Journal of Achievements in Materials and Manufacturing Engineering
VOLUME 27
ISSUE 2
April
2008

Influence of increased nitrogen content on tool steels structure and selected properties

M. Cieśla*, K.J. Ducki
Materials Science Department, Silesian University of Technology,
ul. Krasińskiego 8, 40-019 Katowice, Poland
* Corresponding author: E-mail address: marek.ciesla@polsl.pl

Received 01.02.2008; published in revised form 01.04.2008

Materials

ABSTRACT

Purpose: The paper addresses the problem of determining the influence of an increased nitrogen content in the range 0.03-0.09% on the structure and selected functional properties of melts made of X155CrMoV12-1 and X40CrMoV5-1 tool steels and HS6-5-2 high-speed steel.

Design/methodology/approach: The tests consisted of an assessment of structure and determination of selected characteristics of as-annealed, quenched and tempered tool steels with nitrogen. Measurements of precipitates basic stereological parameters on the studied stages of heat treatment were performed. Nitrogen's influence on steels' crack resistance (K_{IC}) and low-cycle fatigue (LCF) in heat improved condition were analysed.

Findings: The investigated tool steels revealed that nitrogen addition has positive influence on carbides and carbonitrides' enhanced fraction and dispersion in as-annealed condition, and homogenizing and refinement of the structure in state of quenching and tempering. The modified structure of tool steels with nitrogen was shown by their increased functional properties, i.e. higher brittle cracking resistance and higher fatigue durability in the range of a low number of cycles at increased temperature.

Practical implications: The test results obtained can be used in developing technology and production of tool steels with nitrogen with increased functional properties and increased durability in operational conditions.

Originality/value: The paper demonstrated a positive influence of intentional nitrogen content on structure modification and an increase of tool and high-speed steels' functional properties.

Keywords: Tool materials; Metallography; Crack resistance; Fatigue

1. Introduction

One of perspective directions in development of tool and high-speed steels is the introduction of an increased nitrogen content to their chemical composition [1, 2]. The advantageous role of nitrogen in tool steels is connected with its action as an interstitial element in a solid solution and forming in combined state dispersion precipitates of nitrides and carbonitrides. The above-mentioned actions modify steel behaviour during melting, plastic forming and heat treatment which eventually yields more homogeneous and fine-grained structures of tool steels. As a result, there is an improvement of steel resistance to tempering, crack resistance K_{IC} and thermo-mechanical fatigue resistance which guarantees enhancing tools' durability [3-15].

In the paper, examinations concerning the influence of an increased nitrogen content on structure and selected functional properties of tool and high-speed steels were conducted. The aims of the studies were the assessment of structure and comparison of functional properties of experimental batch of products made of industrial alloys of tool steels with an increased nitrogen content.

2. Material and procedure

The research material were selected grades of X155CrMoV12-1 and X40CrMoV5-1 tool steels and high-speed HS6-5-2 steel produced in industrial conditions of a diverse nitrogen content and chemical composition shown in Table 1.

Table 1.
Chemical composition of melts of the examined tool steels with an increased nitrogen content

Chemical composition [wt.%]									
C	Mn	Si	P	S	Cr	Mo	W	V	N
X155CrMoV12-1 steel									
1.55	0.30	0.29	0.024	0.021	11.65	0.71	0.04	1.02	0.037
1.57	0.27	0.32	0.025	0.009	11.59	0.72	0.04	0.97	0.085
X40CrMoV5-1 steel									
0.40	0.44	1.00	0.018	0.004	5.06	1.20	0.02	0.95	0.006
0.36	0.53	0.91	0.018	0.004	5.15	1.15	0.03	1.01	0.029
0.37	0.37	1.03	0.016	0.005	5.20	1.24	0.02	0.93	0.057
HS6-5-2 steel									
0.85	0.24	0.34	0.029	0.006	3.97	4.70	5.73	1.82	0.019
0.84	0.17	0.28	0.029	0.010	3.73	4.82	6.53	1.79	0.030
0.86	0.20	0.30	0.030	0.019	4.05	4.76	6.38	1.88	0.036
0.85	0.24	0.41	0.030	0.015	4.11	4.67	5.77	1.86	0.039
0.88	0.22	0.27	0.030	0.011	3.98	4.75	6.14	1.85	0.049
0.86	0.18	0.28	0.030	0.009	4.15	4.68	6.31	1.80	0.057

The nitrogen content in X155CrMoV12-1 steel melts is within the range of 0.037-0.085%, in X40CrMoV5-1 steel melts within the range from 0.006% to 0.057% and in case of HS6-5-2 steel within the range of 0.019-0.057%. The examined tool steels can be recognized as steel with an increased nitrogen content.

From the tool steels melts provided, in industrial conditions forged or rolled rods 35mm in diameter were produced, from which sample sections were taken to the tests. Provided rods constituted the input material for the examinations in as-annealed condition and after heat treatment consisting of quenching and tempering. The parameters of heat treatment were determined on the basis of the results of the earlier works [16, 17].

The scope of the research scheme carried out included the following cycle of structural research and selected properties:

- microscopic observations and evaluation of steels structure in as-annealed, quenched and tempered state;
- stereologic examinations of precipitates in tool steels in their initial state and heat treated;
- examinations of crack resistance in flat state of strain;
- fatigue tests in a range of a low number of cycles.

The detailed data concerning methodology of conducted research concerning structure and functional properties of the analysed tool steels were presented in the paper [17].

3. Experimental results

The results of microscope observations of selected melts of tools steels and high-speed steels in as-annealed state are presented in Figs. 1 and 2. The examined tool steels melts with an increased nitrogen content are distinguished by dispersion structure of divorced pearlite with a little amount of large irregular primary carbide particles. Carbides and probably also carbonitrides in X155CrMoV12-1 and HS6-5-2 steels structure are uniformly distributed and precipitates banding typical of conventional high-speed steels and ledeburitic tool steels are not observed. Nitrogen addition caused in X40CrMoV5-1 steel refinement of the structure and increase of precipitates dispersion [16, 17].

The results of examinations of size and distribution of precipitates in selected HS6-5-2 steel melts with an increased nitrogen content in as-annealed condition are shown in Fig. 3. In the examined HS6-5-2 steel melts diversified quantities and sizes of precipitates on the investigated rods' section were observed.

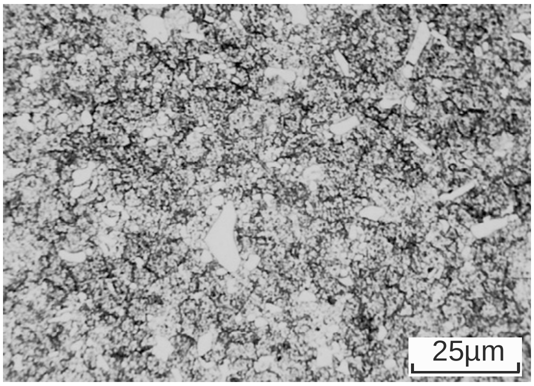

Fig. 1. Structure of X155CrMoV12-1 steel (N=0.085%) in as-annealed condition. Spheroidal and irregular carbides in ferrite

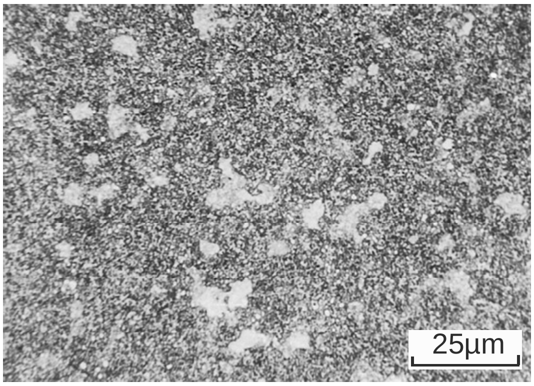

Fig. 2. Structure of HS6-5-2 steel (N=0.057%) in as-annealed condition. Spheroidal and irregular carbides in the ferrite matrix

The analyzed high-speed steels' melts are characterized by increased precipitates fraction in structure as the nitrogen content increases from 18.5-20.3% for steel containing 0.019%N to 23.0-24.1% for 0.049%N. Similar dependence was also found for X155CrMoV12-1 and X40CrMoV5-1 steels with diversified nitrogen concentration [17].

The positive influence of nitrogen on the structure of examined tool steels was also observed in states of quenching and tempering (Figs. 4 and 5). In X155CrMoV12-1 and HS6-5-2 steels' melts, influence of nitrogen consists of refinement of the structure of matrix and increase of fraction, dispersion degree and homogeneity of precipitates distribution. In X40CrMoV5-1 steel, the incorporation of nitrogen caused refinement and homogenizing of tempered martensite structure [16,17].

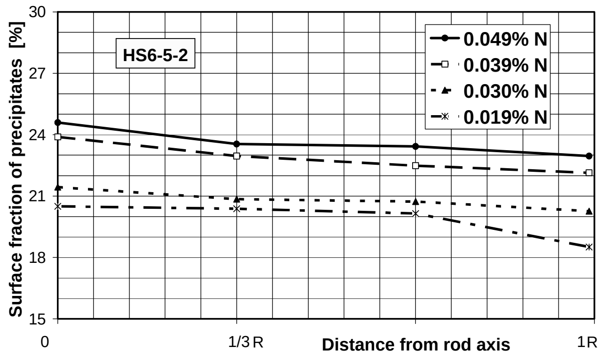

Fig. 3. The influence of concentration of nitrogen and distance from rod axis on the surface fraction of precipitates in annealed HS6-5-2 steel

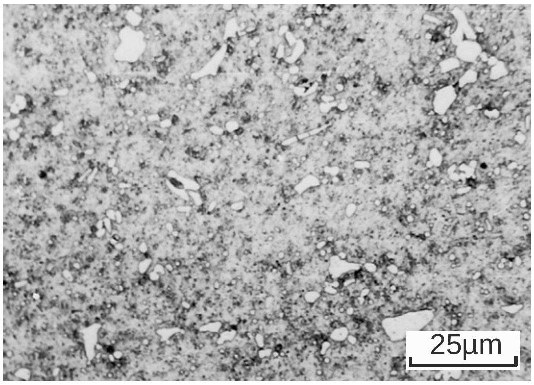

Fig. 4. Structure of X155CrMoV12-1 steel (N=0.085%) after quenching (1020°C/oil) and tempering (2×300°C). Tempered martensite with primary carbides

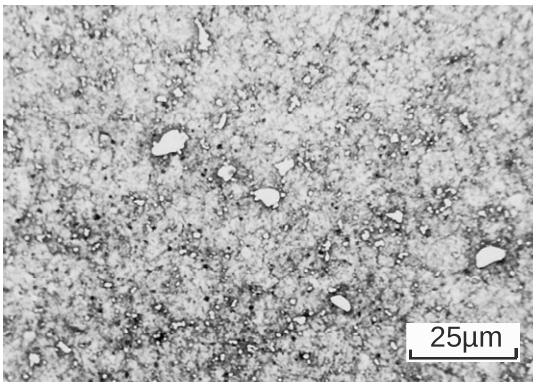

Fig. 5. Structure of HS6-5-2 steel (N=0.057%) after quenching (1220°C/oil) and tempering (2×550°C). Tempered martensite with primary and secondary carbides

The results of examinations of size and distribution of precipitates in selected HS6-5-2 steel melts with an increased nitrogen content in quenched and tempered condition are shown in Fig.6. The results obtained show an insignificant diversity of the amount of precipitates on the rod section, whereas mean precipitations size changes along the rod radius. As the quantity of nitrogen in steel increases it is observed that mean precipitates size decreases from 5.154-4.606 μm^2 value for steel containing 0.019% of nitrogen to 4.631-4.221 μm^2 for steel with content 0.049% N. Similar dependence was also found for X155CrMoV12-1 and X40CrMoV5-1 steels' melts with an increased nitrogen content [16, 17].

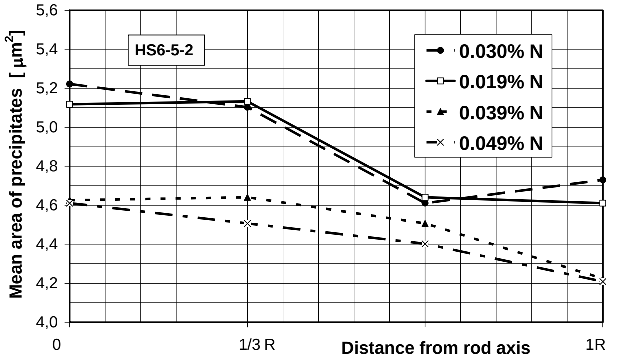

Fig. 6. The influence of concentration of nitrogen and distance from rod axis on the mean area of the precipitates in HS6-5-2 steel after quenching (1220°C/oil) and tempering (2×550°C)

The results of crack resistance tests in flat state of strain for specimens from selected tool and high-speed steel melts were shown in Fig.7. Analysis of coefficients values of intensity of stress K_{IC} allows affirming that examined tool steels with an increased nitrogen content are usually characterized by higher brittle cracking resistance. In the group of X155CrMoV12-1 and HS6-5-2 steels, the melts with the highest nitrogen content i.e. 0.085% and 0.057%N were characterized by the highest value of coefficient K_{IC} (42.1 and 17.4 $MPa \cdot m^{1/2}$ respectively). In the case of X40CrMoV5-1 steel melts, no significant influence of nitrogen content on value of coefficient K_{IC} has been found.

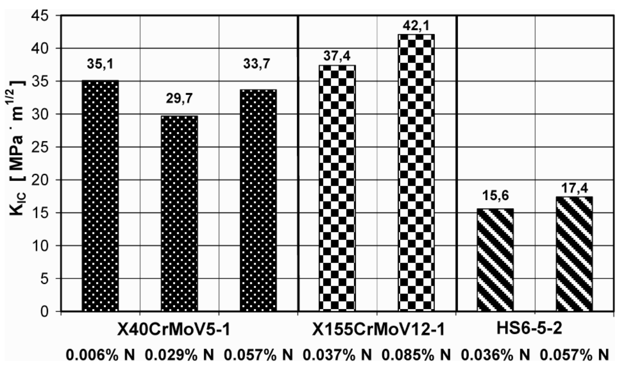

Fig. 7. Collation of values of coefficients K_{IC} for examined tool steel melts with an increased nitrogen content

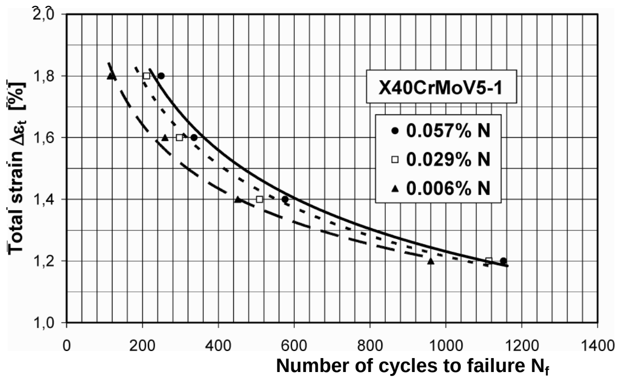

Fig. 8. Collective diagrams of low-cycle fatigue durability at a temperature of 550°C for X40CrMoV5-1 tool steel with diversified nitrogen content

Fatigue examinations in a range of a low number of cycles were carried out at a temperature of 550°C on specimens of X40CrMoV5-1 steel with an increased nitrogen content. The results of examinations were presented in the form of collective diagrams of fatigue durability in Fig.8. The analysis of fatigue characteristics shows that X40CrMoV5-1 steel with the highest nitrogen amount i.e. 0.057%. is characterized by the highest durability expressed as the number of cycles until failure (N_f). The steel with a 0.029% addition of nitrogen showed lower fatigue durability and conventional X40CrMoV5-1 steel melt with content 0.006% N was characterized by the lowest durability on all applied strain levels ($\Delta\varepsilon_t$).

4. Conclusions

The obtained results of research on structure and functional properties of pilot batch of products made of tool and high-speed steels with an increased nitrogen content show positive influence of nitrogen on structure and properties of investigated steels in as-annealed, quenched and tempered condition.

Introducing nitrogen to tool steels causes refinement of the structure, increase of fraction and degree of carbide phase dispersion and increasing homogeneity of primary and secondary carbides. In the products' structure, no banding and segregation of carbides is observed what is typical of conventional ledeburitic tool and high-speed steels.

In the group of investigated melts of ledeburitic tool steels for cold work and high-speed steels introducing an increased nitrogen content significantly increases resistance to brittle cracking (K_{IC}) of these materials.

In condition of low-cycle loads at a temperature of 550°C, steel with the highest nitrogen content i.e. 0.057% N was characterized by the highest fatigue durability among X40CrMoV5-1 steel melts. The lowest durability in all investigated strain ranges was shown by conventional X40CrMoV5-1 steel melt with the lowest nitrogen content.

References

[1] T. Rashev, High nitrogen steels. Metallurgy under pressure, Academic Publishing House of Bulgarian Academy of Science, Sofia, 1995.

[2] F.B. Pickering, Some beneficial effects of nitrogen in steel, Proceedings of the Conference "High Nitrogen Steels" HNS'88, Lille, 1988, 10-31.

[3] L.A. Dobrzański, J. Mazurkiewicz, E. Hajduczek, Influence of the Zr and Ce on the structure of experimental hot-work tool steel, Journal of Achievements in Materials and Manufacturing Engineering 17 (2006) 49-52.

[4] L.A. Dobrzański, A. Zarychta, M. Ligarski, High-speed steels with addition of niobium or titanium, Journal of Materials Processing Technology 63 (1997) 531-541.

[5] L.A. Dobrzański, M. Ligarski, Role of Ti in the W–Mo–V high-speed steels, Journal of Materials Processing Technology 64 (1997) 101-116.

[6] P. Bała, J. Pacyna, J. Krawczyk, The kinetics of phase transformations during the tempering of HS6-5-2 high-speed steel, Journal of Achievements in Materials and Manufacturing Engineering 18 (2006) 47-50.

[7] M. Rosso, D. Ugues, Structural changes and properties modifications in heat treating of tool steels, Proceedings of the 11th International Scientific Conference "Contemporary Achievements in Mechanics, Manufacturing and Materials Science" CAM3S'2005, Gliwice – Zakopane, 2005, (CD-ROM).

[8] S.Z. Qamar, A.K. Sheikh, A.F.M. Arif, T. Pervez, R.A. Siddiqui, Heat treatment of a hot-work die steel, Archives of Materials Science and Engineering 28/8 (2007) 503-508.

[9] P. Bała, J. Pacyna, The kinetics of phase transformations during tempering in high-speed steels, Journal of Achievements in Materials and Manufacturing Engineering 23/1 (2007) 15-18.

[10] J. Mazurkiewicz, L.A. Dobrzański, E. Hajduczek, Comparison of the secondary hardness effect after tempering of the hot-work tool steels, Journal of Achievements in Materials and Manufacturing Engineering 24/2 (2007) 119-122.

[11] P. Bała, J. Pacyna, J. Krawczyk, The kinetics of phase transformations during tempering in the new hot working steel, Journal of Achievements in Materials and Manufacturing Engineering 22/2 (2007) 15-18.

[12] A.G. Svyazin, E.S. Shaidurova, J. Siwka, L.M. Kaputkina, V.G. Prokoshkina, A. Hutny, Structure and distribution of nitrogen in Fe–N, Fe–V–N alloys after casting and heat treatment, Materials Engineering 3 (2004) 197-199.

[13] H. Berns, J. Lueg, Properties of hot-working tool steels containing nitrogen, Proceedings of the Conference "High Nitrogen Steels" HNS'88, Lille, 1988, 322-326.

[14] I. Rasheva, T. Rashev, High-nitrogen tool steels, Proceedings of the Conference "High Nitrogen Steels" HNS'90, Aachen, 1990, 381-386.

[15] J. Lueg, High nitrogen tool steels for various applications, Proceedings of the Conference "High Nitrogen Steels" HNS'93, Kijev, 1993, 580-585.

[16] K.J. Ducki, M. Hetmańczyk, M. Cieśla, D. Kuc, Influence of nitrogen content on structure and properties of the WCLV grade hot-work tool steel, Proceedings of the Conference "Steels with nitrogen" SWA'96, Wisła, 1996, 255-259 (in Polish).

[17] J. Wiedermann, W. Zalecki, M. Malec, F. Grosman, M. Hetmańczyk, J. Okrajni, E. Hadasik, K. Ducki, K. Pogoda, H. Smyczek, Principal characteristics of nitrogen alloyed tool steels, IMŻ Works 1 (1999) 22-40 (in Polish).