Increase of durability of three-cone rock bit cutters

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Abstract

The influence of physico-mechanical and technological indices on the crack resistance of different melting of 14HN3MA-B steel for three-cone rock bit cutters has been studied. When the strength index values of rock bit steel melting are about DI=4.0 or in the case of the tendency of this steel to crack formation, the rolled stock shall be subjected to diffusion annealing prior to forging. The cone blank manufacturing shall be performed by forging of rolled stock if the deformation is not less than ε=40 %. It is also necessary to perform the quench to 830±10 °C after carbonizing, and the second hardening shall be performed with temperature of 870 °C as a starting point.

Keywords: *cone, crack resistance, durability, forging, melting, quench, rock bit steel.*

Durability of three-cone drill bits determines the efficiency and economic performance of drilling operations. One of the main causes of premature disability of bits is insufficient cutters strength and their rock cutting equipment. Such incidents are unacceptable during drilling. Thus there is an urgent task to develop effective ways to improve the durability of cutters, which are important for the national production of bits.

Many researchers [1–4] and others have studied this problem in recent years.These studies substantiated effective ways to improve the durability of drill bits strengthening by technology improvement. However, modern production of bits requires updating and improving the efficiency of quality assurance methods of cutters bits for input control stages of chemical, heat and rock bit steel treatment.

It is known that the requirements for the physico-mechanical and operational parameters of bit steels are not only contradictory, but sometimes also mutually objectionable. Thus, with the provision of high wear resistance, bit steel sometimes gets their fragile fracture (Fig. 1), and, when measures to prevent brittle fracture are sometimes observed, there occurs an accelerated abrasive wear (Fig. 2).

The analysis of data resulted in identification of two causes for sudden destruction of cutters by splitting. The first reason is the formation of surface and sub-surface cracks caused by non-optimal technology of

Figure 1 – Fragile fracture of the cone from 14HT3MA-B steel

Figure 2 – Abrasive wear of three-cone bit from 14HT3MA-B steel

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machining and strengthening. The second reason is the formation of cracks in the cutter body at full compliance with physical and mechanical properties, regulating technical requirements for rock bit steel (Fig. 3, 4). Therefore, the current bit manufacturing technology needs to be improved in terms of quality assurance of cone blanks during forging.

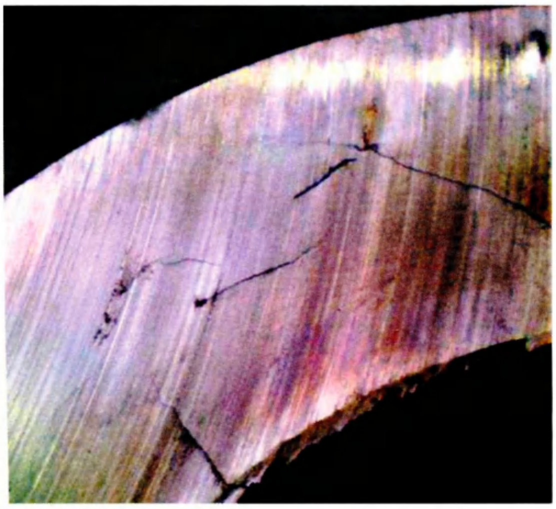


Figure 3 – General view of cracks in the body of bit cutter from 14HN3MA steel (melting index is DI=4.0), × 2

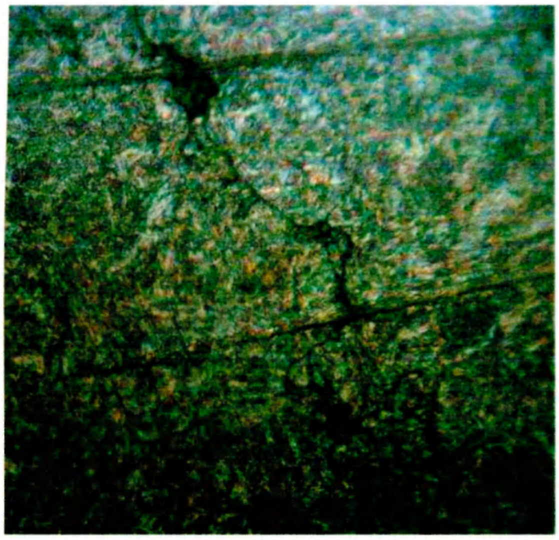


Figure 4 – A typical view of cracks etched at cutter core of 14HN3MA steel (melting index is DI= 4.0), × 500

The analysis revealed that melting 14HN3MA steels in the input plant controls shows different physical and mechanical properties, and crack resistance. Therefore, the practical value may be a connection between DI and K_c^{oc} criteria [4].

The recession of K_c^{oc} at high DI (<4.0) is established. However, the difference between the melting steels with criteria DI = 4.0 and DI = 3.0 values is approximate, and in some cases even higher. This decrease of crack resistance leads to numerous cases of brittle fracture of carbonized bit cutters.

Prevention of brittle fracture of bit cutters is possible to obtain by rejecting melting 14HN3MA steels with criteria DI $\geq$ 4.0, or using chemical thermo processing technology to correct the structure of rolled blanks and to increase the steel toughness. Carbonization of bit cutters shall provide the set parameters of carbon distribution and hardness depth of carbonized layer, which is effective for quenching after carbon saturation in the endogas environment of oven and observance of precise parameters of the second hardening [2, 4].

The manufacturing technology of bit cutter blanks with consideration of fiber orientation and shrinkage of rolled stock is described in [3], and the optimum temperature and technological process parameters are proposed.

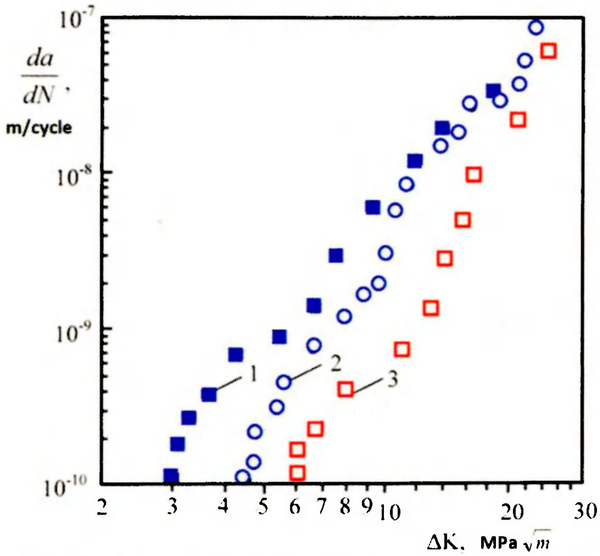
Based on positive effect of forging steel blanks of rock bit 14HN3MA steels, obtained in [3, 5], on their toughness and experience of "Varel" drill bits [6], production made it possible to continue research in this area.

The influence of specimen deformation ε = 40% on 14HN3MA steel fatigue crack is studied at current drilling enterprises in terms of chemical and heat treatment technology. According to the experimental technology, specimens were normalized at temperature of 880–900 °C after hot volumetric forging and air cooling, and tempered at 680 °C with subsequent cooling in the furnace to 550 °C, then air-cooled. As a result there were obtained the complete phase recrystallization of steel, the restoration of the grain size of superheated forged steel, increased uniformity and fine-grain structure.

Test results on fatigue crack resistance are shown in Fig. 5. Note that carbonization dramatically reduces crack resistance for rock bit steels (Fig. 5, curve 1).

It was determined that forging didn't have a significant effect on fatigue crack resistance of 14HN3MA steel within the range of high values $\Delta K = 20-30\ MPa\sqrt{m}$. The positive effect of reduction of cycling load level becomes more noticeable: it is increased with decreasing ΔK and most evident in the threshold area of loading. Similar results were obtained in [5], strain ε = 0.2 %.

Application of technology, developed in [4], including quenching carbonizing temperature of up to 830 ± 10 °C, can significantly increase cyclic crack resistance (see Fig. 5, curve 3). This threshold level of stress intensity factor ΔK_{th} is increased from $3\ MPa\sqrt{m}$ specimens strengthened by serial technology to $6\ MPa\sqrt{m}$ for steel strengthened by the developed technology. Note that the cyclic crack resistance study of specimens manufactured using a serial technology of chemical heat treatment, deformation of 0.2 % and subsequent isothermal annealing has shown the value $\Delta K = 1.3-2.5\ MPa\sqrt{m}$. In addition, it was determined that specimens produced by serial technology are very sensitive to even low levels of cyclic loading.



1 – after forging (strain ε = 40 %) normalization and high quenching, carbonization according to standard technology;
2 – after hardening and low quenching at initial fit (strain ε = 0 %) [5];
3 – after forging (strain ε = 40 %) normalization and high quenching, quenching to 830±10 °C after carbonization

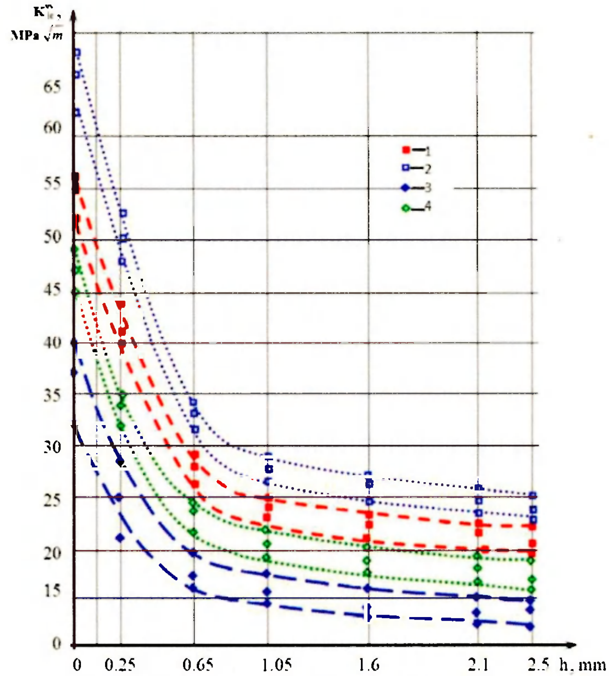
Figure 5 – Kinetic diagrams of fatigue fracture of 14HN3MA steel specimens

The research result of fracture toughness of beam specimens with different thickness, manufactured from 14HNZMA steel, has shown [2, 7] that averaged toughness is the main criterion to be used during selection of steel and its chemical heat treatment type to provide maximum durability of carbonized parts of bits. Therefore, studies related to influence of DI index and strength parameters on chemical heat treatment were continued. The test results of specimens beam, 18 mm wide, are shown in Fig. 6.

Analysis of fracture surface of specimen revealed that the proposed version of chemical heat treatment (including regulated parameters of quenching after carbonizing temperature and the second hardening) is more expressed by the zone of accumulation of fatigue damages in the area of destruction. A fracture zone contains more intercryslalline cleavage, causing a brittle fracture in the traditional version of chemical heat treatment microstructure. These data are fully verified by the previously obtained results [2].

The destruction nature of 393.7 M-HVU-D34 drill bit cutters, manufactured using serial and experimental technologies, were studied, including options of designed manufacturing processes of blanks and chemical heat treatment of cutters. So milled steel equipment of experimental rock cutting bits have completely different type of fracture compared with serial bits.

The theoretical indicator of DI does not provide with an exhaustive assessment of the suitability of bit steel melt. Therefore, much attention is paid to setting requirements for the structure of rolled bit steel in the practice of bit producing.



1 – DI = 3.0 forging blank, strain ε=40 % (after carbonization and quenching to 830±10 °C, 2nd hardening starting from 890 °C);
2 – DI = 3.0 forging blank, deformation ε=40 % (after carbonization and quenching to 830±10 °C, 2nd hardening starting from 870 °C);
3 – DI = 4.0 forging blank (carbonization by series technology, 2nd hardening starting from 890 °C);
4 – DI = 4.0 forging blank, deformation ε=40 % (after carbonization and quenching to 830±10 °C, 2nd hardening starting from 870 °C)

Figure 6 – Values of K_{1c}^{oc} for specimens from melting steel 14XH3MA with different parameters of chemical heat treatment

Leading manufacturers of three-cone bit cutters, such as: Hughes Christensen Co., Smith International Inc., Reed Tool Co., Security DBS Dresser Industries Inc., Varel Manufacturing Co., use steels with strictly regulated chemical composition, purity of structure, physical and mechanical properties, and the quenching ability in accordance with ASTM Standard A 304–78 "Steel Parts, Alloy, Subject to End-Quench Hardenability Requirements", as well as ASTM Standard A 8720 "Steel Forging Bar Specification" (Table 1). As you can see, the existing technical conditions in the domestic bit producing industry allow higher values of sulfur, and also have a wider field of the values variation of alloying elements. It is also assumed that the 14PN3MA bit steel, after normalization of 900 ± 20 °C, air cooling and quenching with 840 ± 20 °C, cooling in water, hardens within the limits given in Fig. 7.

As the operational properties of the drill bits cones significantly depend on the quality of rolling, its chemical composition and physico-mechanical values are subject to strict requirements. In particular, steel contamination with non-metallic inclusions is controlled according to ASTM E45–97, method A (Table 2). Since

Table 1 – The chemical composition of high-quality steels according to ASTM A 304–78 (values S and P – maximum "target") and according to TU 14-550-51–2004

Steel grade acc. AISI		9315H	4813H	–
Domestic steel grade		14HN3MA	14HN3MA	14HN3MA
Chemical composition, %	C	0.11–0.15	0.12–0.18	0.11–0.15
	Si	0.20–0.26	0.15–0.35	0.20–0.35
	Mn	0.65–0.75	0.40–0.70	0.60–0.80
	Cr	1.40–1.50	1.00–1.45	1.35–1.55
	Ni	3.15–3.35	2.95–3.55	3.10–3.40
	Mo	0.10–0.14	0.08–0.15	0.10–0.15
	S	up 0.005	up 0.010	up 0.015
	P	up 0.010	up 0.015	up 0.015
	Cu	up 0.25	up 0.35	up 0.25

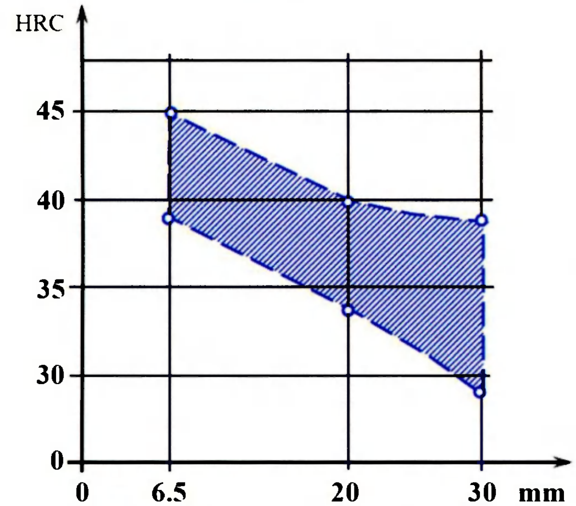


Figure 7 – The field of admissible values of steel hardening of 14HN3MA according to the existing technology and TU 14-550-51–2004

Table 2 – Admissible non-metallic inclusions in the rolling of bit steels

Type of inclusions	Type of inclusions			
	A (sulfides)	B	C (silicates)	D
thin	2.5	2.0	0.5	1.5
thick	1.5	1.0	0.5	1.0

steel is subjected to modified treatment with calcium and its alloys, an important requirement is to prevent the content of calcium more than 0.02 %.

In particular, an analysis of the oxygen, nitrogen and hydrogen content in the steel fusions of 14HN3MA-B showed that the content of these chemical elements can be equal to 0.0023–0.0025 % O, 0.011–0.012 % N, 0.0003–0.0004 % H in individual fusions, indicating an increased and inadmissible level in the rolled stock. At the same time, the evacuation of 14XH3MA-B liquid steel allows to reduce the hydrogen content to 0.0002 %, and nitrogen – to 0.008 %.

It is known that Fe-Cr-Ni-Mo steels can form a fragile phase of Fe3SrMo and others. Also, the presence of high content of P in the melt causes an increase in cold brittleness (each 0.01 % P increases the temperature of cold brittleness by 20–25 °C). But the high content of sulfur increases the red brittleness (fusion of FeS eutectic), so the 4813H steel provides higher strength. That is, trends in the choice of steel melts of advanced manufacturers are fully justified by the requirements for ensuring high crack resistance. In this case, the carbonized and hardened layers of the details of imported drill bits exhibit high hardness, and the core, along with its high strength, has viscosity and elasticity.

Note that the macrostructure of rolled products should not have shrinkage, leaching, porosity, flaccidity, cracks, bundles, slag inclusions, as well as other defects on treated steel ingot sections. Nevertheless, the study of the structure of those 14HN3MA steel fusions, of which the bit cones were brittle destroyed, revealed coarse nonmetallic inclusions in the form of strip fragile silicates from 3 to 4.5 points according to the scale of GOST 1778–70 (Fig. 8).

Figure 8 – Strip brittle silicates (4.5 points) for steel fusion 14HN3MA × 350

The streakiness of the structure of the point number 5, by the scale GOST 801–78 (Fig. 9), was also observed in such fusions. The observed sites of different types of etching, located in the form of strips along the direction of the fibers, were formed during the manufacture of rolled products. Such structural heterogeneity of steel smelting is a consequence of dendrite liquidation. The defect in the form of dendrite

Figure 9 – Inappropriate structural heterogeneity in the form of coarse striping on one of the steel melts 14HN3MA (roll stock in the state of delivery) × 100

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liquidation is inherited from the ingot, and, when it is forged, the rotation becomes a kind of alternating strips. In order to reduce dendrite separation, it is necessary to make diffusion annealing of ingots before rolling, which is based on long-term heating of steel at a temperature of 1100 °C.

There was made an analysis of the nature of the fractures of the bit cones 393.7 M-GVU-D34, manufactured by serial and experimental technologies.

The existing primary and the largest wear of relit hardened teeth tops leads to the exposure of the basic material of the cutter. The most abrasive wear progresses in the direction from the top to the base of cutter teeth due to different wear resistance, while the reinforced surface of teeth is susceptible to shear. However, high toughness and strength of steel core cutter and milled teeth cause destruction by plastic strain, which promotes a kind of teeth self-sharpening. Even completely destroyed teeth, unlike sheared teeth of serial cutters bits, have a surface that does not allow cutter sliding on the surface of the bottom hole. Typical destruction of serial cutter teeth up to the base is a shear leading to the suspension of drilling by sliding cutters on the bottom hole.

Conclusions

It was determined that control of chemical composition purity of supplied steels and their mechanical parameters such us strength, ductility, crack resistance prevent unpredictable sudden failure of bits. Rolling is necessary to expose high-heating performing diffusion annealing before making forging blank when strength index values are close to DI = 4.0 or there is susceptibility of drilling melting steel to crack.

The deformation of rolling during producing of cutter bit blanks should not be less than ε = 40 %. After carbonizing it is also necessary to perform the quench to 830±10 °C, and the second hardening shall be performed starting from 870 °C.

Further research will make it possible to determine relationship between the physico-mechanical and technological parameters of drilling steel of bit parts to predict strain formation during their chemical heat treatment.

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Підвищення довговічності тришарошкових бурових доліт

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Досліджено вплив фізико-механічних і технологічних показників на тріщиностійкість різних плавок сталі 14ХН3МА-В для шарошок бурових доліт. Встановлено, що широке поле розсіювання фізико-механічних і технологічних показників плавок цієї сталі у стані поставки створює передумови високої схильності шарошок бурових доліт до крихкого руйнування. Для недопущення таких явищ рекомендується застосовувати сталі підвищеної якості згідно з ASTM A 304–78, які мають однорідну мікроструктуру та забезпечують заданий рівень прогартовування і показники міцності. При значеннях показника міцності плавки долотної сталі близьких до DI = 4.0 чи виявленні її схильності до тріщиноутворення, прокат слід піддавати дифузійному відпалу перед виготовленням поковки. Виготовлення заготовки шарошки рекомендується проводити куванням прокату при деформації не менше ε = 40 %. Також після цементації необхідно здійснювати відпуск до 830±10 °C, а друге гартування проводити з температурою 870 °C.

Ключові слова: *відпуск, довговічність, долотна сталь, кування, плавка, тріщиностійкість, шарошка.*