Comparison of properties of cutting edges made of HSS obtained by conventional methods and in powder metallurgy process

Porównanie właściwości ostrzy skrawających ze stali szybkotnących wytworzonych metodami konwencjonalnymi i w procesie metalurgii proszków

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Selected fragments of investigations of technological and functional properties of cutting edges made of conventional and sintered high speed steel with similar chemical composition are presented. Investigations of technological and functional properties have comparative character and concern among other things estimation of chemical composition, hardness, structure and durability during toughening steel machining.

KEYWORDS: cutting edges, high-speed steel, technological and functional properties

Conventional high-speed steels are still used in the manufacture of cutting tools at moderate machining speeds. This is despite the dynamic development of other cutting edge materials [1]. The main advantages of high-speed steels are significant resistance to bending and torsional strength compared to other tool materials and a relatively low cost of production. Due to the improvement in the performance of cutting tools made of conventional high-speed steels, they have been gradually replaced by high-speed sintered steel tools, mainly used in large-lot and mass production, due to their higher cost of production [2÷6].

The beneficial effects of the use of powder metallurgy in place of the classical metallurgical method for the production of high-speed steel cutting blades were seen in that the powder metallurgy gives greater freedom in the choice of the chemical composition of the product, which can be practically arbitrarily interconnected by combining insoluble components at the extreme different melting temperatures, which are materials of different chemical bonds.

Comparison of conventional and sintered high speed steel properties and the extent of their applicability seems only seemingly simple and obvious. The properties of high-speed steel blades not only affect the more or less uniform distribution of carbides in their structure – often referred to in the literature. Based on preliminary own research, it is significant that different surface morphology differentiates tribological properties and therefore also has no significant effect on the operating properties of cutting blades. Different surface morphology makes cutting blades from conventional and high speed sintered steels have different shear stability under dry cutting conditions and in the presence of coolant fluids, and behaves differently depending on cutting speed, and in many cases is not necessarily not in favor of much more expensive high-speed sintered steel. Hence, there is a need to clearly define a reasonable scope for the applicability of both high speed steels. This is the subject of this paper.

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Material used in the study

■ Material for cutting edges. Two types of high-speed steels of similar chemical composition were used to make multi-blade cutting inserts:

- conventional high-speed steel HS6-5-2 forged and rolled;
- sintered high-speed steel PM6-5-2.

The choice of these high-speed steels was dictated by their widespread use.

Cutting plates from conventional high-speed steel were made of billets, while slabs of high-speed sintered steel were made of flat steel. In the delivery state, both types of steel were softened.

After the blanks were prepared, the cutting boards were cut using the Classic 2 wire electrodes from Agiecut. In this way, the rectangular-shaped SNUN slabs with tool included angle ε_r = 90° were obtained. The sides of the plate were l = 9.525 ±0.08 mm, the plate thickness s = 3.18 mm and the distance between the top of the plate and the circle amounted to m = 1.644 ±0.13 mm. Plates of this geometry are destined for the treatment of steels for toughening steels, heat-resistant alloys, stainless steels and soft carbon steels. After cutting, the plate were grinded and polished and the roughness Ra = 0.1 μm was obtained.

The expected properties of HS6-5-2 and PM6-5-2 steels were obtained after heat treatment consisting of heat treatment quenching and tempering. In order to obtain a high hardness of approx. 65 HRC, the austenitization temperature was 1,150°C and the tempering temperature was 560°C. Properly selected tempering temperature allows secondary hardness to occur. Such blades retain the cutting ability at elevated temperatures near the blade tempering temperature [3, 4].

Fig. 1 shows the course of heat treatment. For this purpose, SECO/WARWLCK type vacuum furnace type 6.0VPT-4022/24IQHV with high vacuum system, was used.

Fig. 1. Course of heat treatment of high speed steel plates in SECO/WARWICK vacuum oven type 6.0VPT-4022/24IQHV: red line – temperature; aquamarine line – pressure

■ **Workpiece.** In the study, a 110 mm diameter and 350 mm length of shafts with a hardness of 30 HRC made of 40HM-T toughening steel was used.

Performance testing

The wear and durability of the cutting blades was investigated in the longitudinal turning of 40HM-T steel heat-treated to a hardness of 26 ±2 HRC. Interchangeable cutting inserts are fixed to the hR 110.16-220 holder. After insertion of the cutting insert in the holder, the following geometry is obtained: tool cutting edge angle κ_r = 75°, tool orthogonal clearance α_0 = 6°, tool included angle ε_r = 90°, tool orthogonal rake angle y_0 = -6°, tool cutting edge inclination λ_s = -6°.

a)

b)

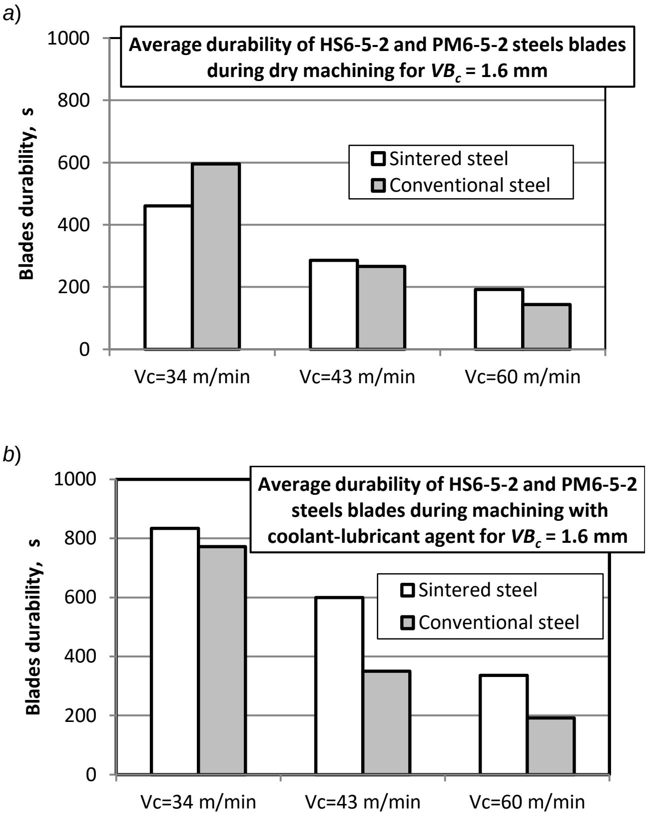


Fig. 2. Average cutting life of conventional and sintered high speed steels for 40HM-T steel processing: *a*) without coolant-lubricant, *b*) with coolant-lubricant

The following treatment conditions were adopted:

- cutting speed v_{c1} = 34 m/min, v_{c2} = 43 m/min, v_{c3} = 60 m/min,
- feed f = 0.204 mm/rev.
- cutting depth a_p = 0.75 mm,
- dry turning or in the presence of a lubricant in the form of a semi-synthetic emulsion Statoil Toolway S455N manufactured in Norway.

The subject of the study were cutting plates made of high-speed steel produced:

- conventionally (HS6-5-2),
- using powder metallurgy technology (PM6-5-2).

Based on the obtained wear curves, the cutting tool life was determined for the indicator of the wedge blunting VB_c = 1.6 mm. The results are shown in fig. 2.

Verification tests

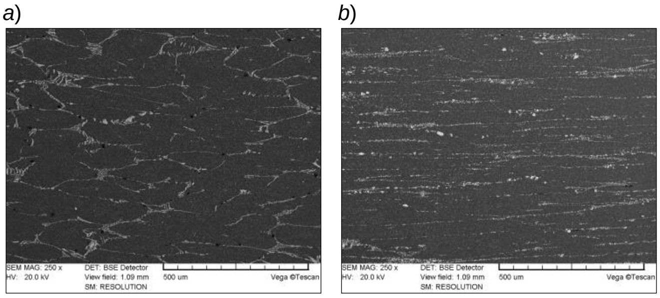
Verification tests were aimed at finding a different behavior of cutting inserts from conventional and sintered high-speed steels during steel turning to 40HM-T thermal improvement.

HM500 PICODENTOR Vickers hardness tester manufactured by Fischer was used to measure the hardness. As measured, the hardness of the sintered blades was slightly higher (5%) and corresponded to data by Sandvik [4].

The actual chemical composition of the cutting blades was checked using an X-ray fluorescence spectrometer – Fischerscope X-ray XDV-SDD Fisher. The average values of the content of the alloying elements did not differ significantly from those given in the relevant standards.

With the Tescan Vega 5135 scanning microscope, a series of cutting pictures of conventional and sintered high speed steel (fig. 3) were made.

a) b)



c)

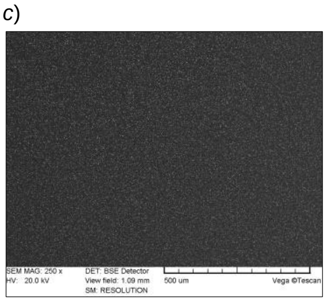


Fig. 3. BSE images of high speed steel blades:
a) conventional hot rolled,
b) conventional forged,
c) sintered

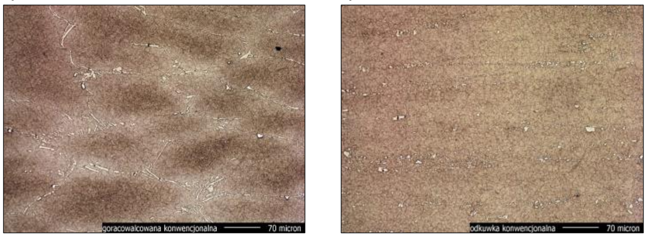
Photos have confirmed a much more uniform distribution of carbide in the matrix in the case of sintered steel.

In conventional high-speed steel purchased in Sweden, despite of good forging to break up the mesh of carbides, it was noticeable that the carbides are not evenly distributed and form band cluster locations, which is typical for high-speed steels subjected to rolling, stretch forging or stretch forging with indirect upsetting.

With the Neophot 32 metallographic microscope, a series of cutting pictures of conventional and sintered high-speed steels were made.

The images from the microscope show a significant difference in the surface morphology of conventional and sintered high-speed steels. The surface of the sintered steel produces from sharp-edged grains, but after rolling and forging the surface does not have such topography (the grains are "smooth" and form a more continuous surface), although both surfaces have a similar roughness *Ra* = 0.1 µm.

a) *b*)



c)

Fig. 4. Microscopic image of high-speed steel blade surfaces:
a) conventional rolled,
b) conventional forged,
c) sintered

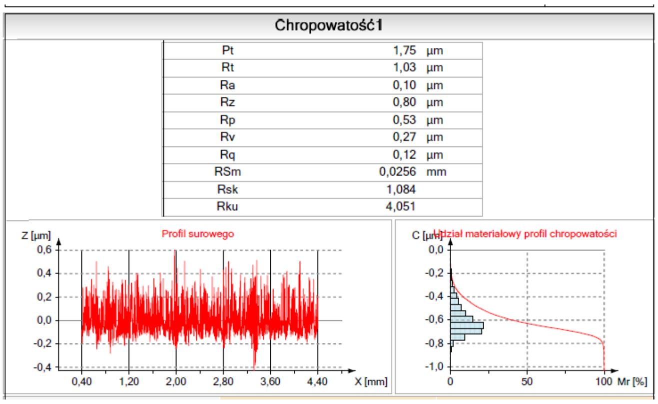


Fig. 5. Results of surface roughness measurements of conventional high-speed steel cutting inserts

Based on the measured surface topography parameters, the oil volume of the cutting surface area of the conventional forged, conventional hot-rolled and sintered high-speed steels was determined. The volume values of the surface oil volume were calculated from the following relationships:

$$V_o = R_{vk}\,(100 - M_{r2}) / 2000 \quad \mathrm{mm^3/cm^2}$$

where: V_o – surface oil volume, R_{vk} – surface valley, M_{r2} – material contribution to the lower boundary of the roughness profile core.

The R_{vk} parameter describes surface valleys. It is a measure of the capacity of the surface of the blade to maintain the grease in the existing cavities.

On the basis of the surface topographs, the following oil volume values for steel: sintered – 0.7206 mm^3/cm^2, conventional forged – 0.4237 mm^3/cm^2, conventional hot rolled – 0.2856 mm^3/cm^2 were obtained.

The test results show that, despite of identical roughness of cutting plates made of conventional and sintered high-speed steels of *Ra* = 0.1 µm, they differ considerably in terms of surface oil volume. The surface of sintered high-speed steel is approximately twice the oil volume of conventional forged high-speed steel and more than 2.5 times longer than hot-rolled conventional high-speed steel.

In order to perform a full interpretation of the functional properties of cutting blades during turning of toughening steels, additional dry and mitigated solid friction (in the presence of a lubricant) coefficients were measured. The conditions used during the tribological tests are shown in table I.

TABLE I. Tribological testing conditions

Material of the friction pair • sample	• conventional steel HS6-5-2 • sintered steel PM6-5-2
• counter-sample	steel 40HM-T
Peripheral speed	27.6 m/min
Load *F*	300/400/500/600 N
Time *t*	• 1200 s for dry friction • 2400 s for mixed friction
Friction (sliding method)	• dry • in the presence of emulsion

The average values of the dry and mitigated solid friction coefficients are given in table II.

TABLE II. Values of dry and mitigated solid friction coefficients

Load, N	Type of high speed steel		
	forged	rolled	sintered
Dry friction coefficient			
300	0.090	0.070	0.165
Mixed friction coefficient			
300	0.028	0.028	0.024
400	0.046	0.044	0.032
500	0.061	0.065	0.040
600	0.075	0.083	0.053

Tribological studies have confirmed the results of blade life during dry turning, the V_o values and the SE images from scanning microscope.

Conclusions

Sintered steel cutting blades exhibit slightly better technological properties (e.g. slightly higher average hardness and much more even distribution of carbides – no disadvantageous banding occurring during forging or rolling).

Cutting blades made of sintered high-speed steel during cutting with coolant-lubricant have been much more durable than conventional high-speed steel blades due to their larger surface volume, which contributes to a lower friction coefficient of the workpiece.

Under dry cutting conditions, cutting blades made of conventional high-speed steel were characterized by the smallest working speed (v_c = 34 m/min), higher durability than sintered steel due to more favorable surface morphology (lack of sharp edges, which influenced lower value of dry friction coefficient).

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REFERENCES

1. Kupczyk M.J. „Hierarchiczny układ twardości materiałów supertwardych stosowanych na ostrza skrawające”. Mechanik, Nr 8-9/2016, pp. 1030-1031.
2. Harlin P., Olsson M. „Abrasive wear resistance of starch consolidated and sintered high speed steel”. *Wear*. 267 (2009): pp. 1482–1489.
3. Kupczyk M.J. „*Inżynieria powierzchni – narzędzia skrawające*”. Poznań: Wydawnictwo Politechniki Poznańskiej, 2015.
4. Materiały firmy Sandvik.
5. Mesquita H.A., Barbosa C.A. „Evaluation of as-hipped PM High Speed Steel for production of large-diameter cutting tools”. *Mater. Sci. Forum.* 416–418 (2003): pp. 235–240.
6. Mesquita R.A., Barbosa C.A. „High-speed steels produced by conventional casting, spray forming and powder metallurgy”. *Mater. Sci. Forum.* 496–499 (2005): pp. 244–250.