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Features of the Heat Treatment of High Speed Steel

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Abstract. *The aim of the study was to determine the optimal heat treatment for cast steel P6M5F3 to ensure an increase in impact strength, under conditions of impact loads (planing cutters), minimize carbide liquation and compare with the impact strength of powder steel P6M5F3-MP. For the study, the issue of quenching P6M5F3 steel by simultaneous tempering was considered in order to select optimal values of impact strength, since the reliability of the tool is provided along with high hardness and high impact strength, especially with intermittent turning. Intensive separation of alloying elements and carbon from the residual austenite during its recrystallization makes it possible to apply the proposed method for the efficient and rational use of high-speed steels operating under conditions of increased dynamic loads, which require increased toughness. An increase in the temperature of the martensitic transformation interval as a result of heating indicates a significant depletion of residual austenite with carbon and alloying components during the holding of samples at these temperatures. The proposed heat treatment of high-speed steel allows, unlike the known methods, to completely avoid the martensitic transformation of high-temperature austenite into lamellar martensite, which causes a noticeable decrease in the strength and viscosity of the steel.*

Keywords: *high speed steels, technology, carbides, heat treatment, tungsten, martensitic transformation, vanadium, impact strength, fineness, tool steels.*

Introduction

In the production of standard high-speed steels used for the manufacture of cutting tools, difficulties arise in obtaining a fine-grained homogeneous structure with a uniform distribution of the carbide phase. In the structure of these steels, a large carbide inhomogeneity is often observed, which significantly worsens the dynamic strength of cast steels [1].

For high-speed steels, in many cases, traditional heat treatments are used, these are either stepped hardening and triple high-temperature tempering, or isothermal hardening, or hardening with cryogenic effects. To a large extent, such complex heat treatment is used to reduce the amount of retained austenite, which to a greater or lesser extent will always be present in the final structure and reduce its mechanical properties.

Martensitic transformation during quenching, which is experienced by complex alloy steels during quenching, including high-speed steels, experience significant volumetric changes in the temperature range close to ambient temperature, which causes warping of products – distortion of geometry and impact strength.

One of the main factors causing a decrease in the above mechanical properties in tungsten high speed steels is the presence of a significant content of carbon and the main alloying element – tungsten.

One of the important factors determining the operating temperature of high-speed steels is the property of its red brittleness – the ability to maintain the martensitic structure obtained as a result of the hardening process – to have high hardness, strength and wear resistance at elevated temperatures that occur in the so-called cutting edge during cutting with high speed. The main properties that a material for cutting tools should have are wear resistance and heat resistance.

The working conditions of the tools depend on the cutting conditions and the properties of the material being processed. The higher the cutting speed, the section of the chip being removed, as well as the strength and toughness of the material being processed, the higher the heating temperature of the cutting edge of the tools. Under these conditions, the performance of the tools is determined by the high «hot» hardness and the ability of the material to maintain it during prolonged heating, i.e. heat resistance. Thus, the cutting performance depends on the heat resistance of the material [2].

Quick cutters are able to maintain a martensitic structure in the temperature range of 600-650°C, and as a result, they can be used at significantly increased cutting speeds (increase in speed up to 4 times) and tool life (10 times) compared to carbon and alloyed tool steels, but like all rapids, they have an increased tendency to brittle fracture.

High cutting properties of high-speed steels are provided by alloying with strong carbide-forming elements (tungsten, molybdenum, vanadium), i.e. elements that increase the temperature of $\alpha \rightarrow \gamma$ phase transformations and the use of special heat treatment, which consists in hardening from high temperatures (1200-1300°C) and tempering, which causes precipitation hardening [3].

In high-speed high-alloy steels, when heated to 800-900°C, austenite is obtained, which contains few basic alloyingelements, because they are bonded into the carbides present in these steels. Therefore, hardening from such temperatures does not give the steel the required hardness and red hardness. The enrichment of austenite with alloying elements is achieved by heating to temperatures close to the solidus line. However, even at such temperatures there is no complete dissolution of carbides such as MeC, Me_6C.

Heat Treatment Technology for High Speed Steel

Using the example of cast high-speed steel and high-speed steel obtained by powder metallurgy, we will try to figure out what the subtleties of its heat treatment are when exposed to high temperatures and significant shock loads. Steel P6M5F3 is intended for the manufacture of finishing and semi-finishing tools when processing non-alloyed and alloyed structural steels of end tools: taps, drills, milling cutters. Also, P6M5F3 steel is used in turning for the production of cutters with replaceable and brazed carbide inserts.

High-speed steel P6M5F3-MP, obtained by powder metallurgy, is used in mechanical engineering for parts heated to 500-600°C, especially for heat-resistant ball bearings. In addition to tools from this steel, it is also used in industry: for the production of hot-rolled and forged strips, hot-rolled, forged and calibrated bars, bars with a special surface finish, made by hot gas static pressing (HGP) of sprayed powder with subsequent deformation of blanks; shaped cutters, drills, reamers, countersinks, taps, broaches, cutters,cutters, shavers for processing low- and medium-alloy steels; tools for cold and semi-hot extrusion of alloyed steels and alloys. In its chemical composition, steel P6M5F3 contains chemical elements in %: C 0.95-1.05; Si up to 0.5; Mn up to 0.5; Ni up to 0.4; S up to 0.025; P to 0.03; Cr 3.8-4.3; Mo 4.8-5.3; W 5.7-6.7; V 2.3-2.7; Co up to 0.5; Fe ~79. High-speed steel P6M5F3 should have high fracture resistance, hardness (cold and hot), red hardness, and, importantly, have sufficient impact strength [4].

Let us consider in more detail the effect of alloying elements included in its composition on properties. The chemical composition and alloying elements largely determine the main properties and use of high-speed steels, including P6M5F3 steel, so tungsten and molybdenum, which is part of the steel, in the presence of chromium bind carbon into a special carbide of the Me_6C type, which is difficult to coagulate during tempering, and thus delay the decay the martensite itself. This factor determines the increase in the transition time of austenite to martensite and the content of austenite in the structure itself.

Fold high-temperature tempering leads to the release of dispersed carbides, causes dispersion hardening of martensite – the phenomenon of secondary hardness. The secondary hardness and heat resistance are especially effective when the steel contains strong carbide-forming elements – tungsten together with molybdenum and vanadium, which are also present in the composition of the steel. However, tungsten reduces the thermal conductivity of steel, which complicates heating for hardening (heating of steel for hardening requires 1-2 heatings to avoid cracks).

Part of the tungsten can be replaced by molybdenum in the ratio Mo / W = 1/1.5, but molybdenum can be introduced up to 5%, because it burns out during high-temperature heating, so P6M5F3 steel is currently the most widely used. The disadvantage of tungsten steels is a strong carbide heterogeneity. In tungsten-molybdenum steels, this drawback is less noticeable, but still exists, and it is he who contributes to lowering the impact strength of P6M5F3 steel, making it rather brittle.

Vanadium increases the precipitation hardening of steel and increases wear resistance, heat resistance and secondary hardness. Vanadium forms a hard carbide VC (2700-2800 HB), it increases red hardness, hardness, promotes precipitation hardening and increases wear resistance, but reduces the grindability of steel and lowers toughness. During tempering, vanadium, separating out in the form of carbides, enhances precipitation hardening, and tungsten (molybdenum), remaining in martensite, delays its decay [5].

The cobalt contained in the steel also contributes to an increase in heat resistance. It does not form carbides, but, by increasing the energy of interatomic bonding forces, it hinders the coagulation of carbides and increases their dispersion. High-speed steels belong to the ledeburite class, in the structure of which there is carbide segregation, so it is extremely important to say that its presence is also a factor affecting mechanical properties. Carbide inhomogeneity and the presence of carbide eutectic in cast high speed steels is a factor in increasing its brittleness, that is reducing its ability to work under increased shock loads, and lowering its strength.

Excess carbides of high-speed steels are part of the eutectic formed along the grain boundaries of austenite or ferrite, and to reduce its influence or eliminate it, hot plastic deformation methods are used. However, practically under all deformation conditions used, an absolutely uniform distribution of carbides was not observed in experimental studies [5].

When analyzing experimental data on the industrial use of tools made of powdered high-speed steel

P6M5F3-MP, it was characteristic that the causes of tool failure are, as a rule, wear and chipping of the working part, and the proportion of the tool that failed as a result of chipping is higher than as a result of wear. This is especially evident on a tool made of powdered high-speed steel, which experiences shock loads during operation. Unlike cast steel P6M5F3-MP, it is not prone to the formation of carbide segregation, due to the technology of its production.

For cast steel P6M5F3, in the microstructure of which carbide eutectic is always present, therefore, it requires preparatory operations for hot forging and annealing with isothermic holding.

The aim of the study was to determine the optimal heat treatment for P6M5F3 cast steel to ensure an increase in impact strength, under the conditions of impact loads(planing cutters), to minimize carbide segregation and compare with the impact strength of P6M5F3-MP powder steel.

For the study, the issue of hardening steel P6M5F3 with simultaneous tempering was considered in order to select the optimal values of impact strength, since the reliability of the tool is ensured along with high hardness and high impact strength, especially with interrupted turning.

Heat treatment consisted of quenching with cooling and tempering. Hardening was carried out at a temperature from 1190 to 1290°C, the hardening temperature was strictly observed in order to avoid overheating of the steel and its decarburization. To prevent the formation of cracks and increased thermal stresses, heating for hardening was carried out with two heatings.

The first heating at 400-500°C, the second at 800-850°C. The exposure during final heating was determined at the rate of 10-15 s per 1 mm of thickness (diameter) for a tool with a diameter of 5-30 mm. Chromium and tungsten slow down the rate of decomposition of austenite in the region of pearlite transformation, this contributes to deeper hardenability and overcooling of austenite to the interval of martensite transformation with slower cooling (oil), which is associated with a decrease in the critical rate of quenching Cr, Mo, W, V greatly refine the grain.

Therefore, steel, in the presence of even a small amount of insoluble carbides, retains a fine-grained structure up to high temperatures. In order to increase the impact strength of steel, experiments were carried out with cooling during its hardening, since the holding time at high temperatures of 1190-1210°C causes additional grain growth, which is an unfavorable factor when considering the issue of increasing impact strength.

Cooling down the planer cutter from a hardening temperature of 1200°C for 2 minutes, which was the optimal time, with a tool cross section of up to 30 mm. Cooling is one of the ways that will allow phase recrystallization of steel and carbides in the structure, will serve as its additional centers, the carbides themselves will also be crushed and will have a small size. In the case of cooling, the steel acquires additional fine grain and, consequently, significant brittleness will decrease.

After cooling, the tool was placed in an oven and heated to a predetermined temperature, then placed in oil, it is important to note that the temperature of the quench medium was maintained at the same level in order to obtain more uniform and stable results. Summarizing the above, when hardening the tool, it is necessary to first inform the steel of accelerated cooling (cooling) in the high temperature zone, preventing the precipitation of carbides from austenite and achieving phase recrystallization of the steel, then heat the steel and cool it in oil to a temperature of 250-300°C, and then cool it in air.

The proposed method of processing high-speed steel provides:

1. Stepwise heating of the tool first to 400-500°C, then to 800°C and finally to hardening temperatures of 1190-1210°C (the lower limit for a small tool, the upper one for a larger one), in our case the temperature was 1200°C.

2. Cooling in air up to a temperature of 1150°C.

3. Reheating in the furnace to the hardening temperature of 1200°C.

4. Cooling of the tool in oil to 70-120°C, below the temperature of the beginning of martensitic transformation. Volumetric changes in steel during hardening of the martensitic transformation range are much less (about 2 times) than as a result of cooling to 20°C, in the usual way. This is due to the less complete transformation of supercooled austenite and the fact that the transformation occurs in the upper region of the martensitic interval, i.e. in this case, martensite is formed with a relatively low carbon content.

5. Holding in oil at a temperature of 250-300°C for 1-3 minutes and heating up to 600°C followed by holding for 30-40 minutes will minimize the risk of cracks in the steel.

6. The final cooling was carried out in air to an ambient temperature of 20°C.

7. Accelerated double tempering in air at a temperature of 580°C, the purpose of which was to form finely acicular tempering martensite, reduce quenching stresses and eliminate residual austenite.

A feature of the proposed method of heat treat-

Modes of final heat treatment and properties of Р6М5Ф3 steel

Steel	t, hardening temperature, °C	Coolant	t, tempering temperature, °C	HRC	$\sigma_и$, MPa	Heat resistance (HRC 58), °C	Impact strength, KCU, J/sm², t = 20°C
Р6М5Ф3	1190-1210	oil	540-580	65-66	3500-4400	625	5

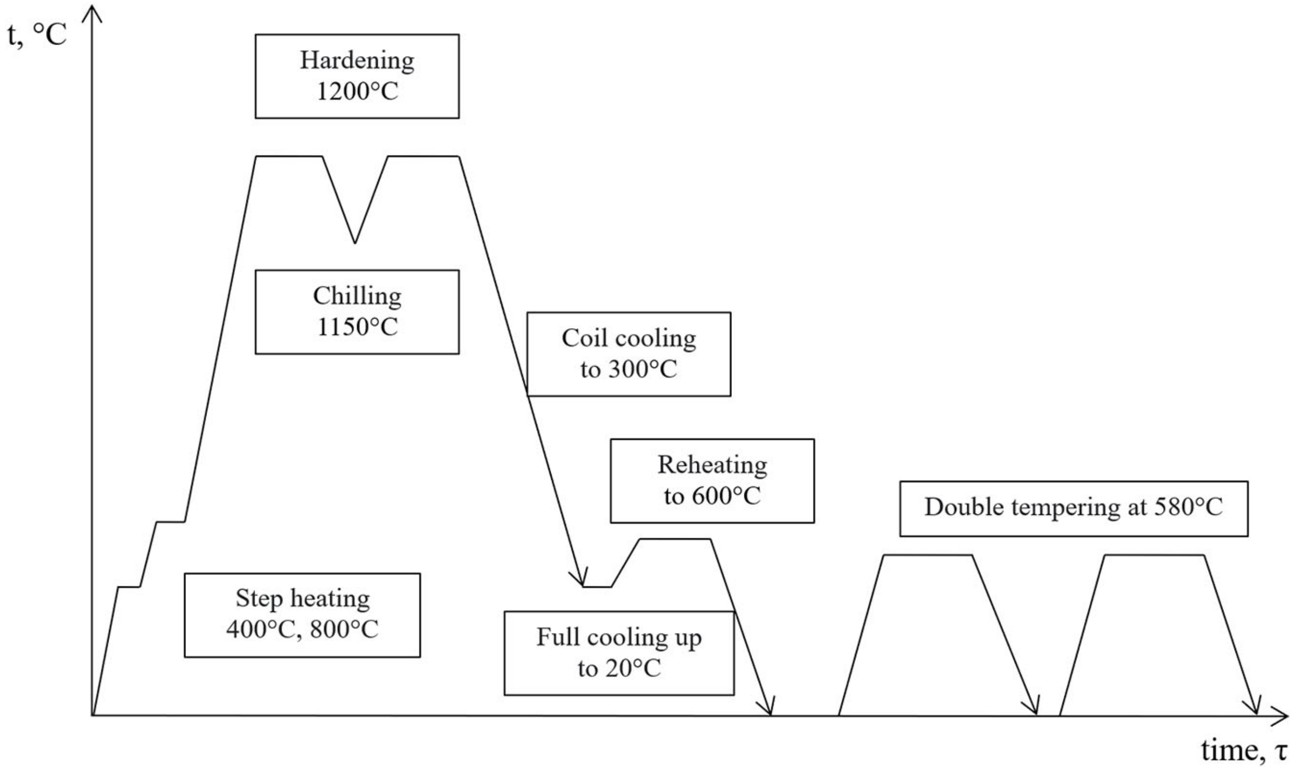

Figure 1 – Chart of heat treatment of high-speed steel Р6М5Ф3

ment of a planer cutter made of high-speed steel is that the temperatures of the beginning and end of the martensitic transformation increase markedly, and the amount of residual austenite will decrease, therefore, the impact strength will increase in comparison with standard heat treatments. Phase recrystallization under cooling conditions will further increase the impact strength.

Tempering of steel is proposed in two stages – tempering at 580°C for 45 minutes. In contrast to the standard 3-fold tempering, with 2-fold tempering, there will be no significant release of carbon from martensite and alloying elements due to the active release of carbides, which will be a source of high tool hardness. After the first and second tempering of both steels at 580°C for 30 minutes or after the second tempering for 25 minutes, the amount of residual austenite in their structure is minimized, which was eliminated by 3-fold tempering in the standard scheme.

Thus, cooling to a certain temperature (depending on the section thickness or tool diameter) carried out during hardening will increase the temperature of the interval of the points of the beginning and end of the Mn-Mk martensitic transformation in steel by approximately 120°C i.e. guarantees complete transformation of retained austenite into martensite.

This is confirmed by the results of X-ray diffraction analysis, indicating the absence of residual austenite after cooling from 600-630°C.

An increase in the temperatures of the martensitic transformation interval as a result of heating indicates a significant depletion of residual austenite in

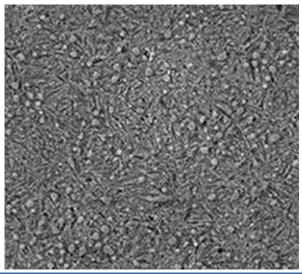

Figure 2 – Microstructure of Р6М5Ф3 steel (quenched with cooling and twice tempered, fine-acicular martensite + KI, II in the structure, residual austenite in the structure is not visible x9000)

carbon and alloying components during the holding of samples at these temperatures.

The proposed heat treatment of high-speed steel allows, in contrast to known methods, to completely avoid the martensitic transformation of high-temperature austenite into lamellar martensite, which causes a noticeable decrease in the strength and toughness of the steel. Tests on a pendulum impact test showed that the impact strength of the sample increased from 3.5 to 5 J/cm^2.

Conclusions

1. The proposed mode of heat treatment of high-speed steel, improves the mechanical properties, including tool toughness, and reduce deformation and warpage, while rational use of processing time.

2. The method involves cooling the tool from the

hardening temperature to a temperature below the Mn point, but above 20°C, heating to 600-630°C (to achieve the highest properties) or up to 500°C (to reduce warping) and cooling in air. After quenching with cooling, it is enough to apply a double tempering at 580°C for a total duration of 55 minutes, instead of the standard triple tempering.

3. Intensive release of alloying elements and carbon from residual austenite in the process of its recrystallization makes it possible to apply the proposed method for the efficient and rational use of high-speed steels operating under conditions of increased dynamic loads, from which increased impact strength is required.

REFERENCES

1. Bashnin Yu.A., Ushakov B.K. etc. Technology of heat treatment. Moscow: Metallurgy, 2016. – 424 p.
2. Gulyaev A.P. Metal science. Moscow: Metallurgy, 2015. – 541 p.
3. Goldstein M.N., Grachev S.V., Veksler Yu.G. Special steels. – Moscow: Metallurgy, 2009.
4. Metal science and heat treatment of steel. Ref. in 3 volumes. Moscow: Metallurgy, vol. 3, 2013.5 Kwon Sv.S., Balbekova B.K., Malashkevichute E.I. Metal science of special steels. Textbook, ed. KSTU, 2008.
5. Development of the theory and practice of metallurgical technologies: in 3 volumes / V.N. Peretyatko [et al.]; ed.: V.N. Peretyatko, E.V. Protopopova, I.F. Selyanina. – Moscow: Teplotekhnik, 2010. Vol. 2: Plasticity and destruction of steel in the processes of heating and processing pressure: monograph / V.N. Peretyatko, M.V. Temlyantsev, M.V. Filippov. – Moscow, 2010. – 351 p.
6. Sharaya, O.A. Theory and technology of heat treatment in situational, expert games and tasks: textbook for specialties 050709 «Metallurgy», 050710 «Materials science and technology of new materials» in the disciplines «Theory of heat treatment», «Technology of heat treatment», «Theory and technology of heat treatment» / O.A. Sharaya, L.A. Dakhno; Ministry of Education and Science of the Republic of Kazakhstan, Karaganda State Technical University, Department of Nanotechnology and Metallurgy. – Karaganda: KarSTU, 2010. – 78 p.
7. Kanaev, A.T. Technology of heat treatment of metal materials: textbook designed for students specializing in materials science / A.T. Kanaev, A.A. Toktanaeva, A.A. Kanaev; Ministry of Education and Science of the Republic of Kazakhstan. – Astana: Arman-PV, 2013. – 388 p.
8. Structural materials and heat treatment. Laboratory workshop: textbook for students / O.A. Sharaya [et al.]; Ministry of Education and Science of the Republic of Kazakhstan, Karaganda State Technical University, Department of Nanotechnology and Metallurgy. – Karaganda: KarSTU, 2015. – 92 p.
9. Heat treatment of materials [Text]: textbook for bachelors of specialties 5B071000 «Materials Science and technology of new materials» and 5B070900 «Metallurgy» / E.S. Platonova, V.A. Yudakova, E.A. Malashkevich; Ministry of Education and Science of the Republic of Kazakhstan, Karaganda State Technical University, Department of Nanotechnology and Metallurgy. – Karaganda: KarSTU, 2019. – 90 p. – (Rating). – ISBN 978-601-315-898-3.
10. Vals A.I. A method for regulating the thermal conductivity of steel, tool steel, in particular tool steel for hot processing, the use of tool steel and a steel product. A patent for an invention. Patent number: RU 2469120 C2 Patent Office: Russia Year of publication: 2012.

Жоғары жылдамды болатты жылмық өңдеудің ерекшеліктері

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Аңдатпа. *Зерттеудің мақсаты – соққы жүктемелерінің (сүргілеу кескіштері) жұмыс жағдайында соққы тұтқырлығын арттыруды қамтамасыз ету үшін Р6М5Ф3 құйылған болат үшін оңтайлы термиялық өңдеуді анықтау, карбидті ликвацияны барынша азайту және Р6М5Ф3-МП ұнтақты болаттың соққы тұтқырлығымен салыстыру. Зерттеу үшін Р6М5Ф3 болатының беріктендіру мәселесі оңтайлы соққы тұтқырлық мәндерін таңдау үшін бір уақытта босату арқылы қарастырылды, өйткені құралдың сенімділігі жоғары қаттылықпен және жоғары соққы тұтқырлығымен, әсіресе үзіліссіз бұралумен қамтамасыз етіледі. Қайта кристалдану процесінде қалдық аустениттен легірлеуші элементтер мен көміртектің қарқынды бөлінуі жоғары динамикалық жүктемелер жағдайында жұмыс істейтін жоғары жылдамдықты болаттарды тиімді және ұтымды пайдалану үшін ұсынылған әдісті қолдануға мүмкіндік береді, олардан жоғары тұтқырлық қажет. Қыздыру нәтижесінде мартенситтік конверсия аралығы температурасының жоғарылауы қалдық аустениттің осы температурада үлгілерді ұстау процесінде көміртегі мен легирлеуші компоненттермен едәуір сарқылуын көрсетеді. Жоғары жылдамдықты болатты ұсынылған термиялық өңдеу, белгілі әдістерден айырмашылығы, жоғары температуралы аустенитті болаттың беріктігі мен тұтқырлығының айтарлықтай* *төмендеуіне әкелетін плиталық мартенситке мартенситтік түрлендіруден толығымен аулақ болуға мүмкіндік береді.*

***Кілт сөздер:** жоғары жылдамдықты болаттар, технология, карбидтер, термиялық өңдеу, вольфрам, мартенситті түрлендіру, ванадий, соққыға төзімділік, ұсақтық, аспаптық болаттар.*

Особенности термической обработки быстрорежущей стали

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***Аннотация.** Цель исследования: определить оптимальную термическую обработку для литой стали Р6М5Ф3 для обеспечения повышения ударной вязкости, в условиях работы ударных нагрузок (строгальные резцы), минимизировать карбидную ликвацию и сравнить с ударной вязкостью порошковой стали Р6М5Ф3-МП. Для исследования рассматривался вопрос закалки стали Р6М5Ф3 одновременным отпуском с целью подбора оптимальных значений ударной вязкости, так как надежность работы инструмента обеспечивается наряду с высокой твердостью также и высокой ударной вязкостью, особенно при прерывистом точении. Интенсивное выделение легирующих элементов и углерода из остаточного аустенита в процессе его рекристаллизации позволяет применить предложенный способ для эффективного и рационального использования быстрорежущих сталей, работающих в условиях повышенных динамических нагрузок, от которых требуется повышенная ударная вязкость. Повышение температур интервала мартенситного превращения в результате нагрева свидетельствует о значительном обеднении остаточного аустенита углеродом и легирующими компонентами в процессе выдержки образцов при этих температурах. Предлагаемая термическая обработка быстрорежущей стали позволяет, в отличие от известных способов, полностью избежать мартенситного превращения высокотемпературного аустенита в пластинчатый мартенсит, которое вызывает заметное понижение прочности и вязкости стали.*

***Ключевые слова:** быстрорежущие стали, технология, карбиды, термообработка, вольфрам, мартенситное превращение, ванадий, ударная вязкость, дисперсность, инструментальные стали.*

REFERENCES

1. Bashnin Yu.A., Ushakov B.K. etc. Technology of heat treatment. Moscow: Metallurgy, 2016. – 424 p.
2. Gulyaev A.P. Metal science. Moscow: Metallurgy, 2015. – 541 p.
3. Goldstein M.N., Grachev S.V., Veksler Yu.G. Special steels. – Moscow: Metallurgy, 2009.
4. Metal science and heat treatment of steel. Ref. in 3 volumes. Moscow: Metallurgy, vol. 3, 2013.5 Kwon Sv.S., Balbekova B.K., Malashkevichute E.I. Metal science of special steels. Textbook, ed. KSTU, 2008.
5. Development of the theory and practice of metallurgical technologies: in 3 volumes / V.N. Peretyatko [et al.]; ed.: V.N. Peretyatko, E.V. Protopopova, I.F. Selyanina. – Moscow: Teplotekhnik, 2010. Vol. 2: Plasticity and destruction of steel in the processes of heating and processing pressure: monograph / V.N. Peretyatko, M.V. Temlyantsev, M.V. Filippov. – Moscow, 2010. – 351 p.
6. Sharaya, O.A. Theory and technology of heat treatment in situational, expert games and tasks: textbook for specialties 050709 «Metallurgy», 050710 «Materials science and technology of new materials» in the disciplines «Theory of heat treatment», «Technology of heat treatment», «Theory and technology of heat treatment» / O.A. Sharaya, L.A. Dakhno; Ministry of Education and Science of the Republic of Kazakhstan, Karaganda State Technical University, Department of Nanotechnology and Metallurgy. – Karaganda: KarSTU, 2010. – 78 p.
7. Kanaev, A.T. Technology of heat treatment of metal materials: textbook designed for students specializing in materials science / A.T. Kanaev, A.A. Toktanaeva, A.A. Kanaev; Ministry of Education and Science of the Republic of Kazakhstan. – Astana: Arman-PV, 2013. – 388 p.
8. Structural materials and heat treatment. Laboratory workshop: textbook for students / O.A. Sharaya [et al.]; Ministry of Education and Science of the Republic of Kazakhstan, Karaganda State Technical University, Department of Nanotechnology and Metallurgy. – Karaganda: KarSTU, 2015. – 92 p.
9. Heat treatment of materials [Text]: textbook for bachelors of specialties 5B071000 «Materials Science and technology of new materials» and 5B070900 «Metallurgy» / E.S. Platonova, V.A. Yudakova, E.A. Malashkevich; Ministry of Education and Science of the Republic of Kazakhstan, Karaganda State Technical University, Department of Nanotechnology and Metallurgy. – Karaganda: KarSTU, 2019. – 90 p. – (Rating). – ISBN 978-601-315-898-3.
10. Vals A.I. A method for regulating the thermal conductivity of steel, tool steel, in particular tool steel for hot processing, the use of tool steel and a steel product. A patent for an invention. Patent number: RU 2469120 C2 Patent Office: Russia Year of publication: 2012.