Journal of Achievements in Materials and Manufacturing Engineering
VOLUME 29
ISSUE 1
July
2008

Effect of increased nitrogen content on the structure and properties of tool steels

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Received 16.04.2008; published in revised form 01.07.2008

Materials

ABSTRACT

Purpose: The influence is analysed of an increased nitrogen content in the range of 0.03-0.09% on stereological features of the microstructure, the principal mechanical properties, crack resistance and fatigue strength of alloy tool steels of X155CrMoV12-1 and X40CrMoV5-1 types, and the HS 6-5-2 high-speed steel.

Design/methodology/approach: The principal stereological parameters of precipitates in the microstructure of as-annealed, quenched and tempered tool steels with nitrogen have been determined. The surface fraction and the mean plane section area of carbides have been determined as well. The influence of nitrogen on abrasion resistance, crack resistance and low-cycle fatigue of a heat improved steel has been examined.

Findings: It has been found that in the investigated tool and high-speed steels, a nitrogen addition enhances size-reduction and homogenization of the structure in the as-quenched and as-tempered condition. Moreover, an advantageous effect of nitrogen additions has been found on increasing the fraction and dispersion of carbides in the as-annealed condition. The tool and high-speed steels with a nitrogen addition have shown increased resistance to abrasion and brittle cracking as well as longer fatigue life at an elevated temperature.

Practical implications: At the laboratory testing stage, the results of the study may constitute an assessment of the effect of nitrogen addition on usable properties of tool steels. The results should be used to develop a production technology of tool steels containing nitrogen of increased durability in operational conditions.

Originality/value: The study has shown the influence of a nitrogen addition in the range of 0.03-0.09% on the modification of the microstructe of selected tool and high-speed steels, which determines the enhanced usable properties of those steels.

Keywords: Tool materials; Quantitative 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 [3-9].

Introduction of nitrogen into high-speed steels reduces the micro- and macroliquation of alloy components, which is conducive to crystallization and facilitates plastic working. Higher nitrogen contents (ca. 0.6%) lead to changes in the primary structure and morphology of eutectic components and to formation of carbonitrides. A dendritic structure is replaced with a cellular-dendritic structure or a completely cellular structure, with the reinforcing phase fraction increasing by 2-3%. In economical high-speed steels, a nitrogen addition, via fine eutectics, contributes to NbC carbides size-reduction. As a result of those interactions, high-speed steels with nitrogen achieve functional hardness higher by 2-3 HRC at temperatures of 500-600°C and enhanced mechanical properties, which extends the operational life of tools. Research conducted in machine-building plants shows that machining tools made of high-speed steels with a nitrogen content have durability by ca. 1.3-1.8 times higher than their equivalents without a nitrogen content [10-17].

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 of 35, 42 and 55 mm 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 [18-20].

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 basic data concerning the methodology of the research regarding the structure and usable properties of the analyzed tool steels are presented below.

Tests of carbides' size and distributions in high-speed and tool steels were carried out using a Morphopercolor image analyzer coupled with a Neophot-2 light microscope. Analyses were performed on microsections perpendicular to the axis of the rod. Measurement of stereological parameters of the carbides were taken in four zones of the analyzed rods with a 42 mm diameter, i.e.: in the middle of the rod, 1/3 of radius, 2/3 of radius and on the rod surface. In each zone, a population of ca. 1000 carbides was examined and the results were averaged.

Values of the following parameters describing the size and inhomogeneity of the carbides were determined [21, 22]:

- fraction of flat surface occupied by carbides A_A, %;
- mean area of carbide plane section $\bar{A}$, µm^2;
- variability coefficient being the measure of carbide size inhomogeneity,
  $v(A) = \frac{S(A)}{\bar{A}}$, %, where: S(A) – standard deviation of carbide plane section area;
- dimensionless shape coefficient, $\xi = \frac{4\pi \bar{A}}{P^2}$, where: P – circumference of precipitates' plane section; this index assumes value 1 for a circle and for objects of other shapes, it falls in the range of [0, 1];
- elongation factor F = F_x/F_y, where: $F_{x,y}$ – Feret's diameters towards axes x, y; F = 1 for equiaxial particles.

Stereological examination of the carbides was carried out mainly for specimens of high-speed steels with an increased nitrogen content in an annealed condition, as well as after quenching and tempering.

Abrasion resistance tests were performed during sliding friction (in dry conditions) on Amsler machine A-135, at a constant pressure. The applied test parameters were as follows: load on specimens – 100 N; rotational speed of specimen – 200 rpm; static load on specimens. To determine the wear of the investigated steels, measurement of the loss of mass was made. The tests were carried with an immobile counterspecimen of sintered carbide G10 and a rotating specimen consisting of discs made of the investigated steels, 50 mm in diameter and 10 mm thick. Before the tests, the specimens' surface was ground, cleaned and degreased in extraction naphtha. The cleaning and degreasing activities were repeated during each test. To maintain a correct course of the abrasion wear process, the so-called wearing-in period was assumed for individual specimens representing each tool steel grade, namely, for the high-speed HS6-5-2 steel, from 0 to 500 cycles; for the X155CrMoV12-1 steel, from 0 to 1000 cycles; and for the X40CrMoV5-1 steel, the wearing-in period ranged between 0 and 2000 cycles.

Tests of crack resistance in a flat state of deformation were carried out at room temperature using a strength testing servo-hydraulic machine, MTS. The tests were made on specimens intended for three-point bending (SENB) of thickness B=20 mm, with a width W to B ratio equal 2. Fatigue crack in the specimen was generated in the conditions of sinusoidally variable load. During the final stage of crack growth, the stress intensity coefficient did not exceed a value of K_I = 8 MPa·m$^{1/2}$. The desirable fissure depth was achieved after 80.000 cycles. The frequency of load change was 10 Hz. A specimen with the so generated fatigue crack was subjected to static bending. A test until failure was carried out using an extensiometer, with controlling the dilation of fissure edges. The stress intensity increase rate while loading the specimen fell within a range of 0.5-2.7 MPa·m$^{1/2}$/s. Based on the obtained diagrams, the critical force (F_Q) was determined. Next, the K_{IC} value was calculated for the tested steels in accordance with the procedure described in standard BS 7448 [23].

Low-cycle fatigue (LCF) tests were carried with deformation control using a servo-hydraulic strength testing machine, MTS, at a temperature of 550°C. The fatigue tests were conducted in an oscillatory cycle of a sinusoidal waveform, in total strain range equal: $\Delta\varepsilon_t$ = 1.2%; 1.4%; 1.6% and 1.8%, respectively. The average deformation rate ($\dot{\varepsilon}$) amounted to ca. 2.5 × 10^{-3} s^{-1}. Round specimens with a diameter d_0 = 12 mm and measuring base l_0 = 30 mm were used for the tests. The specimens were induction heated and the temperature was controlled by means of thermocouples PtRh10-Pt.

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. 1-3. 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 (Figs. 1 and 2). Nitrogen addition caused in X40CrMoV5-1 steel refinement of the structure and increase of precipitates dispersion (Fig. 3).

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 presented in Figs. 4 and 5 and provided in Table 2. In the examined HS6-5-2 steel melts diversified quantities and sizes of precipitates on the investigated rods' section were observed. 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 (Fig. 4). Similarly, as the nitrogen concentration in the high-speed steel structure increases, the mean size of precipitates ($\bar{A}$) decreases from 4.30-5.58 μm for the steel containing 0.019% N, to 4.03-4.73 μm for the steel with a 0.049% N content (Fig. 5). Analogical dependence was detected for X155CrMoV12-1 and X40CrMoV5-1 steels with diversified nitrogen contents [19].

Melt of the high-speed steel with a low nitrogen content (0.019%) is characterized by a high variability ratio ν (255-320%), which testifies to its considerable inhomogeneity (Table 2). As the nitrogen concentration increases (to 0.049%), this ratio falls to a value within the range of 180-202%, showing thereby progressive homogenization of precipitates. An analysis of the dimensionless shape factor (ξ) and the elongation factor (F) for the precipitates shows insignificant differences between these parameters, depending on the place of analysis on the rod and the nitrogen content in the steel. The shape factor values amount to ca. 0.55 on average, which testifies to a shape diverging from a spherical one. At the same time, the elongation factor values, 0.80 on average, show equiaxiality of precipitates. No effect of the variable nitrogen content in the high-speed steel on those parameters has been found.

The positive influence of nitrogen on the structure of examined tool steels was also observed in states of quenching and tempering (Figs. 6-8). 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 (Figs. 6 and 7). In X40CrMoV5-1 steel, the incorporation of nitrogen caused refinement and homogenizing of tempered martensite structure (Fig. 8).

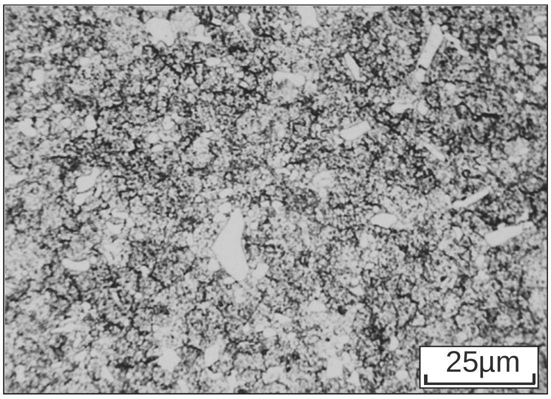

Fig. 1. Structure of X155CrMoV12-1 steel (N=0.085%) in as-annealed condition. Spheroidal and irregular carbides in ferrite

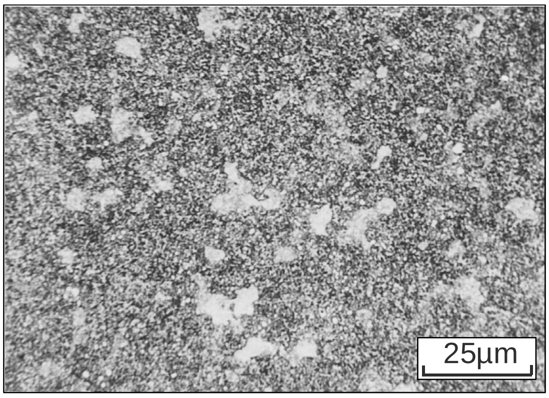

Fig. 2. Structure of HS6-5-2 steel (N=0.057%) in as-annealed condition. Spheroidal and irregular carbides in the ferrite matrix

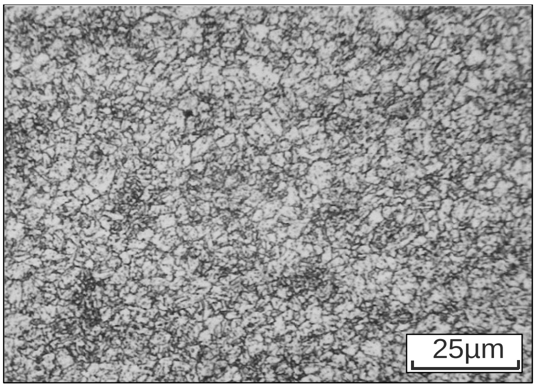

Fig. 3. Structure of X40CrMoV5-1 steel (N=0.057%) in as-annealed condition. Fine-grained ferrite with dispersion carbides

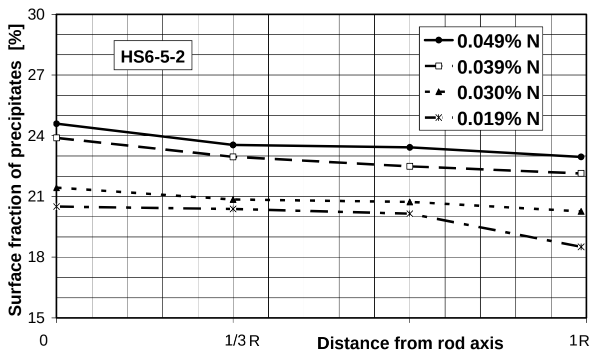

Fig. 4. The influence of concentration of nitrogen and distance from rod axis on the surface fraction of precipitates in annealed HS6-5-2 steel

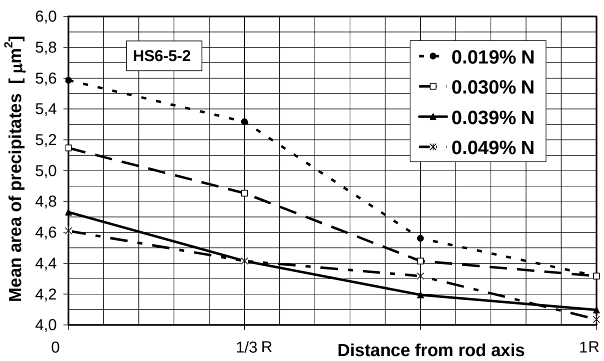

Fig. 5. The influence of concentration of nitrogen and distance from rod axis on the mean area of the precipitates in annealed HS6-5-2 steel

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 Figs. 9, 10 and given in Table 3. 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. In the analyzed high-speed steel melts, the surface fraction of precipitates is the highest in the steel with a 0.019% N content (A_A=10.2-11.3%), whereas it does not show any significant differences at higher nitrogen contents (Fig. 9). 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 (Fig. 10). Similar dependence was also found for X155CrMoV12-1 and X40CrMoV5-1 steels' melts with an increased nitrogen content [19].

Table 2.
Results of quantitative examination of carbide size and distribution in rods made of the analyzed melts of high-speed steel HS6-5-2 in as-annealed condition

Grade of steel	Nitrogen content [%]	Distance from rod axis	A_A [%]	$\bar{A}$ [μm]	ν(A)	F	ξ
HS6-5-2	0.019	rod axis	20.3	5.59	320	0.83	0.56
		1/3R	20.5	5.32	333	0.82	0.52
		2/3R	20.3	4.56	285	0.85	0.60
		surface	18.5	4.30	255	0.84	0.68
	0.030	rod axis	21.6	5.15	200	0.83	0.52
		1/3R	21.0	4.85	225	0.82	0.53
		2/3R	20.7	4.42	170	0.84	0.61
		surface	20.3	4.30	250	0.80	0.61
	0.039	rod axis	24.1	4.73	192	0.82	0.54
		1/3R	23.2	4.42	211	0.84	0.52
		2/3R	22.6	4.20	200	0.82	0.59
		surface	22.2	4.10	211	0.85	0.58
	0.049	rod axis	24.8	4.62	180	0.82	0.54
		1/3R	23.8	4.42	192	0.84	0.52
		2/3R	23.5	4.32	202	0.82	0.60
		surface	23.0	4.03	198	0.85	0.59

Table 3.
Results of quantitative examination of carbide size and distribution in rods made of the analyzed melts of high-speed steel HS6-5-2 after quenching (1220°C/oil) and tempering (2×550°C)

Grade of steel	Nitrogen content [%]	Distance from rod axis	A_A [%]	$\bar{A}$ [μm]	ν(A)	F	ξ
HS6-5-2	0.019	rod axis	11.5	5.15	312	0.73	0.55
		1/3R	10.4	5.13	319	0.80	0.51
		2/3R	10.5	4.63	229	0.79	0.52
		surface	10.1	4.61	165	0.84	0.57
	0.030	rod axis	10.9	5.22	220	0.82	0.61
		1/3R	10.8	5.11	250	0.80	0.59
		2/3R	11.5	4.61	211	0.86	0.63
		surface	10.3	4.73	219	0.84	0.61
	0.039	rod axis	10.7	4.63	221	0.83	0.65
		1/3R	10.9	4.41	208	0.97	0.60
		2/3R	10.5	4.51	232	0.85	0.62
		surface	10.2	4.22	200	0.85	0.68
	0.049	rod axis	10.3	4.63	198	0.86	0.64
		1/3R	10.1	4.62	212	0.86	0.69
		2/3R	10.0	4.50	196	0.89	0.81
		surface	10.1	4.22	175	0.80	0.81

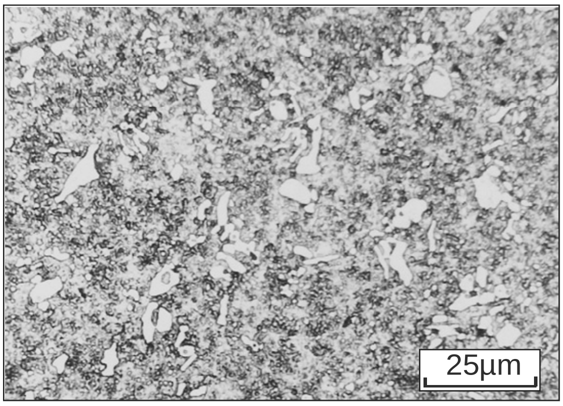

Fig. 6. Structure of X155CrMoV12-1 steel (N=0.085%) after quenching (1020°C/oil) and tempering (2×450°C). Tempered martensite with primary and secondary carbides

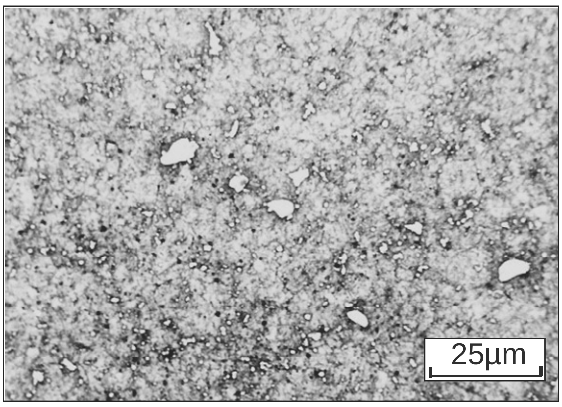

Fig. 7. Structure of HS6-5-2 steel (N=0.057%) after quenching (1220°C/oil) and tempering (2×550°C). Tempered martensite with primary and secondary carbides

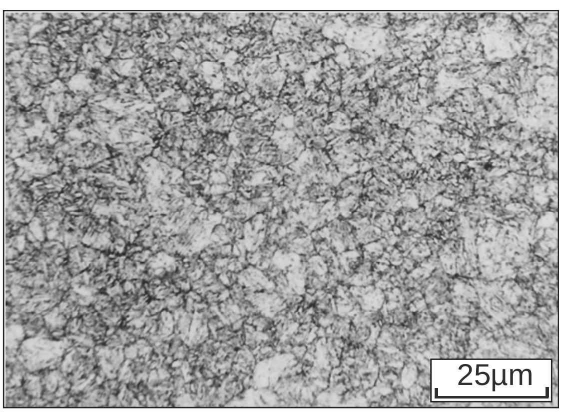

Fig. 8. Structure of X40CrMoV5-1 steel (N=0.057%) after quenching (1050°C/oil) and tempering (2×550°C). Tempered martensite with secondary carbides

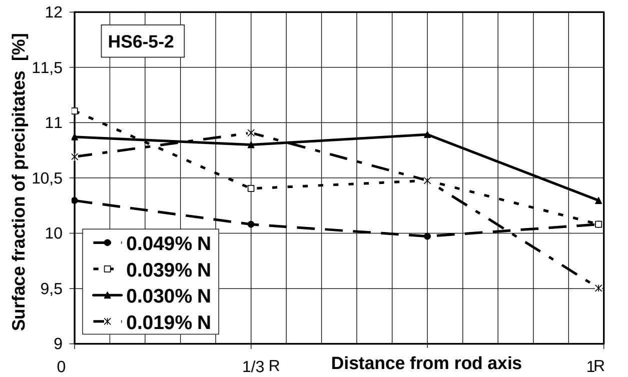

Fig. 9. The influence of concentration of nitrogen and distance from rod axis on the surface fraction of the precipitates in HS6-5-2 steel after quenching (1220°C/oil) and tempering (2×550°C)

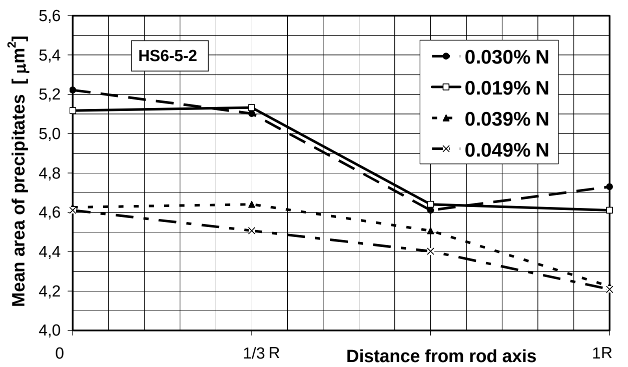

Fig. 10. The influence of concentration of nitrogen and distance from rod axis on the mean area of the precipitates in HS6-5-2 steel after quenching (1220°C/oil) and tempering (2×550°C)

Melts of the high-speed steel with a lower nitrogen content (0.019-0.030%) are characterized by a significant diversity of the variability ratio (ν) in a range of 165-312%, which testifies to considerable variation in the deviation from the mean size of precipitates on the rod's cross-section (Table 3). The discussed ratio decreases and the nitrogen concentration grows (0.039-0.049%) to a value of 175-212%. An analysis of the dimensionless shape factor (ξ) and the elongation factor (F) of the precipitates shows their insignificant diversity, depending on the place of analysis on the rod’s cross-section and the nitrogen content in the steel. The shape factor achieves high values of 0.60 on average for the steel with a nitrogen content of 0.030-0.049%, which testifies to a shape close to a sphere; with a 0.019% N content, the factor is slightly lower and amounts to ca. 0.55. Similarly, the elongation factor values, 0.85 on average, show that the shape of precipitates is close to an equiaxial one.

Results of wear resistance tests of the analyzed high-speed steel and tool steel melts with an increased nitrogen content are shown in Figs. 11-13. Results obtained for four melts of the HS6-5-2 steel with different nitrogen contents depending on the applied quenching temperature are presented in Figs. 11 and 12. As can be seen from the data obtained for two variants of thermal treatment, abrasion resistance is enhanced as the nitrogen content in steel increases. Melts with the highest nitrogen content in steel i.e. within the range of 0.039-0.049%, are distinguished by the highest abrasion resistance. Melts of the high-speed steel containing less nitrogen (N=0.019-0.030%) show lower resistance to abrasion. In addition, an increase of quenching temperature to 1220°C for specimens made of the HS6-5-2 steel favourably enhanced abrasion resistance as a result of higher hardness after heat treatment. Also, in the case of the tool steels X40CrMoV5-1 and X155CrMoV12-1, melts with the highest nitrogen concentration had the highest abrasion resistance (Figs. 13, 14). For steel X40CrMoV5-1, the highest wear resistance was shown by a melt with a highest nitrogen content, i.e. 0.057%, while a conventional melt (0.006% N) had the lowest abrasion resistance (Fig. 13). Analogical wear charts were obtained for melts of the X155CrMoV12-1 steel with different nitrogen contents (Fig. 14). Also in this case, a melt with a higher nitrogen concentration (0.085%) had higher abrasion resistance compared to a melt with a lower nitrogen content (0.037%).

The results of crack resistance tests in flat state of strain for specimens from selected tool and high-speed steel melts were shown in Table 4 and Fig. 15. 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·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.

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 given in Table 5 and presented in the form of collective diagrams of fatigue durability in Fig.16. 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 ($\Delta\varepsilon_t$).

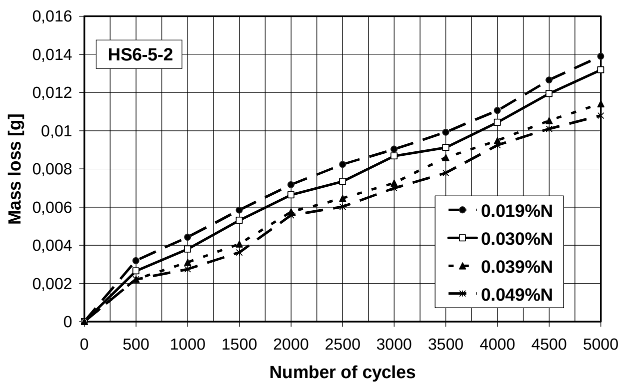

Fig. 11. Relationship of mass loss from number of cycles in wear test for HS6-5-2 steel after quenching (1200°C/oil) and tempering (2×550°C)

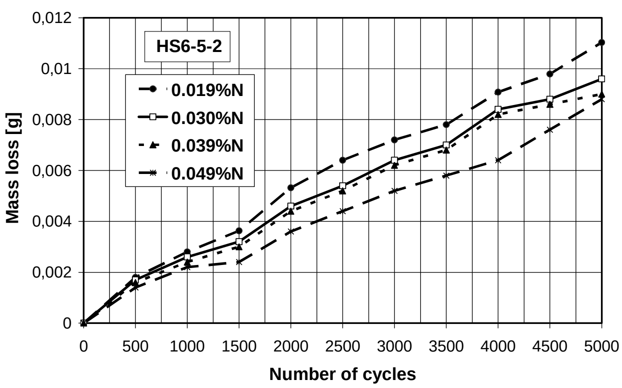

Fig. 12. Relationship of mass loss from number of cycles in wear test for HS6-5-2 steel after quenching (1220°C/oil) and tempering (2×550°C)

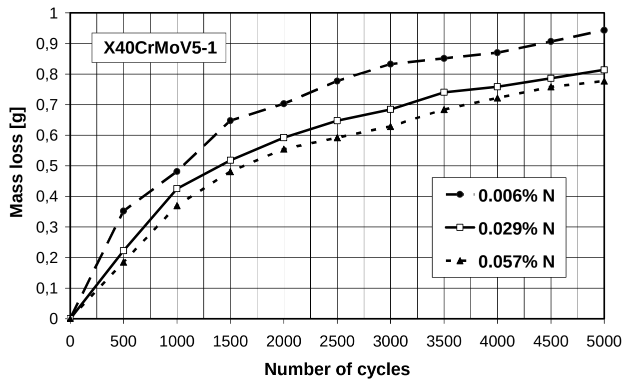

Fig. 13. Relationship of mass loss from number of cycles in wear test for X40CrMoV5-1 steel after quenching (1050°C/oil) and tempering (2×550°C)

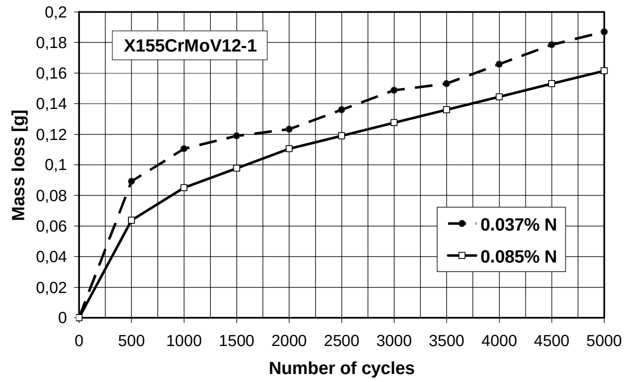

Fig. 14. Relationship of mass loss from number of cycles in wear test for X155CrMoV12-1 steel after quenching (1020°C/oil) and tempering (2×450°C)

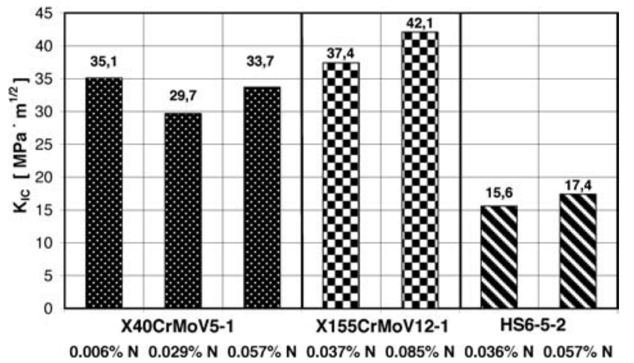

Fig. 15. Collation of values of coefficients K_{IC} for examined tool steel melts with an increased nitrogen content

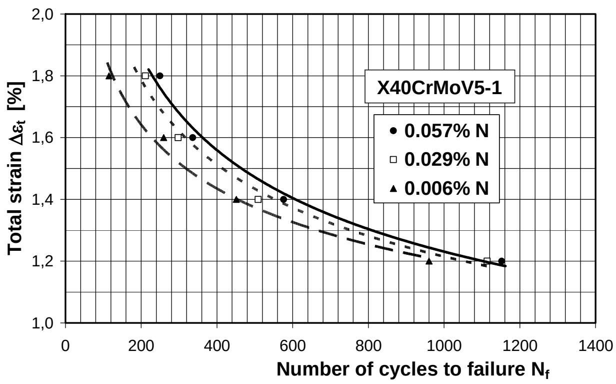

Fig. 16. Collective diagrams of low-cycle fatigue durability at a temperature of 550°C for X40CrMoV5-1 tool steel with diversified nitrogen content

Table 4.
Results of brittle cracking resistance tests in flat state of deformation K_{IC} for tool steels with an increased nitrogen content

Grade of steel	Nitrogen content [%]	K_{IC} [$MPa{\cdot}m^{1/2}$] Number of sample 1	2	3	Mean K_{IC} [$MPa{\cdot}m^{1/2}$]
X40CrMoV5-1	0.006	36.0	35.8	33.5	35.1
	0.029	31.6	30.1	27.4	29.7
	0.057	33.4	34.8	32.9	33.7
X155CrMoV12-1	0.037	40.3	35.5	36.4	37.4
	0.085	40.9	42.8	42.5	42.1
HS6-5-2	0.036	16.2	15.2	15.4	15.6
	0.057	17.6	17.2	17.4	17.4

Table 5.
Results of low-cycle fatigue tests at a temperature of 550°C for specimens made of the X40CrMoV51-1 tool steel with a varied nitrogen content

Grade of steel	Nitrogen content [%]	Range of total strain, $\Delta\varepsilon_t$ [%] 1.2	1.4	1.6	1.8
		Number of cycles to failure			
X40CrMoV5-1	0.006	942	470	274	106
	0.029	1150	508	297	213
	0.057	1130	590	345	254

4. Conclusions

The presented research addressed the problem of the influence of an increased nitrogen content on the structure and selected functional properties of alloy tool steels of types X155CrMoV12-1 and X40CrMoV5-1, and the high-speed HS6-5-2 steel. The nitrogen content in industrial melts of the X155CrMoV12-1 steel was within the range of 0.037-0.085%, in X40CrMoV5-1 steel melts within the range from 0.006% to 0.057%, and for the HS 6-5-2 steel, in the range of 0.019-0.057%. Tests were conducted on specimens taken from the analyzed steel melts in as-annealed condition and after quenching and tempering.

In the as-annealed condition, the examined melts of tool and high-speed steels with an increased nitrogen content are distinguished by a dispersion structure of divorced pearlite, with relatively uniformly distributed carbides. Introduction of nitrogen to the discussed steels causes a size reduction of the structure, an increase of the fraction and degree of carbide phase dispersion and an increase in the homogeneity of primary carbides distribution. In the structure of the tested rods of X155CrMoV12-1 and HS6-5-2 steels, no banding or segregation of carbides was observed, which is typical of conventional ledeburitic tool and high-speed steels.

A favourable influence of nitrogen on the structure of the examined steels was also observed in as-quenched and as-tempered conditions. In X155CrMoV12-1 and HS 6-5-2 steel melts, the influence of nitrogen consists of size reduction of the martensitic matrix structure and an increase of the fraction, dispersion degree and homogeneity of precipitates' distribution. In the X40CrMoV5-1 steel, the incorporation of nitrogen caused size reduction and homogenization of the tempered martensite structure, as well as an increase of secondary carbides dispersion. In the as-quenched and as-tempered condition, a favourable effect of a nitrogen content is observed on the hardness of the investigated tool and high-speed steels.

In the investigated tool and high-speed steel melts, a positive influence of an increased nitrogen content on wear resistance, determined in an abrasion test in sliding friction conditions, can be observed. The tested high-speed and tool steels with an increased nitrogen content are characterized by lower wear compared to conventional grades with analogical abrasion parameters.

In the group of the investigated melts of ledeburitic tool steels intended for cold work, X155CrMoV12-1, and high-speed steels HS6-5-2, an introduction of an increased nitrogen content significantly enhances resistance to brittle cracking (K_{IC}) of these materials. In the case of X40CrMoV5-1 steel melts, no explicitly significant influence of nitrogen content on the K_{IC} coefficient value has been found.

In low-cycle fatigue (LCF) conditions, at a temperature of 550°C, the steel with the highest nitrogen content, i.e. 0.057% N, was characterized by the highest fatigue durability among the melts of steel X40CrMoV5-1. The lowest fatigue durability in all investigated complete deformation ranges was shown by a conventional X40CrMoV5-1 steel melt with the lowest nitrogen content (0.006%N).

Based on the test results, it can be concluded that in the analyzed melts of tool steels X155CrMoV12-1 and X40CrMoV5-1, and the high-speed HS6-5-2 steel, a favourable effect is visible of an increased nitrogen content on the structure and selected functional properties of final products. The research results can be used in developing a production technology and while developing the production of tool steels with nitrogen with enhanced usable properties and increased durability in operational conditions.

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