

Thermodynamic foundations of the rational cutting modes choice under conditions of machining

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Abstract. Durability and tribological tests of standard grades of high-speed steels and experimental single-carbide hard alloys with modified cobalt binder, created on the basis of the standard VK8 grade, under conditions of friction and turning of structural steels 45 and 12X18H10T were carried out. The experiments were carried out for various cutting speeds and friction in order to determine the dependence of the optimal modes from the point of view of reducing the wear rate for cutting materials with different structural and thermodynamic characteristics. It has been experimentally established that high-speed steels with high values of thermal entropy have greater wear resistance in comparison with low-entropy grades, and cutting (sliding) speeds corresponding to minimal wear rates are higher for them. For experimental hard alloys grades characterized by greater thermal entropy values of the binder lower wear rates at optimal cutting speeds compared to the base alloy were also recorded; the values of the optimal cutting speeds for these materials are also higher. Thus, high-entropy cutting materials allow machining at higher speeds, while reducing the wear intensity.

1 Introduction

One of the most important tasks facing modern metalworking production is to obtain the specified output parameters of the cutting system - technological and economical. Technological indicators include the accuracy of processing, the quality of the treated surfaces, the resource of the metal-cutting tool; economic indicators include productivity and cost of processing. The properly selected cutting modes, which include depth, feed and cutting speed values, have a significant impact on the economical parameters of the production process in the machining of materials by blade tools [1]. In operations of machining by blade tool, the cutting speed is the main element of the cutting. The most rational (optimal) cutting speed is the one that, with a sufficiently high productivity of the machining process, provides a minimum wear rate and maximum tool durability. At such speeds, as a rule, the effects of adhesive mechanisms of tool wear are minimized, while the level of thermo mechanical action in the cutting zone remains insufficient to activate the

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oxidative type of wear. Many studies have been devoted to determining the optimal cutting conditions for blade processing of various structural materials. Particularly relevant is the issue of choosing the most successful combination of tool cutting material, workpiece material and cutting parameters for difficult-to-machine structural materials, which include, for example, various high-strength high-alloy steels, titanium alloys, stainless steels [2-8]. The most common cutting materials used for their processing, especially in turning operations, are hard alloys or cemented carbides. The reason for this is their advantages in the field of physical, mechanical and cutting properties compared to other cutting materials, which makes hard alloys one of the most common products of powder metallurgy in the world [9,10]. Hard alloys consist of refractory metal carbides, nitrides or carbonitrides placed in a ductile metal bond. In WC-based alloys, cobalt is the most common binder, and one of the main directions in improving existing and developing new grades of hard alloys is the partial replacement of this expensive and scarce element with other metals [11–13]. Such a modification of the cobalt binder makes it possible to obtain new hard alloys compositions without significant losses in the field of cutting properties or even with an improvement in individual characteristics against the background of a reduction in their cost.

A much smaller share is occupied by high-speed steels, mainly in operations performed using small-sized axial tools. The value of the most rational cutting speed from the point of view of reducing the wear rates of the tool directly depends on the chemical composition, physical, mechanical and tribotechnical characteristics of the cutting tool material (CTM). As the integral characteristics of the chemical composition of such types of CTM as high-speed steels (HSS) and hard alloys their thermodynamic parameters - thermal entropy and absolute (relative) thermo-EMF - may be considered [14]. These characteristics are interrelated: high-entropy CTMs are characterized by low values of absolute (relative) thermo-EMF, which contributes to their greater resistance to oxidative wear [15].

This article is dedicated to the study of the influence of thermodynamic characteristics of the CTM on the value of friction and cutting modes parameters that provide a minimum of wear rates under conditions of friction and turning.

2 Materials and Methods

2.1 An evaluation of wear resistance of high-speed steels in the process of friction.

Tribological tests of cylindrical samples with a diameter of 5 mm made of HSS of seven different standard grades (Table 1) under conditions of friction on counter bodies made of structural steel 45 with the help of a special device for a lathe that allows conducting experiments at different values of specific pressure and sliding speed were performed. During the tests, the cutting speed varied between 0.16-1.3 m/s, specific pressures - between 30-60 MPa, the friction path was constant and equal to 1000 m. An evaluation of relative wear resistance was carried out by comparing the linear wear of samples.

Table 1. Researched HSS grades.

№	HSS grade	Chemical composition	Thermal entropy S, J/mol·K
1	R6M3	W(6%)+Mo(3%)+Fe	26.86
2	R6M5	W(6%)+Mo(5%)+Fe	27.26

3	R6M4F4	W(6%)+Mo(4%)+V(4%)+Fe	27.46
4	P8M3F4	W(8%)+Mo(3%)+V(4%)+Fe	27.53
5	R18	W(18%)+Fe	28.04
6	EP658(R6F2K8M5)	W(6%)+V(2%)+Co(8%)+Mo(5%)+Fe	30.60
7	EP657(R12F2K8M3)	W(12%)+V(2%)+Co(8%)+Mo(3%)+Fe	30.78

2.2 An evaluation of wear resistance of HSS and HA tools in the process of machining.

The studies of wear resistance of different HSS grades in the process of machining were carried out during turning work pieces of structural steel 45 with special one-piece tool bits. Geometry parameters of the cutting part of the tool bits: rake angle $\gamma = 8^\circ$, clearance angle $\alpha = 10^\circ$, side cutting edge angle $\varphi = 45^\circ$. Cutting depth was $t = 0.5$ mm, feed $s = 0.15$ mm/rev. Durability tests also were carried out when turning work pieces of heat-resistant steel 12H18N10T by tool inserts made of experimental single-carbide hard alloys with modified cobalt binder [14] created on the basis of the standard HA grade VK8 (Table 2). These HA grades are characterized by high thermal entropy values of the binder together with small values of absolute thermo-EMF which increases the electrochemical stability of these materials, and also characterized by an improvement in a number of operational and tribotechnical characteristics in comparison with the base composition [15,16].

Table 2. Chemical composition and properties of experimental hard alloys.

HA grade	Composition	Thermal entropy $S, \text{J/mol}\cdot\text{K}$	
		$(S_{298}^0)_{WC}$	$(S_{298}^0)_b$
1	2	3	4
2.1	91.69% WC+ 8.31%[6.23%Co+2.08%Mo]	35.6	30.67
2.20	92.38% WC+7.62%[3.6%Co+ +3.2%Fe+0.82%Cu]		29.31
2.21	92.45% WC+7.55% [5.3%Co+1.43%Fe+0.82%Cu]		29.83
2.22	91.95% WC+8.05% [5.65%Co+1.8%Mo+0.6%Ti]		29.72
2.23	91.59% WC+8.41% [5.1%Co+2.7%Mo+0.61%Ti]		29.59
VK8	92% WC [7.5-8]%Co, Fe $\leq$ 0.3%		28.5

Geometry parameters of the cutting part of the tool inserts: rake angle $\gamma = 8^\circ$, clearance angle $\alpha = 6^\circ$, side cutting edge angle $\varphi = 45^\circ$. Durability tests were carried out at longitudinal turning without cooling on the engine lathe mod. 16K20 equipped with a Frequency converter Mitsubishi, allowing stepless adjustment of the spindle speed. The cutting speed was set with

high accuracy using the MEGEON laser tachometer. The studies were conducted at cutting speeds in the range of 0.6-1.4 m/s for HSS and 0.5-2.9 m/s for HA. The wear resistance of the CTM was determined by measuring the linear wear of the bits and inserts on the flank.

3 Results and Discussion

The dependences of wear intensity on specific pressure for tested HSS grades are shown in Fig. 1. For most of the HSS studied, the $J(P)$ curves have an minimum point corresponding to the pressure at which the wear intensity of the HSS grade is minimal. According to the test results, the high-entropy grades R6M4F4, EP658, EP657, R8M3F4 can be considered as the best, since the materials for all the studied values of specific pressures are characterized by high wear resistance. The $J(P)$ curves for these HSS grades have a pronounced minimum point located in the region of pressures of the order of 40-50 MPa which is higher than for other HSS grades.

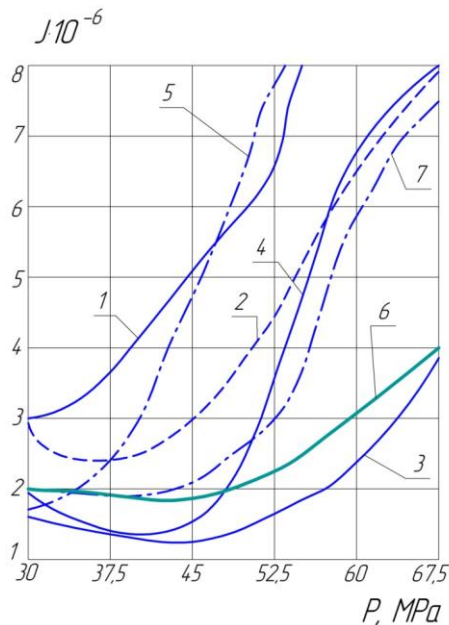


Fig. 1. Dependence of wear intensity J of HSS samples on specific pressure P at constant sliding speed $V = 0.33$ m/s: 1 – R6M3; 2 – R6M5; 3 – R6M4F4; 4 – R8M3F4; 5 – R18; 6 – EP658; 7 – EP657.

The dependences of wear intensity on sliding speed for tested HSS grades are shown in Figure 2. The lowest wear intensity at low sliding speeds belongs to steels R6M4F4 and R8M3F4. With an increase in speed of more than 0.5 m/s, the greatest wear resistance was demonstrated by HSS grades EP657 and EP658. For high-entropy HSS grades (EP657, EP658 and R18), the curves $J(V)$ have an minimum point at higher sliding speeds, in the range of 0.66-0.83 m/s. For steels with low thermal entropy values, the minimum wear intensities were observed at speeds of 0.33-0.5 m/s.

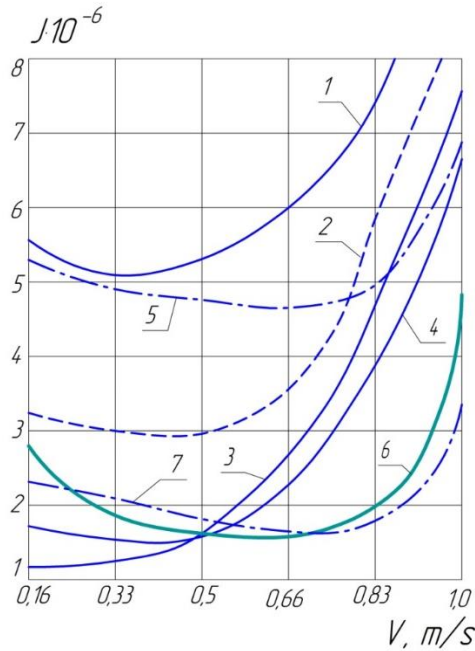


Fig. 2. Dependence of wear intensity J of HSS samples on sliding speed V at constant specific pressure $P = 45$ MPa: 1 – R6M3; 2 – R6M5; 3 – R6M4F4; 4 – R8M3F4; 5 – R18; 6 – EP658; 7 – EP657.

The highest wear resistance among HSS was demonstrated by high-entropy compositions EP657 and EP658, and cutting speeds corresponding to the minimum wear intensity for these materials were in the range 1.1-1.2 m/s which is higher than for grades with low thermal entropy values (Fig. 3).

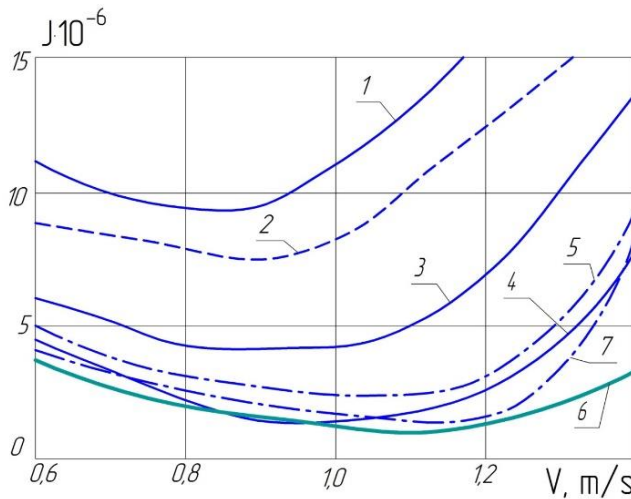


Fig. 3. Dependence of wear intensity J of HSS tool bits on cutting speed V : 1 – R6M3; 2 – R6M5; 3 – R6M4F4; 4 – R8M3F4; 5 – R18; 6 – EP658; 7 – EP657.

When turning heat-resistant steel 12H18N10T by tool inserts of HA, the lowest wear intensity was demonstrated by experimental compositions characterized by high thermal

entropy of the modified cobalt binder (Fig. 4). Cutting speeds corresponding to minimum wear are higher for these materials than for the base alloy VK8. The greatest wear resistance at the optimal cutting speed was fixed for alloy 2.1., and the value of the optimal speed is 1.7 times higher than for VK8.

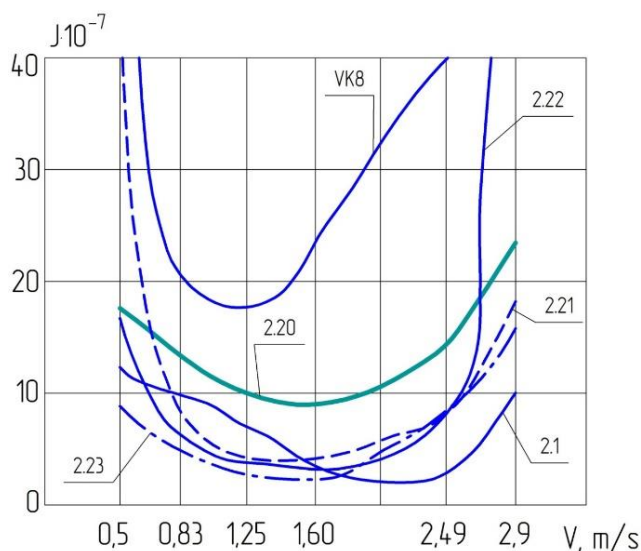


Fig. 4. Dependence of wear intensity J of HA tool inserts on cutting speed V .

High-entropy CTMs have a number of better physical, mechanical and tribotechnical characteristics in comparison with low-entropy materials. Such advantages include lower cutting forces and temperatures in the cutting zone, higher surface micro hardness and modulus of elasticity and better frictional characteristics [16]. The complex of such properties provides for these materials a general reduction in the wear intensity under various friction and cutting modes. Due to the high resistance to abrasive, adhesive and oxidative types of wear, maximum wear resistance for high-entropy CTMs is observed in the range of higher sliding (cutting) speeds than for cutting materials with lower thermal entropy values.

Thus, the use of high-entropy CTMs in the processes of machining allows not only to reduce the wear intensity of the cutting tools, but also to achieve an increase in the cutting speed, at which the wear intensity of the CTM reaches its minimum value.

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