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Scientific Statements of Technological Solutions Related to Control of Structure Formation in High-Strength Wheel-Tire Steel

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The current technological process of new generation microalloyed wheel-tire steel thermal hardening is analyzed in view of temperature-time parameters correspondence to positions of critical points and intervals of phase transformations. It is determined that Widmanstatten structure of ferrite with needlelike morphology is a "structural marker" of adequately realized thermal hardening technological process.

Keywords: WHEEL-TIRE STEEL, VANADIUM MICROALLOYING, THERMAL KINETIC OF STRUCTURE FORMATION, PHASE TRANSFORMATIONS, WIDMANSTATTEN STRUCTURE, FERRITE STRUCTURE OF NEEDLELIKE MORPHOLOGY, THERMAL HARDENING, CRITICAL POINTS AND INTERVALS OF PHASE TRANSFORMATIONS

Introduction

Significant number of investigations by scientists of Z. I. Nekrasov Iron & Steel Institute of National Academy of Sciences of Ukraine in collaboration with specialists of JSC "INTERPIPE NTZ" [1-3] study parameters of through technology of wheel-tire steelmaking. These works cover a wide spectrum of such problems as: study of effect of original ingot quality on the structural condition and properties of commercial product; the features of structure formation at alloying and microalloying of wheel-tire steel; analysis of temperature-deformation parameters on structure and properties of products; determination of optimum temperature-time parameters of austenitization, hardening, cooling and tempering of steel as well as complex investigation of all specified factors of wheel-tire production in view of their effect on the formation of final properties of finished products.

It is possible to formulate the general conditions according to results of investigations. When quenching the cooling rate is ≤ 4.5 °C/s in the rim cross-section in case of railway seamless-rolled wheel with the maximum value 6 °C/c in a thin near-surface layer [2]. That is hardening of wheel-tire carbon steel products with obtaining bainite or martensite structures is impossible at current cooling conditions. Therefore at specified level of cooling rates for all cases considered in [4] austenite decomposition in wheel-tire products has a diffusion mechanism of perlite transformation. Raise of cooling rate to 6 °C/s causes growth of strength due to reduction of structurally free ferrite amount. Plasticity and hardness grow in the same way. However, hardness for carbon steel does not reach 320 HB even on the tread surface [5].

The parameters of wheel-tire products thermal hardening are studied in present research. Results of these investigations are published in co-authorship with specialists from Z. I. Nekrasov Iron & Steel Institute of National Academy of Sciences of Ukraine and JSC "INTERPIPE NTZ" [6, et al.]. It is determined that effective cooling devices [6, 7] enable to raise cooling rate almost to 10 °C/s. Microalloying additions of vanadium in optimum amount (**Table 1**) change radically thermal kinetics of austenite decomposition when cooling in the area of phase gamma → alpha recrystallization. According to [4] if in case of carbonaceous wheel-tire steel the interval of diffusion perlite transformation on thermokinetic diagram is up to values 15-18 °C/s and steels only get quasi-eutectoid structural condition to specified values, cooling of microalloyed steel КПТ (БЛТ) at the rate > 6.5-7.0 °C/s is accompanied by intermediate shear-diffusion mechanism of

austenite transformation [7] with natural qualitative change of mechanical characteristics. The task of present research is analysis of current process of thermal hardening of new generation optimum microalloyed wheel-tire steel in view of its temperature-time parameters correspondence to studied positions of critical points [7] and intervals of phase transformations and specific structural conditions with characteristic levels of mechanical properties.

Methodology

New generation wheel-tire products produced by JSC "INTERPIPE NTZ" (Technical Specifications of Ukraine 35.2-23365425-600:2006 and 35.2-23365425-641:2009) are subject of research. Chemical composition of steel in comparison to requirements of corresponding standards is presented in **Table 1**.

Metallographical observation is carried out using the standard methods (GOST 5639-82) with the application of optical microscope "Neophot-2". Raster electron microscope investigation is carried out with the application of microscope РЭМ-106-И.

Results and Discussion

Optimum microalloyed wheel-tire steel (КПТ, БЛТ – **Table 1**) is characterized by hypoeutectoid structure with polygonal ferrite on boundary lines of perlite grains at cooling rates to 4 °C/s. Cooling of these steels at the rate ~4 °C/s leads to formation of quasieutectoid structures. At all cooling rates their strength parameters [6, 7] are higher than corresponding values of carbonaceous wheel-tire products even in the area of diffusion transformation. It is explained by additional contribution of secondary solidification during the subsequent tempering of vanadium-containing steel. Calculation of effect of structure parameters on the strengthening mechanism by Hall-Petch equation is indicative of this [8].

When tempering such structures (**Figure 1**) under condition of presence of microalloying additions the perlite microhardness essentially raises as a result of two processes:

- precipitation of fine-dispersed carbide particles in the eutectoid between cementite plates;
- reduction of interlamellar spacing of perlite phase components because of raise of austenite stability in the diffusion area of transformation.

Grain refining enhances resistance to breaking and provides better wear-resistance of the product.

Calculations by Hall-Petch equation [8] show that there is a significant hardening of products at vanadium content 0.05-0.20 % in wheel-tire steel because of their secondary solidification during the tempering but at simultaneous drop of viscosity and plasticity [1]. That is in this case hardening with tempering naturally leads to plasticity drop despite superfine grain [1, 3]. The reason is a negative effect of carbide particles on the value of brittle fracture resistance. Thus, the parameters of ferrite-perlite structural condition of vanadium microalloyed products fall into the pattern of production method at JSC "INTERPIPE NTZ".

Table 1. Chemical composition of investigated wheel-tire steels of grade "T" as compared to requirements of standards

Normative document / Smelting No.	Mass fraction of elements, %										[H], ppm
	C	Mn	Si	P	S	Cr	Ni	Cu	V	Al	
52085 (БЛТ)	0.65	0.79	0.30	0.014	0.012	0.18	0.12	0.07	0.093	0.020	1.3
32501 (КПТ)	0.63	0.72	0.32	0.007	0.007	0.16	0.11	0.05	0.094	0.022	1.7
TS U 35.2-23365425-641:2009	0.60-0.68	0.70-0.90	not more 0.40	0.025	0.020	0.40	0.25	0.30	0.08-0.15	0.013-0.030	≤2.0
TS U 35.2-23365425-600:2006	0.61-0.69	0.70-0.90	0.40	0.025	0.020	0.40	0.25	0.30	0.08-0.15	0.013-0.030	≤2.0

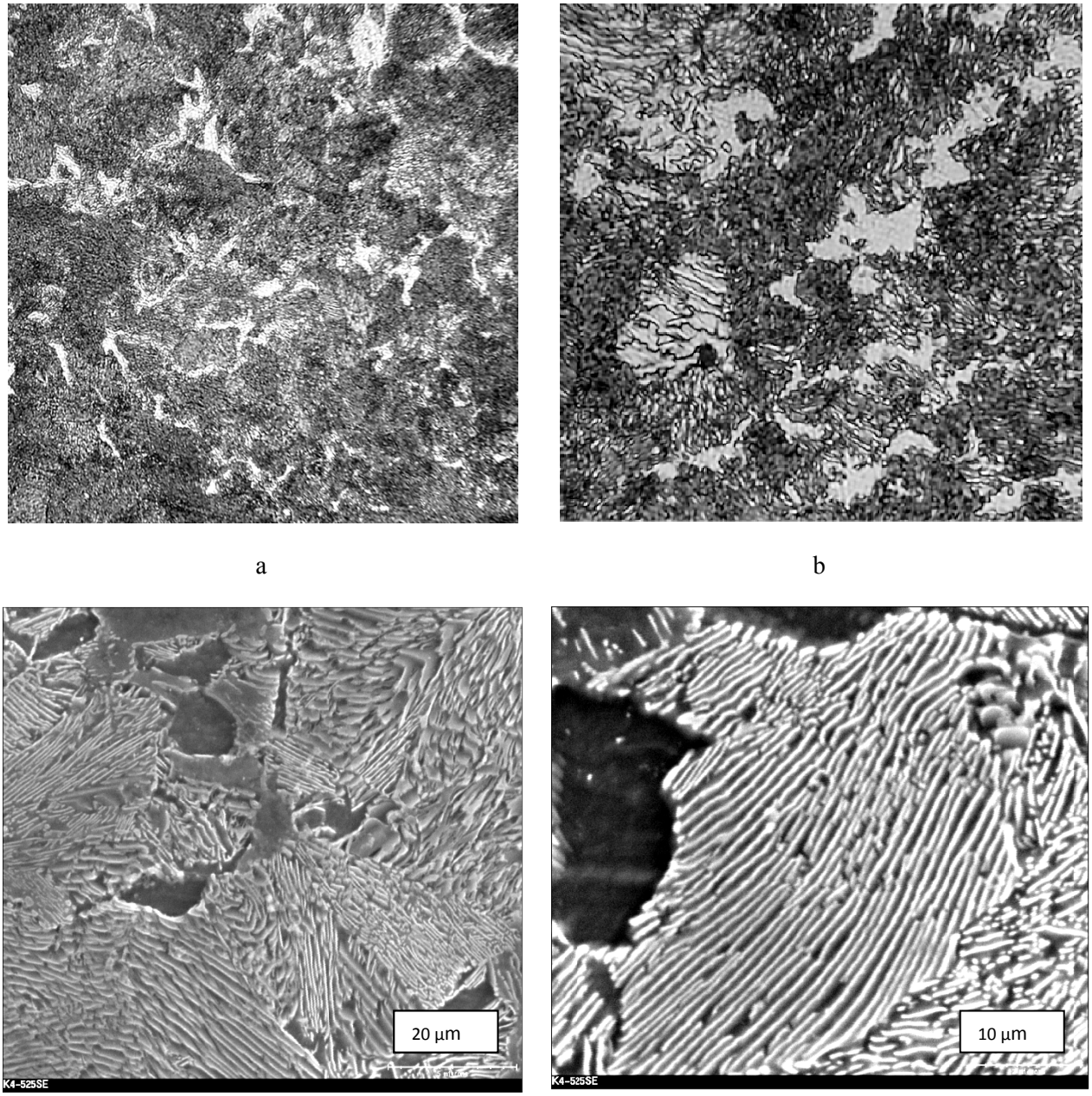

Figure 1. Microstructure of optimum microalloyed wheel steel КПТ (smelting 32501) cooled at the rate 0.15 °C/s: *a* – x 400; *b* – x 1000; *c*, *d* – scanning electron microscopy

But first it is necessary to estimate the reasonability of cost price increase which is related to inoculation by vanadium in view of achievability of all properties - strengths, hardness, wear-resistance, plasticity and viscosity simultaneously.

As mentioned above, cooling of microalloyed steel КПТ (БЛТ) at the rate > 6.5-7.0 °C/s is accompanied by intermediate shear-diffusion mechanism of austenite transformation [7].

Two options of procedure "hardening + tempering at minimum 500 °C" are possible.

Option 1. Hardening to cooling means temperature through all critical points of phase transformations (including B_S 525 °C and M_S 270 °C [7]) with the subsequent high tempering. Such structure after cooling at the rate ~10 °C/s (**Figure 2a**) is featured by the presence of needlelike ferrite (as "structural marker" of shear-diffusion reaction [6]), perlite and bainite components as well as martensite. The subsequent high tempering at ~500 °C naturally changes the structure (**Figure 2b**) because of martensite natural transformation with the formation of typical

troostite components in which the coagulative processes of sorbitizing take place during tempering (**Figure 2c, d**). Such a condition, which after "improvement" provides high level of strength and viscosity because of obvious “heterostructure”, should have a negative effect on contact-fatigue operating characteristics of the products due to change of fracture mechanisms in local sections of point interaction "wheel-rail".

Really, martensite transformation products in the structure of wheel steel do not reveal positive characteristics of operational wear-resistance. The fundamental monography [1] defines this rule as follows: “Growth of hardness values related to the formation of martensite decomposition products at tempering leads to drop of wear-resistance”.

Option 2. Isothermal hardening of wheel-tire products. Results of investigations of comparative characteristics of wheel vanadium microalloyed (to 0.2 %) steel after thermal hardening are presented in [3]. The results are as follows:

- "improvement": σ_B = 132.7 kgf/cm^2; δ = 12,.2 %; a_H = 4.4 kgf·m/cm^2;
- "isothermal hardening": σ_B = 134.0 kgf/cm^2; δ = 13.0 %; a_H = 4.3 kgf·m/cm^2.

Analysis of considered results is indicative of their complete identity. The comparative analysis of corresponding properties presented in works [6, 7] gives the same results. That is, the optimum master schedule corresponding to "isothermal hardening" should be accomplished under such conditions:

- cooling rate - not less than 6.5-7.0 °C/s;
- rim cooling should not be lower than 300 °C (> M_S) neither at the hardening stage nor during cooling-down;
- rim should not be heated above 525 °C in the process of high-temperature tempering.

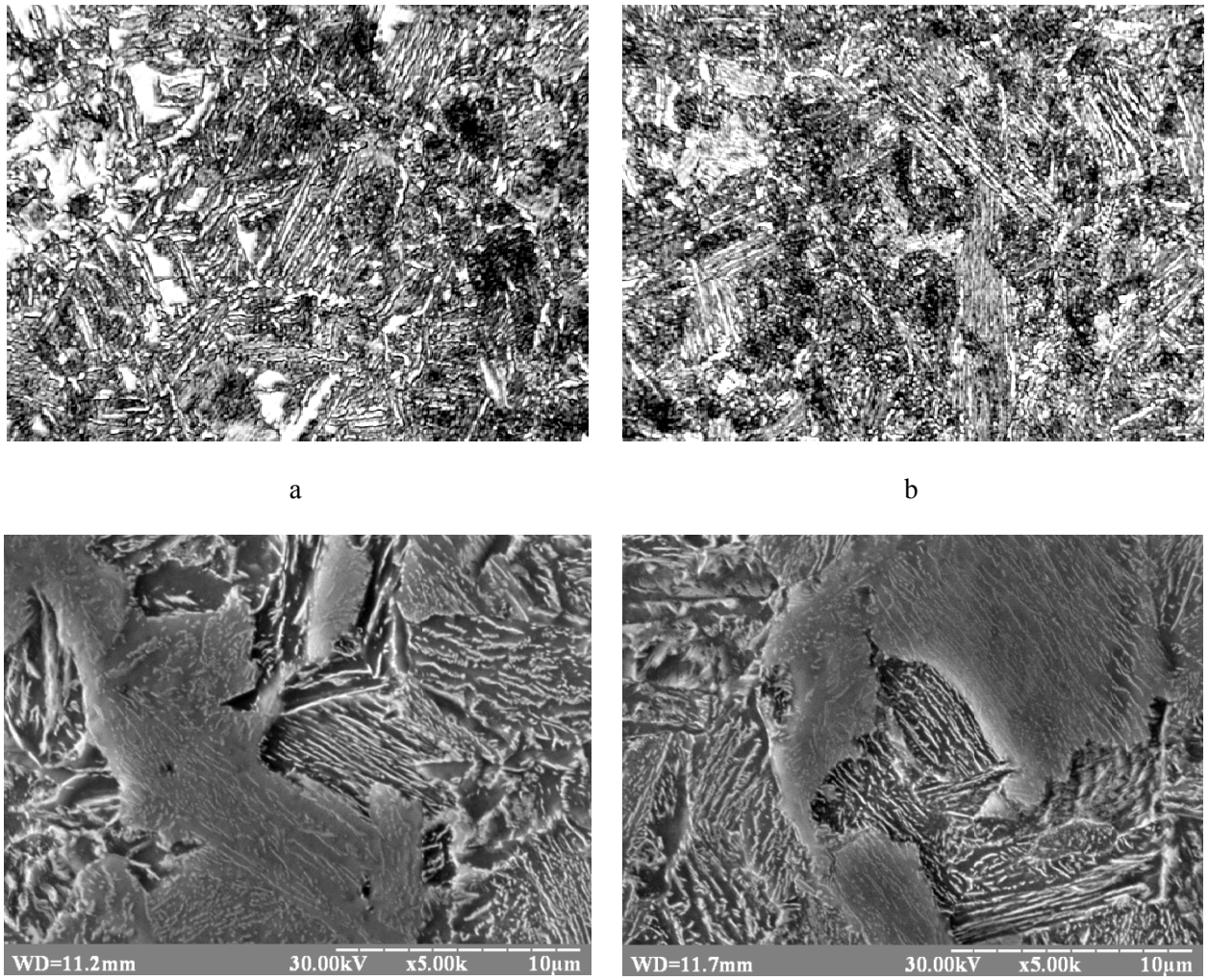

Figure 2. Microstructure of optimum microalloyed tire steel БЛТ (smelting 52085) after quenching at the rate 10 °C/s (*a*) and tempering at 500±10 °C (*b-d*): *a, b* - x1000; *c, d* - scanning electron microscopy

But, as in case of option 1, the considered condition is not a technological problem as additional special measures on re-equipment of current flow processes at JSC "INTERPIPE NTZ" are not required. In this respect optimization of flow diagrams taking into account the intervals of phase equilibriums of microalloyed wheel-tire steel is sufficient. Then stable properties of industrial product are achieved under condition of reliable industrial implementation of optimized regimes of thermal hardening. The structural condition of products characterized by needle-like ferrite ("structural marker" - **Figure 3a**) and mainly bainite component in a grain body (**Figure 3 b-d**) of final commercial product provide specified mechanical and operational properties.

The general view of wheel and tire thermal hardening optimized processes thermograms are schematically illustrated in **Figures 4, 5**. Suggested and industrially implemented at JSC "INTERPIPE NTZ" production method of wheel-tire products effective thermal hardening is austempering [9]. It is obvious that after cooling at the optimum rate (according to CCT diagram in [7]), low-temperature heat treatment is carried out in the intercritical interval of temperatures $M_S \leftrightarrow B_S$ (**Figures 4, 5**), that is in the intermediate area of austenite phase transformation with structure formation by shear-diffusion mechanism (**Figure 3**).

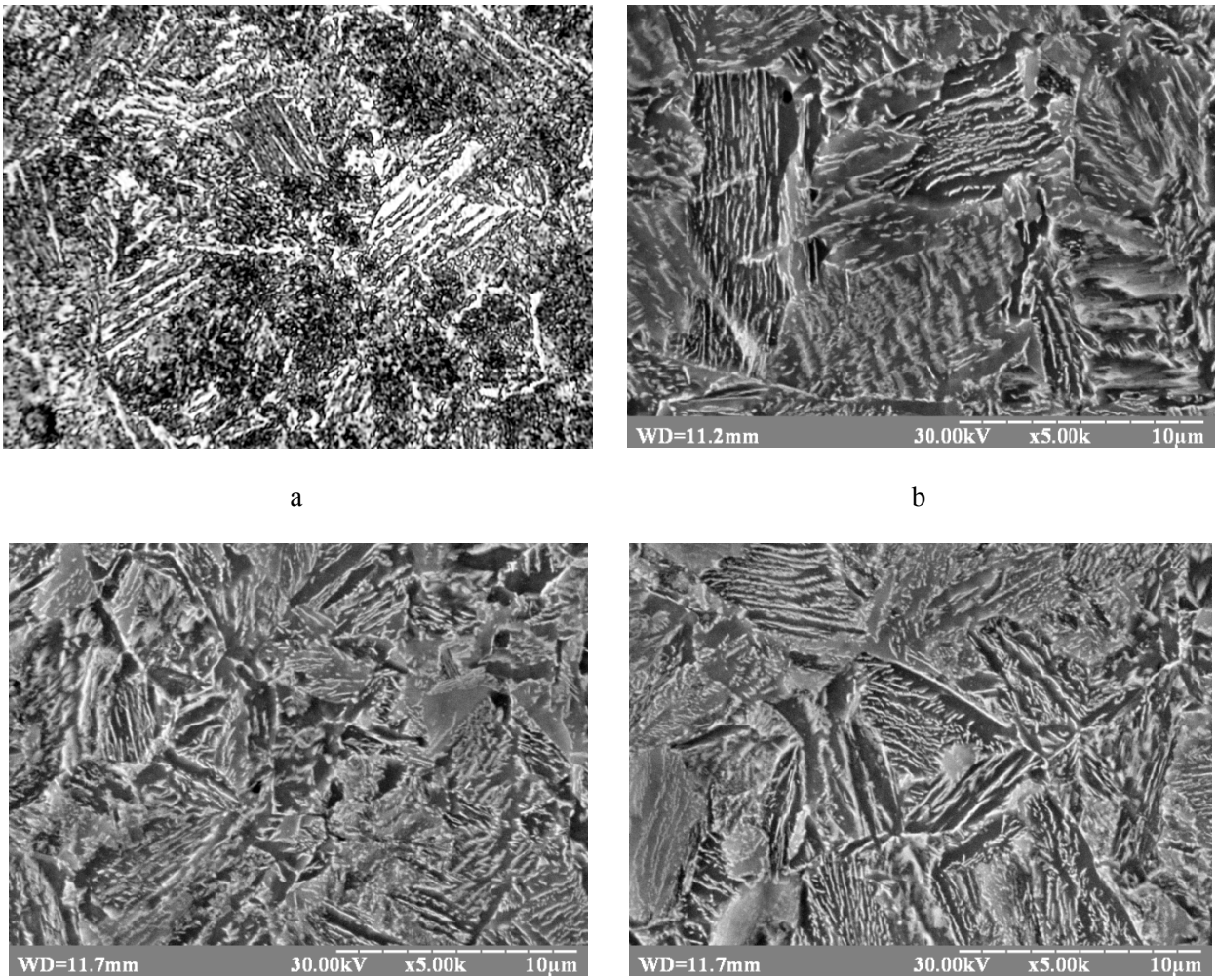

Figure 3. Microstructure of optimum microalloyed tire steel БЛТ (smelting 52085) after quenching at the rate 10 °C/s (*a*) to 310 °C with subsequent isothermal soaking at 490±5 °C during 4.5 hours: *a* - x1000; *b*, *c, d* - scanning electron microscopy

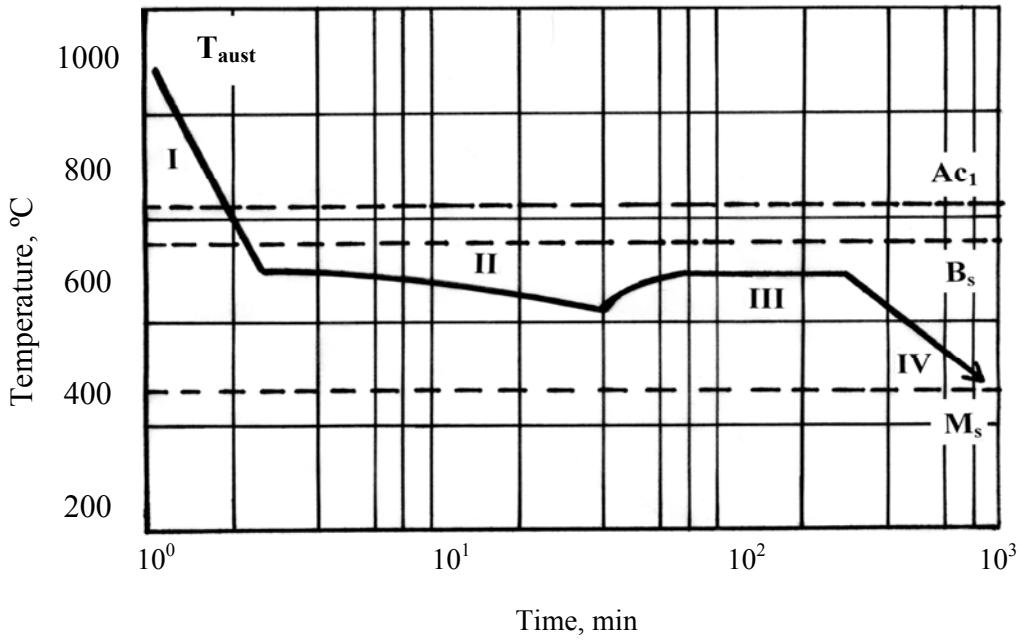

Figure 4. Thermal hardening thermogram of new generation seamless-rolled wheels under Technical Specifications of Ukraine 35.2-23365425-600:2006 at JSC "INTERPIPE NTZ":
I. Hardening: $T_{austenitization}$ = 885 ± 10 °C; $V_{cool.}$ = 7-10 °C/s; hardening time τ = 180-220 ± 5 s; T_{end} = 500 °C.
II. Cooling-down: $T_{start\ rim}$ = 500 °C; cooling-down time τ = 45 ± 5 min; T_{end} = 420-450 °C.
III. Tempering: heating time and soaking in coffers τ = 2.5 hours ± 10 min; $T_{tempering}$ = 450-500 ± 10 °C.
IV. Air cooling

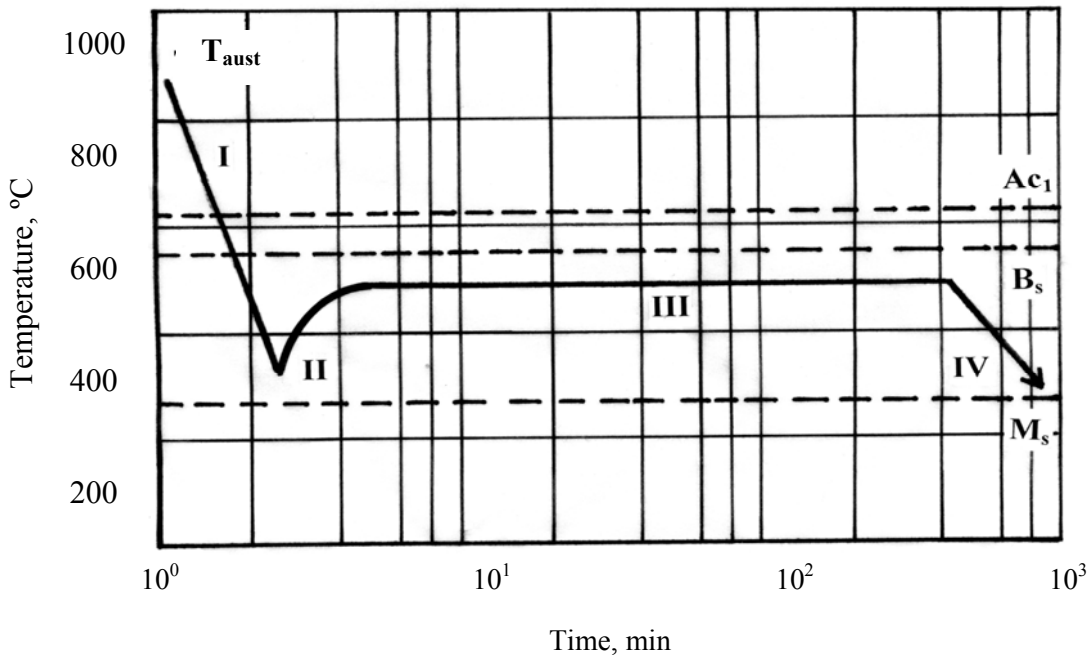

Figure 5. Thermal hardening thermogram of new generation tires under Technical Specifications of Ukraine 35.2-23365425-641:2009 at JSC "INTERPIPE NTZ":
I. Hardening: $T_{austenitization}$ = 880 ± 10 °C; $V_{cool.}$ = 7-10 °C/s; hardening time τ = 150-200 ± 5 s; T_{end} = 315-360 °C.
II. Delivery to cooling-down: delivery time τ ≤ 5 min.
III. Tempering: heating time and soaking in coffers
τ = 4.5 hours + 30 min; $T_{tempering}$ = 500 ± 10 °C.
IV. Air cooling

Such optimum parameters of the process are included in the technological documentation of JSC "INTERPIPE NTZ" on production of new generation high-strength wear-resistant wheels and tires. Requirements to products are accepted as obligatory for standard documentation on the specified kind of products, for example, Technical Specifications of Ukraine 35.2-23365425-600:2006 and Technical Specifications of Ukraine 35.2-23365425-641:2009 (**Table 1**).

Conclusions

1. The current production process of new generation optimum microalloyed wheel-tire steel thermal hardening in view of correspondence of temperature-time parameters to positions of critical points and intervals of phase transformations is analyzed.

2. It is determined that a set of industrial parameters of control of phase changes and resultants structural conditions should be qualified as austempering in case of wheel-tire steel microalloying.

3. It is shown that Widmannstatten pattern of needle-like ferrite is a "structural marker" of adequately realized production process of thermal hardening.

References

1. I. G. Uzlov, M. I. Gasik, A. T. Yesaulov, et al. *Kolesnaya Stal*, Kiev, Tehnika, 1985, 168 p.*
2. I. G. Uzlov, N. I. Danchenko. *Metallovedenie i Termicheskaya Obrabotka Metallov*, 1971, No. 5, pp. 54-56. *
3. I. G. Uzlov, N. G. Miroshnichenko, M. V. Kuzmichev, et al. *Termicheskaya Obrabotka Metallov*, Moscow, Metallurgiya, 1977, Vol. 5, pp. 56-60. *
4. M. F. Evsyukov, V. I. Uzlov, E. A. Shapoval, E. S. Romanenko, et al. *Proizvodstvo Termicheski Obrabotannogo Prokata*, Moscow, Metallurgiya, 1986, pp. 76-79. *
5. *Kompleksna Programma Onovlennya Zaliznichnogo Ruhomogo Skladu Ukrainy na 2008-2020*, Kiev, Ukrzaliznytsya, 2009, 299 p. **
6. I. G. Uzlov, K. I. Uzlov, O. N. Perkov. *Metallurgicheskaya i Gornorudnaya Promyshlennost*, 2004, No. 1, pp. 84-88. *
7. I. G. Uzlov, M. F. Evsyukov, K. I. Uzlov, Zh. A. Dementyev. *Metallurgicheskaya i Gornorudnaya Promyshlennost,* 2010, No. 4, pp. 66-69. *
8. I. G. Uzlov, A. M. Nesterenko, K. I. Uzlov, et al. *Metallurgicheskaya i Gornorudnaya Promyshlennost,* 2010, No. 3, pp. 67-70. *
9. R. I. Entin. *Prevrascheniya Austenita v Stali*, Moscow, Metallurgizdat, 1960, 252 p. *

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Научные положения технологических решений управления структурообразованием высокопрочных колесно-бандажных сталей

Узлов К.И.

Проанализирован современный технологический процесс термического упрочнения оптимально микролегированных колесно-бандажных сталей «нового поколения» с точки зрения соответствия его температурно-временных параметров позициям критических точек и интервалов фазовых превращений. Формирующаяся Видманштеттова структура феррита игольчатой морфологии является «структурным маркером» адекватно реализованного технологического процесса термического упрочнения.