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 $\lambda$ 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.

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

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:

$$HL = \frac{5.47}{V^2}$$
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.

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 \( \lambda \) 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.
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].

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.

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REFERENCES


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