References:

1. Orientation selection in dendrite evolution / *T. Haxhimali, A. Karma, F. Gonzales, M. Rappaz* // Nature Materials. – 5, – P. 660-664 (9 July 2006). doi:10.1038/nmat1693 Article

2. *Flemings M. C., Yurko J.A., Martines R.A.* Semi-solid forming – our understanding today and its implications for improved processes // Symposium in Honor of Wilfred Kurz, Charlotte, NC, USA, March 14-18, 2004.- P. 3-14.

3. *Somboonsuk K., Trivedi R.* Dynamic studies of dendritic growth // Acta metallurgica. – 1985. – Vol. 33. – № 6. – P. 1051-1060.

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**DISSOLUTION OF NITROGEN IN AUSTENITE STEEL 10Cr14NMn15**

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It is necessary to control and calculate the nitrogen content in the metal during the production of nitrogen-containing steel in order to determine in advance the conditions for obtaining a given grade of steel. For this, a thermodynamic calculation should be used, which describes the solubility based on the parameters of the interaction of nitrogen with alloying elements in iron.

There are different approximations of the calculation, which include the interaction parameters of the first, second, second and first order and their various combinations and temperature dependences. A comparison was made of various methods of calculating the solubility of nitrogen in 10Cr14NMn15 steel, in particular, the Wagner method, the Chipman and Corrigan method, the calculations of V.I. Lakomskyi with co-authors, analytical and experimental material by J. Pitkälä with co-authors and others.

Chromium-manganese steels have high plasticity in a wide range of temperatures and can be used in cryogenic technology. Manganese is an austenizer of steel, it stabilizes the austenite structure at room and lower temperatures. Manganese is cheaper than nickel, but is a less effective austenizer. Therefore, these elements can often be used together.

Nitrogen, as a substitute for nickel, is a much stronger austenizer. A small amount of nitrogen in steel releases a large amount of nickel. Thus, a nitrogen content of 0.1% in chrome-nickel steels is equivalent to 1.5%–2.5 % Ni [1].

Now a large number of studies on the microstructure, properties, mechanisms of deformation, strengthening and destruction of austenitic chromium-manganese steels, including those doped with nitrogen, have appeared [2–8]. Therefore, the purpose of the study was to compare the thermodynamic calculation of nitrogen solubility in 10Cr14NMn15 steel by different authors and the experimentally determined solubility.

The calculation using the Wagner interaction parameters of the first and second order gave the following result for the temperature 1873 К:

$$lg[\%N]_{\mathrm{10Cr14NMn15}} = -0.4592 \quad \text{and} \quad [\%N]_{\mathrm{10Cr14NMn15}} = 0.347\ \%.$$

Using only the first-order interaction parameters in the calculation, as done by Wagner, gave a larger and, in our opinion, less likely estimate of nitrogen solubility.

The calculation according to the Chipman–Corrigan equation [9], which allows taking into account the influence of temperature on interaction parameters, made it possible to obtain the following data for a temperature of 1873 K:

$$lg[\%N]_{\mathrm{10Cr14NMn15}} = -0.4586 \quad \text{and} \quad [\%N]_{\mathrm{10Cr14NMn15}} = 0.348\ \%.$$

The advantage of using the Chipman-Corrigan equation remains the ability to calculate solubility at any temperature, but with approximately the same temperature effect on all interaction parameters.

Taking into account the temperature dependence of the interaction parameters when calculating the solubility according to the works of V.I. Lakomskyi and V.V. Lakomskyi was reflected in their monograph [10]. In the case of steel 10Cr14NMn15, the calculation gave the following results:

$$lg[N]_{10Cr14NMn15} = -0.4936 \quad \text{and} \quad [N]_{10Cr14NMn15} = 0.321\ \%.$$

The formula given in [11] was obtained using averaged literature data and the authors' own experimental data. That is, the authors obtained an averaged dependence that made it possible to obtain for the temperature 1873 K:

$$lg[N]_{10Cr14NMn15} = -0.4342 \quad \text{and} \quad [N]_{10Cr14NMn15} = 0.368\ \%.$$

To determine the differences in the solubility values obtained by different authors, a calculation was made for the temperature range 1873–2300 K, the results of which are shown in the fig. 1.

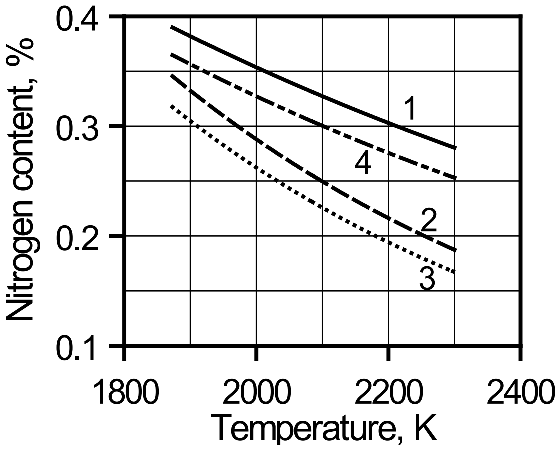


Fig. 1. The effect of temperature on the estimated solubility of nitrogen in 10Cr14NMn15 steel:
1 – Wagner's method taking into account the effect of temperature; 2 – the Chipman-Corrigan method; 3 – calculation according to the formulas of V.I. Lakomskyi [10], 4 – calculation according to the formula of Pitkälä J. with co-authors [11]

Experimental determination of the solubility of nitrogen at a temperature of 1923 K showed that the Sieverts constant is 0.306775, and the obtained dependence has the following form:

$$[\%N] = 0.306775 \cdot \sqrt{P_{N_2}}.$$

Thus, it is quite justifiable to estimate the solubility of nitrogen in 10Cr14NMn15 steel according to the formulas of V.I. Lakomskyi. The calculation error in this case is on the level 5 %.

It is sufficient to maintain the partial pressure of nitrogen in the system at the level of 0.3–0.7 atm to obtain 10Cr14NMn15 steel with a nitrogen content of 0.15–0.25 % when the melt is saturated from the gas phase at a temperature of 1923 K.

References:

1. Григоренко Г.М. Водород и азот в металлах при плазменной плавке / Г. М. Григоренко, Ю. М. Помарин. – Киев: Наукова думка, 1989. – 200 с.

2. Kamali Hamidreza. Void Formation and Crack Propagation in a Cr–Mn–N Metastable Austenitic Stainless Steel During Bending / Hamidreza Kamali, Haibo Xie, Hongyun Bi, E Chang, Haigang Xu, Haifeng Yu, Zhengyi Jiang, Azdiar A. Gazder // Advanced Engineering Materials. –·2022. – Doi: 10.1002/adem.202200891.

Режим доступу: https://www.researchgate.net/publication/365583982

3. Lefor K. Influence of the PM-Processing Route and Nitrogen Content on the Properties of Ni-Free Austenitic Stainless Steel / Kathrin Lefor M. Walter, A. Weddeling, E. Hryha, S. huth, S. Weber, L. Nyborg, W. Theisen // Metallurgical and materials transactions A. – 2015. – V. 46. – P. 1154–1167. DOI: 10.1007/s11661-014-2701-7.

Режим доступу: https://link.springer.com/article/10.1007/s11661-014-2701-7

4. Minha Park The Effects of Recrystallization on Strength and Impact Toughness of Cold-Worked High-Mn Austenitic Steels / Minha Park, Moon Seok Kang, Geon-Woo Park, Eun Young Choi, Hyoung-Chan Kim, Hyoung-Seok Moon, Jong Bae Jeon, Hyunmyung Kim, Se-Hun Kwon, Byung Jun Kim // Metals. – 2019. – V. 9 (9). – 948. Doi:10.3390/met9090948.

Режим доступу: https://www.mdpi.com/2075-4701/9/9/948

5. Wei Wang Temperature Dependence of Tensile Behaviors of Nitrogen-Alloyed Austenitic Stainless Steels / Wei Wang, Wei Yan, Ke Yang, Yiyin Shan, Zhouhua Jiang // Journal of Materials Engineering and Performance. – 2010. Режим доступу: https://www.researchgate.net/publication/226430970

6. Syahwira Taqwa Triadi. Dynamic plastic deformation induced by repetitive hammering on Cr-Mn austenitic stainless steel // Syahwira Taqwa Triadi, Cherly

Selindiana, Hermawan Judawisastra, Aditianto Ramelan // Metalurgi. – 2022. – V. 37. – № 1. – P. 7 – 14.

Режим доступу: http://dx.doi.org/10.14203/metalurgi.v37i1.618

7. Шипицин С.Я. Механічні та функціональні властивості Cr-(Ni)-Mn-N аустенітних жароміцних і жаростійких сталей // С.Я. Шипицин, І.Ф. Кірчу, Т.В. Степанова, П.М. Кучеренко // Металознавство та обробка матеріалів. – 2019. – Т.91. – № 3. – С. 23-29.

8. Risto Juhani Ilola. Mechanical Properties of Austenitic High-Nitrogen Cr-Ni and Cr-Mn Steels at Low Temperatures / Risto Juhani Ilola, Hannu Eelis Hanninen, Kari Martti Ullakko // ISIJ International. – 1996. – V. 36. – № 7. P. 873-877. DOI: 10.2355/isijinternational.36.873.

Режим доступу: https://www.researchgate.net/publication/290054065

9. Chipman J. Prediction of the solubility of nitrogen in molting steel / J. Chipman, D.A. Corrigan // Trans. AIME. – 1965. – V. 233. – № 7. – P.1249 – 1252.

10. Лакомский В.И. Азот в жидких сталях и шлаках / В.И. Лакомский, В.В. Лакомский. – Киев: Наукова думка, 2012. – 141 с.

11. Pitkälä J. A Study of the Effect of Alloying Elements and Temperature on Nitrogen Solubility in Industrial Stainless Steelmaking / J. Pitkälä, L .Holappa, A. Jokilaakso // Metallurgical and Materials Transactions B: Process Metallurgy and Materials Processing Science. – 2022. – V. 53. – № 4. – P. 2364 – 2376. Advance online publication. Режим доступу: https://doi.org/10.1007/s11663-022-02534-1

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## THE EFFECT OF CARBIDES ON THE INTERACTION OF HYDROGEN WITH Fe-Ti-C ALLOYS

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Hydrogen is an attractive energy source in terms of availability, environmental friendliness and energy efficiency. The development of hydrogen energy is limited by the problems of hydrogen storage. One of ways to solve this problem is the storage of