lamellas. In the case of quenching from 1100°C grains are coarser. Because of retardation of diffusion processes nitrogen causes delaying of the precipitation processes to the higher temperatures.

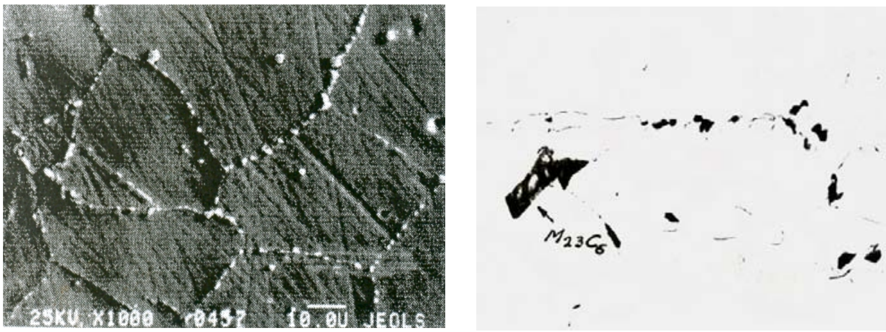

Figure 3. Microstructure after quenching from 950°C – austenite and precipitates at grain boundaries (left - SEM x 1000, right - TEM x 6000)

4. CONCLUSION

On the base of performed research in semi industrial conditions it was determined that additions of the nitrogen up to 0,12% have positive influence on yield and ultimate tensile strength without significant negative influence on deformability and corrosion resistance if carbides and carbonnitrides are dissolved in solid solution by quenching. It means that addition of nitrogen in amount 0,12%, under mentioned conditions, enables reducing of nickel content to the lower prescribed limit (10,5%) in steel AISI 316.

5. REFERENCES

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