The investigation of the influence of thermomechanical treatment of the material of rotary cutter bit toolholders on its hardness

S A Chupin and V I Bolobov
Saint-Petersburg Mining University, 2, 21st Liniya, Saint-Petersburg, 199106, Russia
E-mail: Staseg-88@mail.ru

Abstract. The causes of failure of the tangential rotary cutter bits of the road header during stonedrift in rocks of medium strength are analyzed in the article. It was revealed that the most typical cause of failure of cutter bits is premature wear of the toolholder (body) of the cutter bit. It is well known that the most effective way to improve the wear resistance is to increase hardness. The influence of the thermomechanical treatment of the material of the cutter bit toolholder on its hardness is studied. It was established that the thermomechanical treatment of the cutter bit toolholder material results in the increase of its hardness. It was found that the increase of material hardness is proportional to the increase of material strain intensity during thermomechanical treatment. It was concluded that the use of thermomechanical treatment can lead to the increase of both the hardness and wear resistance of the cutter bit material.

1. Introduction
Currently, the most advanced technique for permanent and service headways during subsurface mining is road headers, while for the mining operation – shearers that break rocks with operating devices of the cutting type.

The effectiveness of rock massif breaking and the productivity of power-loaders are defined by the engineering level of applied cutting tools. The quality of applied cutting tools affects mine costs both directly (via tool cost) and indirectly (via their replacement timing, the reduction of resource elements of transmission, actuators and other power-loader components) [1].

The exploitation of damaged cutter bits causes an increase in power and energy parameters of rock breaking. The above-mentioned reasons cause substantial costs for cutting tool replacement: depending on rock hardness and abrasiveness, they can reach up to 30% of the total cost of the tunneling work [1].

It is conventional that the runout of indexable insert holders is similar to the wearout of cutter bits having a plane face [2, 3]. A finely-divided volume-compressed core built up in the contact zone of the cutting tool and a rock prevents further movement of the cutter bit (Figure 1). Since the cutter bit does not stop moving, and the openness and cleavage of a rock massif are not sufficient for continuous cutter bit movement without crush evacuation, a part of the pressure bulb ‘utpours’ at a high speed along the cutter bit face towards the free face. Due to high stress of the fragmented rock in the pressure bulb, its ‘outpouring’ through a narrow gap is accompanied by significant friction on both the undecayed rock and the cutter bit (figure 1, c). In Figure 1, it is shown that most of the time, the hard alloy insert and the bolster of the shoulder of the rotary cutter bit toolholder interacts with the rock.
Thus, rock cutting with the rotary cutter bit causes prompt appearance and destruction of the pressure bulb resulting in tool wear.

![Figure 1. The scheme of cutting the rock massif with the rotary cutter bit at different times during a single big fracture: 1 – rotary cutter bit, 2 – pressure bulb (finely-dispersed fractions of the rock) under the conditions of triaxial compression; 3 – shear zone, 4 – zone of elastic strain of rock massif surrounding areas (big fracture); \(P_Y\) – feed force, \(P_L\) – cutting force, \(V_p\) – cutting velocity vector, \(V_H\) – feed velocity vector.]

Most of the tunneling work with the use of mechanical combine systems is realised with the rocks of medium hardness and abrasiveness [4, 5]. Due to the operating experience of roadheaders rotary cutter bits, the main cause for cutter bits malfunction is wearing of the toolholder head accompanied by the breaking out of the hard alloy insert (figure 2). The early wearing of cutter bits in relation to its hard alloy insert leads to incomplete resource consumption of the entire tool. The increased wear resistance of the cutter bit toolholder will lead to the increase of the service life of the rock-destruction tool.

![Figure 2. The view of rotary cutter bits RSh32-70/16SK after their operation: the worn cutter bit a) before the breakage of the hard alloy insert and b) after the breakage of the hard alloy insert [6, 7].]

The producers use different methods in order to improve the wear resistance of a rock-destruction tool of mining equipment. A considerable amount of research is done in the area of rational design parameters of the cutter bits, the use of sophisticated and hard-wearing materials or the use of special processing techniques.

The special processing techniques include some kinds of heat treatment, in particular, thermomechanical treatment (TMT) combining steel plastic strain at elevated temperature and heat
treatment. The formation of the structure of hardened steel during TMT occurs under conditions of increased density of dislocations caused by technological conditions of the hot strain process [3]. Materials processing using this technique causes a significant increase of strength properties of the processed steel [8 – 11]. It is known that the increase of material hardness leads to the increase of its wear properties [12]. Consequently, one of the effective ways to improve the wear resistance of rotary cutter bit toolholders is to increase their hardness.

This paper presents an investigation of the influence of different values of strain on the hardness of steel of cutter bit toolholders during thermomechanical treatment.

2. Experimental methods and materials
The study of the impact of various modes of TMT on material hardness of the road header rock-destruction tool was studied on the basis of steel 30KhGSA, which is the most commonly used material in the production of tangential rotary cutter bit toolholders. The value of strain intensity \( \varepsilon_p \) (effective strain) in the samples surface layer is set as a changing parameter of the TMT mode (other parameters are constant).

Cylinder samples with \( D_0 = 8 \text{ mm} \) and are \( H_0 = 15 \text{ mm} \) high (figure 4) were subjected to TMT according to the scheme:
1. Heating in the thermostat to the temperature of 1200 °C and soaking for 10 minutes to establish the process of steel austenitizing;
2. Compression of the sample of height \( H_0 \) in line to its axis on the compressed-air hammer at the temperature of 900 °C up to different values of height \( H_i \);
3. Hardening of the sample in oil;
4. Low-temperature tempering at 250 °C.

![Figure 4](image)

\[ \text{Figure 4. The representation of the cylinder sample strain process before (a) and after (b) uniaxial compression.} \]

The measurements of hardness and strain intensity were carried out on the side surface of the deformed samples in the central (working) part (figure 4 b). The plot with \( a = 3 \text{ mm} \) and \( h = 2 \text{ mm} \) was accepted as a working part. Hardness measurements were carried out using universal hardness tester Zwick ZHU 187.5.

3. Results and Discussion
The results of hardness measurement of samples made of the 30KhGSA steel, subjected to TMT of various strain intensity are presented in table 1.
Table 1. Hardness of the working part of samples subjected to thermal and thermomechanical treatment of various strain intensity

| № samples | Hi, mm | Strain intensity εр | Hardness, |  |
|-----------|--------|----------------------|------------|---|
| 1         | 15     | 0                    | HRC 44 (35÷45) | HB 4090 (3270÷4210) |
| 2         | 13     | 0.17                 | HRC 48     | HB 4550     |
| 3         | 12.3   | 0.22                 | HRC 49     | HB 4690     |
| 4         | 11.1   | 0.32                 | HRC 52     | HB 5120     |
| 5         | 9.6    | 0.44                 | HRC 53     | HB 5250     |
| 6         | 8.9    | 0.49                 | HRC 54     | HB 5430     |
| 7         | 6.1    | 0.69                 | HRC 55     | HB 5600     |

There are also data on hardness of the head part of cutter toolholders in accordance with GOST R 51047-97 ‘Cutter bits for roadheaders and shearsers. General technical specifications’, shown in brackets for comparison.

The table shows that the increase of strain intensity leads to a significant increase of hardness in these samples. In this case, maximum strain εр = 0.69 conditions of the hardness increase up to 1.2 times compared with the underformed samples.

The curve in figure 5 shows the dependence of hardness variation of the working part of fragments after undergoing TMT, given in terms of HB, on the intensity of plastic strain εр, to which this area was subjected before hardening.

Figure 5. Dependence of the hardness variation of the 30KhGSA steel on the intensity of strain during TMT

As a result of mathematical processing of experimental data, it was found that the variation in hardness depending on strain intensity is accurately described by the equation of the following kind:

\[ HB = HB_0 + \Delta HB = HB_0 + A \varepsilon^x, \]

where HB_0 – hardness of the material (steel 30KhGSA) not being subjected to strain before hardening (εр = 0); ΔHB – hardness increment due to the strain during TMT; A, x – empirical coefficients, constant for a given material (A = 73, x = 0.73).

The obtained results of experimental researches were used to create a computer model of the TMT process of rotary cutter bit toolholders TMT using the finite-element method of the software package ‘DEFORM-3D’ (figure 6).
According to the results of the computer simulation of traditional manufacturing of the shape of rotary cutter bit toolholder RSh 32-70/16.M1, it was established that the use of cylindrical workpieces conditions insufficient strain intensity $\varepsilon_p = 0.17$ for a substantial increase of the toolholder metal hardness as a result of subsequent hardening. The existing technology of cutter bits manufacturing provides a technological stage of forging cooling in the still air during the time period sufficient for the process flow of recrystallization of the deformed metal and removing of the surface hardening of the working part of the toolholder.

The head part of the cutter bit toolholder ‘RSh 32-70/16.M1’ has the worst wear during cutting of rocks. The change of the direction of the metal flow in the head part of the cutter bit toolholder during forging can increase strain $\varepsilon_p$ in this part. As a result of the metal flow investigation, we decided to make a bevel in the head part of the workpiece (Figure 7). As a result of simulation of the metal flow process, it was established that the maximum value of strain $\varepsilon_p\sim0.7$ is achieved when the bevel length is $b = 12...14$ mm, and the angle is $\alpha = 45...55^\circ$.

It is recommended that the hard alloy insert fixing should be conducted according to the cold fit technology, used when equipping the rotary cutter bits of foreign manufacture. It should be noted that the proposed technology of cutter bits production does not lead to the increase of the cost of their production [3].
4. Conclusion
1. It was established that both the strain of the cutter bit toolholder steel at elevated temperatures and subsequent hardening increase steel hardness. The strain in the head part of the cutter bit toolholder of about 0.7 and subsequent hardening can increase the hardness up to 1.2 times.
2. The dependence of hardness on strain was determined.
3. It is supposed that such type of the hardness increase will lead to the increase of the wear resistance of this material, but this supposition requires further background studies.

References
[1] Levankovskij L A and Glatman L B 1998 Rocks and composite materials breakdown by rotary cutter bits: Collected scientific papers vol 1 (Moscow: Academy of mining science press) pp 81-109
[2] Krapivin M G, Racov I Ja and Sisoev N I 1990 Mining tools (Moscow: Nedra)
[3] Chupin S A 2016 Improving wear resistance of rotary cutter bits of road headers for the mining in medium strength rocks (Saint Petersburg: Mining University Press)
[4] Thuro K and Plinger R J 1998 The 8th International IAEG Congress (Vancouver) vol 2 p 3545-52
[5] Gajewski J and Jonak J 2008 Methods of artificial intelligence research knives and cutting drums heads (Warsaw)
[6] Horeshok A A, Mametev L E and Cehin A M 2013 Manufacturing and exploitation of mining machines breaching tools (Tomsk: Tomsk polytechnic university press)
[7] Bobrov V L 2012 Increasing wear resistance of road headers tangential cutter bits by enhancement of heat treatment during their manufacture (Saint Petersburg: Mining University Press)
[8] Lahtin Ju M and Leonteva V P 1990 Materials science (Moscow)
[9] Makarov D N, Kornelkov E M, Didenko A P and P’yankov A A 2007 Metallurgist 51 503-504
[10] Kruglova A A, Orlov V V, Khlusova E I and Nemetinov A A 2007 Metallurgist 51 116-120
[11] Naumov A A, Bezobrazov Y A, Kolbasnikov N G and Chemikov E V 2013 M. Sci. Forum 762 62
[12] Bolobov V I and Chupin S A 2015 Proceedings of the Mining Institute 216 44-49