J. JAWORSKI, T. TRZEPIECIŃSKI

ISSN 0543-5846
METABK 56(1-2) 75-78 (2017)
UDC – UDK 669.15:669.14.018:621.185:536.45:620.178.1:536.2=111

PROPERTIES OF LOW-ALLOY HIGH-SPEED STEEL AT ELEVATED TEMPERATURE

Received – Prispjelo: 2016-04-11
Accepted – Prihvaćeno: 2016-08-15
Original Scientific Paper – Izvorni znanstveni rad

This paper presents the results of research on the determination of the coefficient of thermal conductivity and hot hardness of cutters made of selected grades of low-alloy high-speed steels, HS6-5-2 and HS3-1-2. The investigations of hot hardness and yield stress values of HS6-5-2 steel at elevated temperatures have shown that the hot hardness value decreased to 650 – 700 HV (59 – 60 HRC) in the temperature range of 500 – 550 °C. However, the hardness of the samples preheated to the temperature of 500 – 550 °C and measured at room temperature does not change. A decrease of the hot hardness of the steel is correlated with decreasing yield stress at elevated temperature.

Key words: low-alloy steel, high-speed steel, temperature, hardness, thermal conductivity

INTRODUCTION

The selection of suitable material for a tool is dependent on the method of its wear or destruction. Detailed reviews of tool wear mechanisms in machining have been undertaken by, for example, Akhtar et al. [1] and Dolinšek et al. [2]. This selection is facilitated by characteristics describing the relations between the tool material structure and properties and the work conditions of the tool and method of its wear [3]. It is very important to establish suitable physical and mechanical properties of selected tool attributes such as hardness, thermal conductivity, and yield stress of the tool material [4, 5].

To ensure applicable quality requirements during the production of tools made of low-alloy high-speed steel, it is very important that their cutting ability will not be lower than analogical tools made of classical high-speed steels [6, 7].

However, if the operating temperature of the tool is close to the tempering temperature of the individual steel grade, reversible processes may affect the stability of the cutting edge of the tool, leading to intensification of the tool wear [8].

One of the methods of measurement of thermal conductivity λ of metal is a quasi-stationary technique that makes use of phase transition. This method is used to absolutely non-stationary measurements of thermal conductivity [9]. The temperature of a blade during the cutting process can reach significant values [10, 11]. Hot hardness is one of the main parameters that affect the tool durability at elevated temperatures [12, 13].

In this paper, the results of research on the determination of the coefficient of thermal conductivity and hot hardness of cutters made of selected grades of low-alloy high-speed steel are presented.

J. Jaworski, T. Trzepieciński: Faculty of Mechanical Engineering and Aeronautics, Rzeszow University of Technology, Rzeszów, Poland

EXPERIMENTAL DETAILS

Materials. The investigations of thermal conductivity and hot hardness were carried out for selected grades of low-alloy high-speed steel. The hardness and chemical composition of the tested steel are presented in Table 1.

Table 1 **Hardness and chemical composition of low-alloy high-speed steel**

Steel grade	Chemical constitution / mas. %							Hardness / HRC
	C	W	Mo	V	Cr	Si	W+1.5 Mo	
HS 3-1-2	1,11	3,35	1,15	1,75	4,65	2,05	5,075	44
HS 6-5-2	0,82	5,55	5,13	2,06	4,18	–	13,245	40

Hardness measurement. In the tests, the measuring head is equipped with a spherical indenter with a diameter of 3 mm. The indenter is made of cemented carbide and is attached in a movable flume that additionally contains a permanent magnet (Figure 1).

The hard indenter tip deforms the test material elastically and plastically and is deformed itself elastically. After the impact body is fully stopped, elastic recovery of the test material and the impact body takes place and causes rebound of the impact body. Both bounce and impact velocities are measured using the coil, in which a voltage proportional to the velocity is induced.

Elastic strain energy is calculated based on the measurement of the speed of impact and rebound of the indenter. The Leeb hardness HL is evaluated according to the formula:

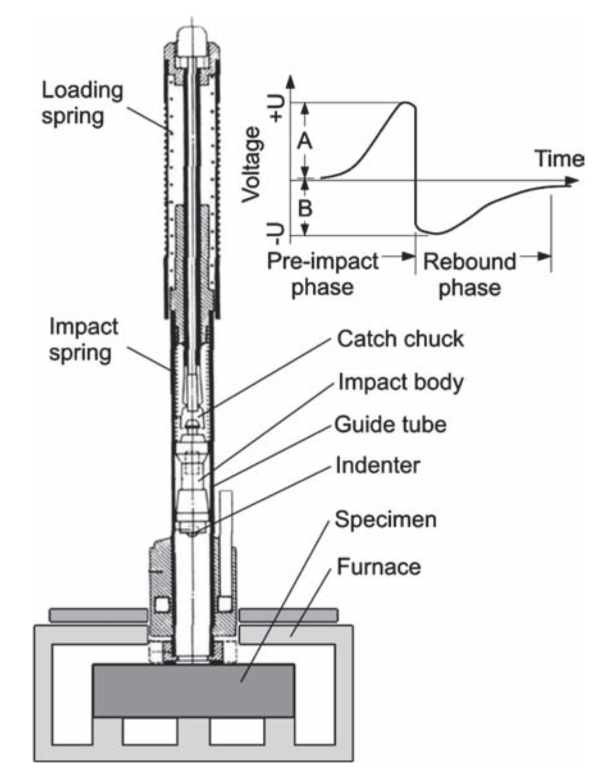

Figure 1 Schematic of the Leeb hardness tester for measuring hardness at elevated temperature

$$HL = \frac{v_2}{v_1} \cdot 1000 \quad (1)$$

where v_1 is the impact velocity and v_2 is the velocity of indenter bounce.

The test samples are heated in a resistance furnace. The temperature of the sample is recorded by a thermocouple placed on its surface. The measuring head is placed in the hole in the furnace housing and the measurement of hardness HL is carried out. The head is then moved in the *x* or *y* direction (Figure 1) and the measurement is repeated. The research was carried out at the Materials Center Leoben (Austria).

Thermal conductivity measurement. The measurement of thermal conductivity based on the quasi-stationary method was carried out on two samples. The first cylindrical sample with a diameter of 6 mm and height of 21 mm was made of HS3-1-2 steel. The second was made of HS6-5-2 steel with a diameter of 6 mm and height of 20,5 mm. In the measurement method, the sample is located vertically between heat sources. The stream of water flows in from the upper source, generating an increase in the temperature of the sample and the lower source.

Four measurements were performed on each sample. Two measurements were also made for average sample temperatures of 50 and 300 °C.

RESULTS AND DISCUSSION

The hardness of HS6-5-2 steel measured after heating the sample to a temperature of 550 °C, holding at this temperature, and cooling to ambient temperature shows almost no change (Figure 2). This suggests that there are no irreversible processes in the steel at this temperature. However, the measurement of hardness at elevated temperature indicates a decrease in hardness of about HV 30 – 40 for every 100 °C, wherein the hardness at 500 °C is about HV 700, which corresponds to a hardness of about 60 HRC. The second area of hardness reduction occurs in the temperature range of 550 – 600 °C and is characterized by a decrease of hardness at elevated temperature. The decrease in hardness value is equal to 300 – 400 HV for every 100 °C.

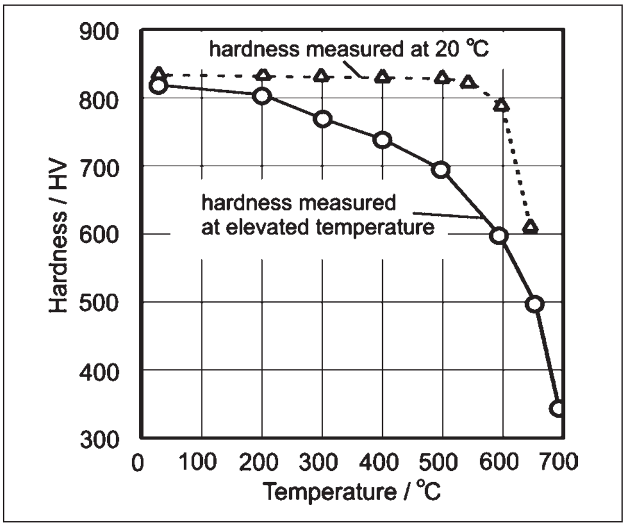

Figure 2 Effect of temperature on the hardness of HS6-5-2 steel

The results of measurement of the yield stress (Figure 3) at temperatures corresponding to Figure 2 are comparable to the results of hardness measurements at elevated temperature. The areas of the slight decrease in hardness and an intensive decrease in hardness correspond to the areas of intense and slight declines in the value of the yield stress.

To assess hardness at elevated temperatures, an indirect method can be used. It is known that the dependence between the yield stress and the temperature is close to the curve describing the hardness–temperature relationship. Knowing the value of the yield stress at a given temperature, we can estimate the changes of hardness with increasing temperature [14].

For each measurement of thermal conductivity, the temperature between the upper source T_u and the lower source T_l and the average sample temperature T_a are registered (Table 2).

The thermal conductivity decreases for HS3-1-2 steel and increases for the HS6-5-2 in the measured range of temperatures (Figure 4). In the case of a temperature of 50 °C, the thermal conductivity differs by only about 20 % for both steel grades. A decrease of the λ coefficient for HS3-1-2 along with an increase in temperature (Figure 4) causes a decreasing amount of conducted heat and, at the same time, an increase of temperature.

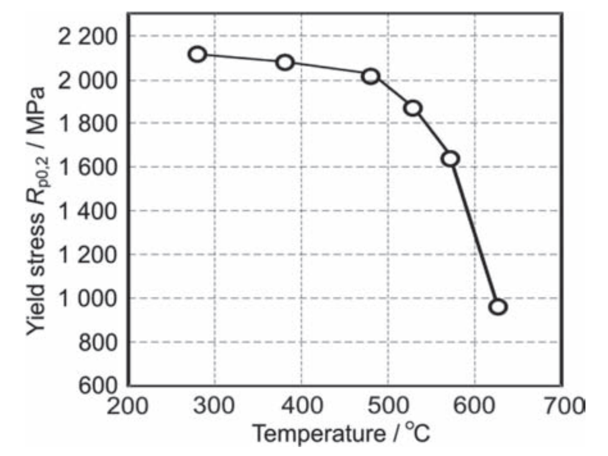

Figure 3 Effect of temperature on the yield stress of HS6-5-2 steel

Table 2 **Contact sample temperatures**

Material	Sample no.	T_u / °C	T_l / °C	T_a / °C
HS 3-1-2	1	37,317	41,463	33,171
	2	43,659	52,683	34,634
	3	280,488	317,07	243,90
	4	315,854	375,61	256,09
HS 6-5-2	1	52,366	61,317	43,415
	2	53,415	63,902	42,928
	3	314,63	356,098	273,17
	4	348,78	404,878	292,68

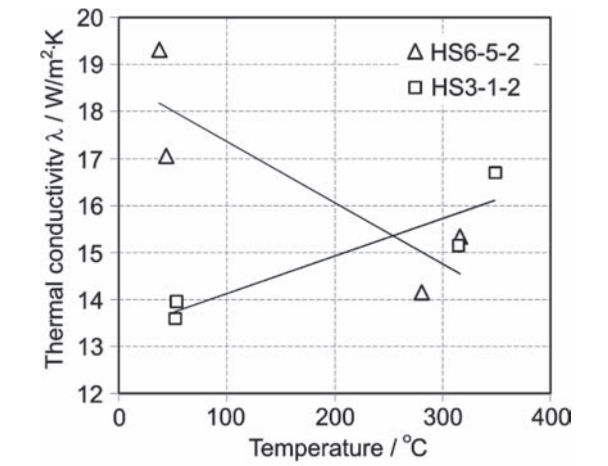

Figure 4 Effect of temperature on the value of the thermal conductivity coefficient

The obtained results show that the increased content of alloy additions has not affected the change of the thermal-physical properties of HS3-1-2 steel. For the temperature of 590 °C, the hardness value decreases to about HV 600 and a further reduction in hardness value with increasing sample hold time is observed.

After a hold time of approximately 1000 minutes, the sample hardness reaches a value of about HV 500. This means that irreversible processes were proceeding in the sample material. The results of the research show that the decrease in tool life in the temperature range of 500 – 650 °C, which is equal to approximately HV 40 per 10 minutes, is associated with the occurrence of plastic deformation of the edge of the cutting blade [15].

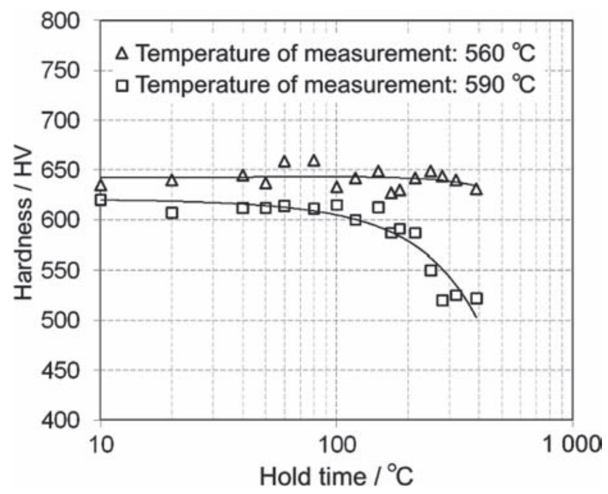

Figure 5 Effect of temperature and hold time on the hardness of the sample made of HS6-5-2 steel

CONCLUSIONS

In the case of low-alloy high-speed steel, a decrease in hot hardness begins at a lower temperature than in the case of steel with a high tungsten content. Furthermore, for low-alloy steel, the coefficient of thermal conductivity decreases with an increase in temperature. The thermal conductivity coefficient of steel with a high tungsten content increases with an increase in temperature. HS3-1-2 steel, which has a reduced content of alloy additions, does not show significant deterioration of the thermal-physical properties compared to HS6-5-2 steel. A decrease in the thermal conductivity coefficient value with increasing temperature for HS3-1-2 steel causes a decrease in the amount of conducted heat and, at the same time, an increase in temperature in the cutting edge, which is disadvantageous.

Aknowledgements

The work has received funding from the People Programme (Marie Curie Actions) of the European Union's Seventh Framework Programme FP7/2007-2013/ under REA grant agreement PIRSES-GA-2013-610547 - TAMER

REFERENCES

[1] W. Akhtar, J. Sun, P. Sun, W. Chen, Z. Saleem, Tool wear mechanisms in the machining of Nickel based super-alloys: a review, Frontiers of Mechanical Engineering 9 (2014) 2, 106-119, doi: 10.1007/s11465-014-0301-2

[2] B. Dolinšek, J. Šuštaršič, J. Kopač, Wear mechanisms of cutting tools in high-speed cutting processes, Wear 250 (2001) 1-12, 349-356, doi: 10.1016/S0043-1648(01)00620-2

[3] S. Jozić, D. Bajić, A. Stoić, Flank wear and surface roughness in end milling of hardened steel, Metalurgija 54 (2015) 2, 343-346

[4] V. P. Astakhov, The assessment of cutting tool wear, International Journal of Machine Tools and Manufacture 44 (2004) 6, 637-647, doi 10.1016/j.ijmachtools.2003.11.006

[5] M. Kowalik, T. Trzepieciński, Examination of the influence of pressing parameters on strength and geometry of joint between aluminum plate and sheet metal, Archives of Civil and Mechanical Engineering 12 (2012) 3, 292-298, doi: 10.1016/j.acme.2012.05.002

[6] J. Jaworski, T. Trzepieciński, Research on durability of turning tools made of low-alloy high-speed steel, Kovove Materialy–Metallic Materials 54 (2016) 1, 17-25, doi: 10.4149/km_2016_1_17

[7] J. Jaworski, R. Kluz, T. Trzepieciński, Operational tests of wear dynamics of drills made of low-alloy high-speed HS2-5-1 steel, Eksploatacja i Niezawodnosc – Maintenance and Reliability 18 (2016) 2, 271-277, doi: 10.17531/ein.2016.2.15

[8] B. Podgornik, V. Leskovšek, Experimental evaluation of tool and high-speed steel properties using multi-functional K_{Ic}-test specimen, Steel Research International 84 (2013) 12, 1294-1301, doi: 10.1002/ srin.201300053

[9] T. F. Fodemski, Thermal Measurements, WNT, Warszawa, 2001, pp. 145-157

[10] M. Pellizzari, D. Cescato, M. G. De Flora, Hot friction and wear behaviour of high speed steel and high chromium iron for rolls, Wear 267 (2009) 1-4, 467-475, doi: 10.1016/j.wear.2009.01.049

[11] M. Sato, T. Aoki, H. Tanaka, S. Takeda, Variation of temperature at the bottom surface of a hole during drilling and its effect on tool wear, International Journal of Machine Tools and Manufacture 68 (2013), 40-47, doi: 10.1016/j.ijmachtools.2013.01.007

[12] D. Bombač, M. Terčelj, M. Fazarinc, P. Fajfar, Increasing of hot workability of 1.3302high speed steel, Metalurgija 51 (2012) 3, 313-316

[13] W. D. Kingrey, Property Measurements at High Temperatures, John Wiley & Sons, New York, 1959, pp. 352-362

[14] P. Helman, ASP High-Speed Steels, Properties and Possibility of Application, Stora Koparberg, Warsaw, 1977, pp. 18-19.

[15] J. A. Geller, Tool Steels, Metallurgy, Moscow, 1983, pp. 89-97 (in Russian)

Note: The person responsible for English language is Mrs. Anna Pilch, Rzeszów, Poland