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Research of thermal processes in cutter edge made of HS 3-1-1,5 low-alloyed high-speed steel

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ABSTRACT

Purpose: The physical and mathematical description of tools wear during technological process and need to the enlarge tool life require knowledge of material data, e.g. density, specific heat and coefficient of thermal conductivity. A formation of heat during tool work and increase of cutting edge temperature are results of friction between tool and stock. The distribution of temperature in cutting edge material during machining can be defined in selected places with the use of thermocouple. The measurement of arisen heat during machining is determined by analytic way as a measured temperature distribution and the thermal properties of cutting edge and work piece, which are known. The knowledge of temperature distribution and thermal flux process, which accompanies to, is the one of the factors influencing on reach the conclusions in relation to describe wear and suggestion to increase tool life.

Design/methodology/approach: The results of investigations of the temperature field in cutter edge of cutters made of HS 3-1-1,5 and HS 6-5-2 low-alloyed high speed steel and the coefficient of thermal conductivity of listed kinds of steels to determinate their effective use on cutting tools were described.

Findings: Decreasing of contents of alloy addition did not significantly affect the thermal and physical properties changes of SW3S2 steel.

Research limitations/implications: To ensure applicable quality requirements during production of tools made of low-alloyed high-speed steels, it is very important so that their cutting ability will not be lower than analogical tools made of classic high-speed steels. It requires establishing such good work conditions in case to be competed effectively with classic high-speed steels.

Practical implications: The obtained results of investigation showed, that decreasing contents of alloy addition did not affect the thermal and physical properties changes of HS 3-1-1,5 steel.

Originality/value: The carried out investigation showed, that the cause of lower durability of cutters should be sought in lower temperability of HS 3-1-1,5 low-alloyed high-speed steel.

Keywords: High-speed steel; Temperature field; Thermal conductivity

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MATERIALS

1. Introduction

The deficit of tungsten (W), molybdenum (Mo), cobalt (Co) and vanadium (V) occurring in the world causes that assurance of such important material properties as hardness, strength, temperability, thermal conductivity and grindability becomes more and more hard. On the other hand, in mechanical engineering the high-alloyed construction materials are more often used and they need these chemical elements. In this aspect, the economical management of these alloyed elements is very important issue. One of the methods to solve this question is further development in the economical high-speed steels usage and modern metal finishing [1,2]. Applied high-speed steels used since one hundred years have nowadays more and more limited scope of use for cutting tools (especially at high machining speeds) but they are used for constructional elements, tools for plastic forming and for forms to manufacture products made of plastic [3,4].

The selection of material used for suitable tool is dependent on method of its wear or destruction. This selection is facilitated by characteristics describing relations between tool material structure and properties and work conditions of tool and method of its wear. It is very important issue to establish for selected tools attributes suitable physics and mechanical properties as resistance attribute on action of factors which decide about taking out tool production. Also significant is to establish criteria of tool wear and establish suitable requirements regarding structure and properties of tool material [5]. The data in relation to life of tools made of low-alloyed high-speed steels presented in publications do not have any scientific justification and they are also inconsistent to each other. In many papers the machining parameters used during researches are not provided. Machining speeds still increase and this tendency will be maintained at the same level in the future. Therefore, in order to define area of use and selection of optimal machining parameters, it is necessary action to recognize temperature and force conditions of their work. By knowing these conditions, it can be defined the basic reasons of tool wear (in dependence on specific work conditions) and propose the most effective methods of wear enlargement.

Table 1.
The influence of alloy addition on thermal conductivity of high-speed steels [6]

HS18-0-1 (0.8-0.9C, 3.1-3.6Cr, 12-13W, ≥1.0Mo, 1.5-1.9V)					
T	^oC	27	127	227	327
λ	$\frac{W}{m \cdot K}$	15.5	16.6	19.1	22
HS12-0-2 (0.7-0.8C, 3.8-4.4Cr, 17-18W, ≤1.0Mo, 1.0-1.4V)					
T	^oC	27	127	227	327
λ	$\frac{W}{m \cdot K}$	21.5	25.6	26.2	26.2
Iron (99.93C, 0.005C, 0.04Mn, 0.02Si, 0.004S, 0.001P)					
T	^oC	50	100	200	300
λ	$\frac{W}{m \cdot K}$	83	79.3	70	60.7

The reduction of contents of alloy additions in high-speed steels does not have to indicate the quality deterioration of tools made of these steels. It is a well-known fact, that bigger percentage of tungsten in high-speed steels causes reduction of thermal conductivity, which is presented in Table 1.

Therefore, at higher machining speeds, thanks to better heat dissipation from cutting area, tools made of SW9 steel were more effective than analogical tools made of SW18 steel [7]. To ensure applicable quality requirements during production of tools made of low-alloyed high-speed steels, it is very important that their cutting ability will not be lower than analogical tools made of classic high-speed steels. It requires establishing such good work conditions in order to they could be competed effectively with classic high-speed steels [8].

2. Research of thermal processes as a base to define the field of use tools made of low-alloyed high-speed steels

The physical and mathematical description of tools wear during technological process and need to enlarge tool life, require knowledge of material data, e.g. density, specific heat and coefficient of thermal conductivity [9,10]. A formation of heat during tool work and increase of cutting edge temperature are results of friction between tool and stock. The distribution of temperature in cutting edge material during machining can be defined in selected places with the use of thermocouple. The measurement of arisen heat during machining is determined by analytic way as a measured temperature distribution and the thermal properties of cutting edge and work piece, which are known. The knowledge of temperature distribution and thermal flux process, which accompanies to, is the one of the factors influencing the conclusions achievement in relation to describe wear and suggestion to increase tool life.

2.1. Methodology of research

Research of temperature distribution in cutting edge made of HS 3-1-1,5 and HS 6-5-2 steels during 60 steel turning using semi-natural constantan thermo-element (with cutting edge material) was carried out by the following method: There were prepared specially sectional cutters from both grades of steel with the hardness ~ 63.5 HRC [11]. Parting plane was crossed perpendicularly to main cutting edge in the middle of contact surface between chip and rake surface, where the highest temperature has taken place [12]. For preparing thermo-element, the Ø0.1 mm diameter constantan wire was flattened at the end to dimensions: 0.15 x 0.15 x 0.005 mm and it was isolated. Distance from the middle of contact weld to tool flank and rank surface was measured with 0.01 mm precision on microscope. Temperature was measured after its stabilization using milivoltmeter, which was set up to Celsius degrees. In order to obtain thermometric characteristic of constantan thermo-element, the set up was achieved by locating thermocouple in medium with known temperature.

The coefficient of thermal conductivity λ characterizes selected medium in respect of ability to thermal conductivity. The measurement of λ of metal alloys is hard to realization because of high thermal conductivity of metals, which causes very low decrease of temperature and makes difficult the temperature measurement.

One of the method of measurement of metals λ and their alloys is a quasi-stationary method, which makes use of phase transition. This method is counted to absolutely non-stationary measurements of thermal conductivity [13,14].

This method of measurement is that the sample is located vertically between sources. The stream of warm water flows in from upper source generating increase of temperature of sample and lower source. This process proceeds until metal melting point is achieved (or metrological matter), which is contained in lower source. Temperature in lower source and along sample becomes firm and last during the t time period. During that, metrological matter will subject to phase transition. In this state (quasi-stationary state) thermal power flowing into lower source is determined by metrological matter mass and t time of quasi-stationary grade of temperature.

The measurement of thermal conductivity was achieved on samples made of HS 3-1-1,5 and HS 6-5-2 steels. Their chemical constitution is presented in the Table 2.

Table 2.
Chemical constitution of samples made of HS 6-5-2 and HS 3-1-1,5 steels

Steel grade	Chemical constitution							Hardness
	C	W	Mo	V	Cr	Si	W+1.5Mo	HRC
HS 6-5-2	0.82	5.55	5.13	2.06	4.18	-	13.245	40
HS 3-1-1.5	1.11	3.35	1.15	1.75	4.65	2.05	5.075	44

3. Results of tests and analysis

The permissible cutting speed level is determined first of all by temperature that arises on the contact surface of the tool with the stock material. There is a relationship between temperature and wear of cutting edge surface of the tool caused by progressive loss of its hardness. When temperature in the cutting process exceeds the value at which the cutting edge of the tool loses its hardness then dynamic recrystallization causes its immediate catastrophic wear, even at inconsiderable value of dullness.

The Figure 1 shows temperature fields in cutting edge of cutter made of HS 3-1-1,5 and HS 6-5-2 steels during 60 steel turning, obtained at the same machining conditions (cutting edge geometry, machining speed and feed), which is described in paper [6,7].

At small cut layer thickness, when the feed value f = 0.08 mm/rev, the maximum temperature occurs near main cutting edge on the clearance surface side and it is a little lower in the cutting edge of the cutter made of the HS 3-1-1,5 steel by reason of lower cutting speed (v_c = 47 m/min). The almost equal temperature gradient for both cutting edges can be indirect evidence of equal thermal conductivity of both materials. Even in extent of contact of the chip on the rake surface (b_u) temperature value decreases decidedly what means that the tip is the most loaded part of the cutting edge.

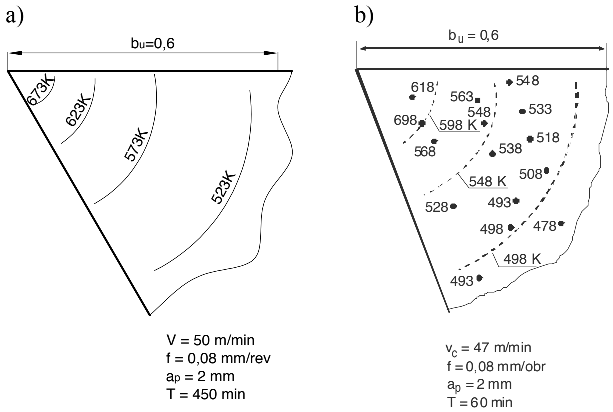

Fig. 1. Thermal field in cutting edge made of a) HS 6-5-2 and b) HS 3-1-1,5 during turning of steel 60 [8,11]

Comparison of durability of cutting edges of cutters made of these steels has proven that durability of cutter edge made of HS 3-1-1,5 steel during straight turning of the 60 steel at v_c = 47 m/min, at cutting depth a_p = 2 mm, f = 0.08 mm/rev and at the wear at back-off surface VB = 0,5 mm has amounted t = 60 min and for the cutter made of the HS 6-5-2 steel – t = 450 min.

The measurement of thermal conductivity λ, to be based on quasi-stationary method, was achieved for two samples. First sample is made of SW3S2 steel and dimensions Ø6 x 21 mm and the second one made of SW7M and dimensions Ø6 x 20.5 mm. Four measurements for each sample were performed – two measurements for average sample temperature 50ºC and two measurements for 300ºC. The results of these λ measurements are presented in Table 3. For each measurement contact sample temperature between upper source T_w and lower source T_k and average sample temperature T_{sr} are given.

Table 3.
Measurement of thermal conductivity λ of samples made of SW7M and SW3S2 steels [15]

	Steel grade							
	SW3S2				SW7M			
	λ	T_{sr}	T_w	T_k	λ	T_{sr}	T_w	T_k
No	$\frac{W}{m \cdot K}$	ºC	ºC	ºC	$\frac{W}{m \cdot K}$	ºC	ºC	ºC
1	19.32	37.317	41.463	33.171	13.60	52.366	61.317	43.415
2	17.06	43.659	52.683	34.634	13.96	53.415	63.902	42.927
3	14.15	280.488	317.07	243.90	15.15	314.63	356.098	273.17
4	15.34	315.854	375.61	256.09	16.70	348.78	404.878	292.68

To compare measured results of λ, they are presented in the Figure 2.

The Figures concerning thermal conductivity metal alloys, which are presented in publications, differ from each other considerably. It is result of big influence of small amounts of alloy additions on thermal conductivity and relatively small influence of larger amount of additions. Coefficient of thermal conductivity is dependent on temperature, technology of its manufacture, which decides about amount of impurities and on heat treatment, which decides about metal structure.

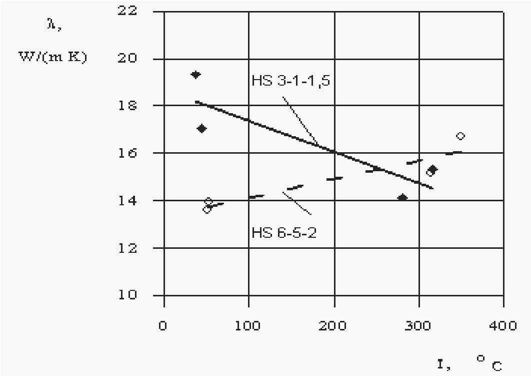

Fig. 2. Relationship between λ coefficient for HS 6-5-2 and HS 3-1-1,5 and measurement temperature

As it can be seen in the Fig. 2, λ for HS 6-5-2 steel increases and for HS 3-1-1,5 steel decreases in measured scope of temperature. For 50ºC temperature measured λ for both steel grades differs only about 20%. Comparing chemical constitution tested steels, it can be found that increase of alloy additions causes inversion of falling tendency of λ along with increase of temperature. This is a positive occurrence.

Specified by measurement values of λ for both grades of steel in principle does not differ. Decrease of λ for HS 3-1-1,5 along increase of temperature causes decreasing amount of conducted heat and at the same time increase of temperature. It is a negative occurrence during tool work process.

The obtained results show that decrease of alloy additions content has not affected change of thermal-physical properties of HS 3-1-1,5 steel (temperature gradient and distribution equal for both cutting edge material grades), and the cause of so large difference in durability of cutters should be searched in lower temperability of HS 3-1-1,5 steel. It could be supposed that for the tools made of low-alloy high-speed steels the main reason limiting their use at high cutting speed will be the loss of hardness and the plastic deformation of the cutter edge that will cause that the catastrophic wear will occur at lower cutting speed than for the HS 6-5-2 steel.

4. Conclusions

1. The changed distribution of temperature in cutting edge of cutter made of SW3S2 and SW7M steels shows, that gradient and value of temperature are the same.
2. The changed values of coefficient of thermal conductivity for both steel grades fundamentally do not differ from each other.
3. Decrease of λ value along with increase of temperature for SW3S2 steel causes decreasing of amount of conducted heat and at the same time increase of temperature in cutting edge, which is an disadvantageous occurrence.
4. Decrease of contents of alloy addition did not significantly affect the thermal and physical properties changes of SW3S2 steel.

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