

STUDY OF THE INTERACTION BETWEEN MANGANESE  
AND NITROGEN IN Cr - Ni STAINLESS STEELS BY THE  
INTERNAL FRICTION METHOD

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It is known that manganese and chromium increase the solubility of nitrogen in steel [1-2]. It has also been reported [1] that increasing the nitrogen added to 0.7-0.8% does not increase its concentration in the metal, i.e., some limit concentration is reached for each steel, depending on its composition.

An attempt was made in this work, using the method of internal friction, to determine the character of the interaction between nitrogen and alloying elements in austenitic Cr-Ni-Mn steels. The experiments were made with steels 03Kh18N10, 03Kh19N10AG3, 03Kh20N16AG6, and 03Kh19N7AG10. The nitrogen content of each steel was varied from the minimal value (0.005-0.008) to the maximum possible value for each steel. The nitrogen and manganese concentrations of the steels are given in Table 1.

The steels were melted from electrolytically pure materials and carbonyl iron to obtain the lowest possible concentration of carbon and impurities. Steels not containing nitrogen were melted in vacuum induction furnaces, and other steels, in open electric arc furnaces. Nitrogen was added at the time of melting in the form of manganese nitride.

With increasing manganese concentrations in the steel, the maximum amount of nitrogen dissolved increases. In steel 03Kh18N10 the maximum amount of nitrogen was 0.16% despite the fact that the amount of nitrogen added was 0.20%; in steel 03Kh19N10AG3 it was 0.24% N (compared with 0.30%); in steel 03Kh20N16AG6 it was 0.33% N (compared with 0.40%); in steel 03Kh19N7AG10 it was 0.38% N (compared with 0.45% added).

Since the relaxation peaks from atoms of carbon and nitrogen are very close on the temperature dependence of internal friction (TDF) curves, the carbon concentration was held to the minimum in the experimental steels - not over 0.01-0.02%.

A chemical analysis was made after quenching, i.e., when the steel had a purely austenitic structure.

Experimental data concerning the effect of alloying elements on the kinetics of precipitation of nitrides and other phases in steels with nitrogen are still inadequate. The effect of manganese has been studied in more detail. It is known that manganese slows down the decomposition of supersaturated solid solutions of nitrogen in  $\alpha$  iron. The interaction of nitrogen and manganese atoms is confirmed by the change and the position of the Snoek peak on the relaxation spectrum. In the opinion of Nacken and Kuhlmann [3], nitrogen atoms are concentrated in octahedral vacancies around manganese atoms, which increases the solubility of nitrogen in the  $\alpha$  solid solution and inhibits nucleation of new phase during thermal aging.

In austenitic steels containing nitrogen a change in the shape and height of the Finkel'shtein-Rozin peak (F-R peak) in relation to the manganese and nitrogen concentrations was observed [4].

The TDF was measured in an apparatus of the inverted torsion pendulum type on wire samples 0.8 mm in diameter and 80 mm long at a frequency of  $\sim 1.5$  Hz. The samples were previously water quenched from 1050°C (holding 15 min).

For all steels containing nitrogen we observed F-R peaks on the TDF curves around 300° (Fig. 1) associated with migration of interstitial nitrogen atoms in the field of elastic stresses. The size of the peak varies with changes in the nitrogen content of the steel. This relationship is clearly evident in the change of

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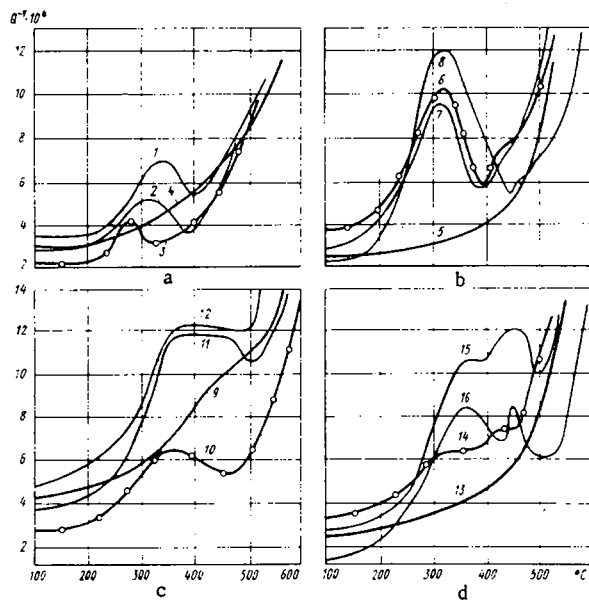


Fig. 1. Temperature dependence of internal friction for chromium steels. The heat numbers are given on the curves (see Table 1).

TABLE 1

Steel	Heat No.	Comp., %	
		Ni	Mn
03Kh18N10	1	0,005	0,98
	2	0,09	0,99
	3	0,11	0,80
	4	0,16	0,78
03Kh19N10-AG3	5	0,007	2,95
	6	0,10	2,95
	7	0,17	2,95
03Kh19N7-AG10	13	0,008	10,09
	14	0,21	10,10
	15	0,26	10,10
03Kh20N16-AG6	9	0,006	6,15
	10	0,19	6,10
	11	0,25	6,15
03Kh19N10-AG3	8	0,24	2,80
	12	0,33	6,6
	16	0,38	9,93

TDF for steel 03Kh19N10AG3 (Fig. 1b). The peak was highest for samples containing 0.24% N (Fig. 1b, curve 8). With decreasing nitrogen concentrations the internal friction peak shifts to lower temperatures. Two subpeaks forming a single F-R peak were observed for steel 03Kh19N7AG10 (Fig. 1d). With decreasing concentrations of nitrogen the height of this peak also decreases, but the shape of the peak remains the same. For the heat not containing nitrogen the peak is almost absent (Fig. 1b, curve 5).

Analysis of the TDF curves indicates that with increasing manganese concentrations the internal friction peak shifts to higher temperatures.

On the basis of literature data and our results, we attempted to explain the elevated solubility of nitrogen in austenitic steels containing manganese.

It is known that scattering of electrons in a field of ions in metals is determined not by the strong Coulomb ion potential  $V_C$  but the weaker effective potential (pseudopotential)  $V_p$  [5]. The theory of pseudopotentials has come to be accepted in recent years. This theory makes it possible to explain many physical and mechanical properties of metals.

From the pseudopotential theory it is known [5] that the following relationship exists between the radius of strongly bound electron shell of an atom  $R_{sh}^l$  and the pseudopotential  $V_p^l$  for electrons with an azimuthal quantum number  $l$

$$V_p^l = \frac{Z}{R_{sh}^l}, \quad (1)$$

where  $Z$  is the ionic charge (valency).

For elements from the same series in the periodic table the radius of the shell  $R_{sh}^l$  decreases with increasing order numbers. Besides iron atoms, the steels investigated contained atoms of chromium, manganese, and nickel. It follows that

$$R_{sh}^l(\text{Cr}) > R_{sh}^l(\text{Mn}) > R_{sh}^l(\text{Fe}) > R_{sh}^l(\text{Ni}). \quad (2)$$

This inequality for the radii of the shells affects the interaction of nitrogen atoms with atoms of alloying elements in two ways - through the size of the shell proper and through the magnitude of the pseudopotential of the ion.

Iron forms substitutional solid solutions with manganese. Since  $R_{sh}^l$  of manganese is larger than  $R_{sh}^l$  of iron, the lattice constant of iron increases when manganese is dissolved, and consequently the internal pore also increases, which leads to an increase in the solubility of nitrogen in such a deformed lattice.

According to Eq. (1), the pseudopotential of manganese is smaller than that of iron, both because of the lower valency and the larger radius  $R_{sh}^2$ . Consequently, the amplitude of scattering in the field of the manganese ion is smaller than in the field of the iron ion. Therefore, when iron atoms are replaced with manganese atoms the diffusion of nitrogen ions in the lattice improves and the solubility increases. Chromium atoms have a similar effect.

The anomalous curves of the F-R peak can be explained on this basis. The larger the quantity of manganese and chromium in the steel, the larger the number of nitrogen atoms they hold around them. Nitrogen atoms vibrate not only in positions with iron but also with manganese and chromium. The interactions of nitrogen with these elements are similar, but the activation energies of the processes differ. Superposed on each other, the relaxation spectra give a broad F-R peak. In steel 03Kh20N16AG6 the interaction of nitrogen with manganese is so large that it leads to an anomalous shape of the F-R peak (more a plateau). In steel 03Kh19N7AG10, with 10% Mn, the F-R peak is divided into two distinct subpeaks.

### CONCLUSIONS

1. It was shown by experiments with four austenitic Cr-Ni stainless steels that with increasing manganese concentrations the solubility of nitrogen increases.
2. With increasing concentrations of manganese the shape of the F-R peak on the TDIF curves is distorted - broadened, transformed into a plateau, or divided into two subpeaks (for steel with 10% Mn).
3. Using the theory of pseudopotentials, we attempted to explain the anomalous form of the TDIF curves and also the character of the interaction between manganese and nitrogen atoms in austenitic Cr-Ni steels.

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### DETERMINING THE LIMITS OF REGULATING THE CARBON POTENTIAL DURING CARBURIZING

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Due to the introduction of modern methods of regulating the carbon concentration on the surface of carburized steel, it is necessary to determine the limits of regulating the carbon potential during carburizing. For this purpose it is necessary to establish specific relationships

$$x_H, C_{sur} = f(C_{lim}, C_i, T, \tau), \quad (1)$$

where  $x_H$  is the depth of carburizing;  $C_{sur}$  is the surface concentration of carbon (the principal indicator of the quality of carburizing);  $\tau$  and  $T$  are the carburizing time and temperature;  $C_i$  is the original (before carburizing) carbon content of the steel;  $C_{lim}$  is the carbon potential of the working atmosphere, numerically equal to the limit concentration of carbon in the steel, which can be achieved in a given atmosphere with "through" carburizing of a thin sample (technological parameters of carburizing).

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