Chip Formation Analysis in Finish Turning of Alloy and PM Hardened Tool Steels Using Coated and Uncoated PBCN Tools

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Abstract. The article presents analysis of influence of the type of cutting blades made of composite materials based on cubic boron nitride (CBN) on the selected parameters of chip formation process during finish turning of hardened tool steels: Sverker21® (SV21) alloy steel and Vanadis 4 EXTRA SuperClean® (V4) powder metallurgy steel. The analysis showed smaller value of the average chip thickening coefficient Kh and friction coefficient μ after machining of V4 powder metallurgy steel by all tested blades, and over the entire range of the studied tool feed rates, as compared with SV21 alloy steel. The value of the sliding angle Φ was found to be smaller for all studied variables during machining of SV21 alloy steel. The highest intensity of changes in the values of all studied parameters was found for uncoated blades 7025 during machining of V4 powder metallurgy steel.

Keywords: Hard machining · PCBN · Chip shape · PM · CBN coatings

1 Introduction

Environmentally clean technologies are used more and more often in the industrial manufacture of machine parts [1]. The aspects related to ecology in a broad sense that influence decisions regarding the choice of optimal production methods, as well as issues related to energy efficiency of the process and minimization of the amount of waste generated during the production process, directly affect the cost efficiency of the production process [2–4]. Powder metallurgy (P/M) is one of the most rapidly developing areas related to manufacturing technologies and finds application, in particular, in aviation, automotive, tool, and machine industries. Smaller energy consumption and formation of less quantity of waste result in cost efficiency of its use as compared to traditional methods of manufacturing semi-finished products [5, 6], and also comply with the accepted global trends of environment friendliness [7].

Steadily growing interest is observed in recent years in regard to using powder metallurgy tool steel in different industries, primarily due to the well-defined chemical

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composition and high purity of this type of material [8, 9]. According to Erden et al. [10], P/M steels are characterized by improved microstructure properties as compared to conventional steels from the point of view of the most uniform distribution of carbides in the base material, as well as finer grain size. Even greater opportunities for application of P/M steels are also seen due to their high mechanical strength and wear resistance.

The problem with components made of P/M steel is their low machinability [8]. Machinability is a concept that is difficult to define, and it means the set of measurable quantitative and qualitative parameters which analysis indicates feasibility of machining the material [11].

Machinability of P/M steel is regarded as low, comparable to machinability of forgings [8, 11]. This leads to more rapid wear of cutting tools, resulting in lower economic efficiency of machining of this group of materials. The two most debated aspects of low machinability of P/M steel relate to its low thermal conductivity due to porous structure, as well as repetitive micro-strikes of the blade against the material being processed—the lack of continuity of structure results in "quasi-interruption" of cutting. Low thermal conductivity of the processed material causes high temperatures in the cutting area, affecting the cutting blade and leading to its rapid wear. Micro-strikes of the blade against the processed material can cause cracks on the used protective coating and its rapid abrasive wear, resulting in increase of the final cost of manufactured finished parts [1]. According to Obikawa et al. [1], Salak et al. [12], this is one of the reasons for the still low popularity of these materials in production. The mentioned "quasi-interruption" of cutting can, however, be a reason for obtaining advantageous shapes of chips as compared to machining of traditional materials.

The described aspects necessitate the application for processing of P/M steel of tools with substantially high durability and resistance to abrasive wear. These include, first of all, cutting blades made of polycrystalline cubic boron nitride (PCBN), which show very high efficiency in terms of their high strength, resistance to oxidation [13, 14], good thermal conductivity, and resistance to temperatures up to 1500 °C [15]. They are also chemically neutral in regard to iron and iron alloys, and chemically stable at high temperatures [16], what makes possible to use them in highly efficient processing of P/M steel. Tools made of PCBN are divided into two groups: the so-called BL group with low percentage of crystalline boron nitride (CBN) in the blade material (40–70%), and the so-called HL group with high, above 70%, CBN content [14, 16].

Machining of "hard" materials, that is, having hardness above 45 HRC according to [17, 18], is performed using dedicated cutting tools, which include tools made of PCBN. "Hard machining" of materials entails, in particular, reducing the time for preparation and manufacturing process, as well as increasing the efficiency of machining, which results in noticeable economic benefits. Moreover, these benefits are further increased due to no need for use of metal working fluids during machining, what makes this type of machining environmentally friendly [2, 17].

The use of protective coatings on the cutting blades (PVD or CVD) allows more efficient machining of P/M steels [17, 19]. Tools with coating compared to tools without coating are characterized by higher permissible mechanical and thermal load, reduced friction between the tool and the chip, and increased wear resistance of the blade in a wide temperature range in the area of the contact of the cutting edge with the processed material [20].

The objective of this study was a comparative analysis of the effect of cutting blades made of PCBN with coating and without coating on the characteristics and selected parameters of chips after finish turning of improved tool steel: P/M steel and alloy steel.

2 Experimental Approach

2.1 Workpiece Materials

The following high-carbon tool steels were used in the research: P/M steel Vanadis® 4 Extra SuperClean (hereinafter: V4; C ~ 1.4%, Si ~ 0.4%, Mn ~ 0.4%, Cr ~ 4.7%, Mo ~ 3.5%, V ~ 3.7%), and alloy steel Sverker® 21 (hereinafter: SV21; C ~ 1.55%, Si ~ 0.3%, Mn ~ 0.4%, Cr ~ 11.3%, Mo ~ 0.8%, V ~ 0.8%). Samples in the form of rollers with dimensions $\phi = 50$ mm, $l = 20$ mm were subjected to the process of thermal improvement according to the requirements of the manufacturer of both steels, providing hardness 60 ± 2 HRC. In case of P/M steel V4, the resulting structure is characterized by the presence of small carbide particles uniformly distributed in the base (Fig. 1b). While for alloy steel SV21, the resulting structure is characterized by presence of large primary carbide particles and small secondary carbide particles formed during tempering (Fig. 1a).

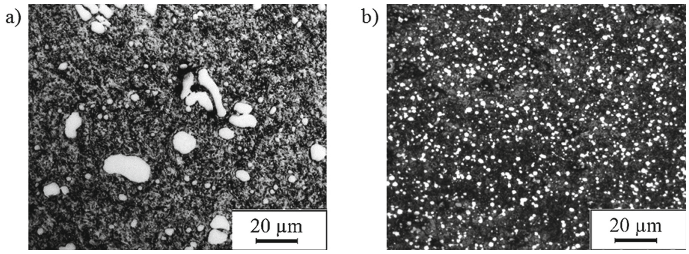

Fig. 1. Structure of heat-treated alloy steel SV21 (**a**) and P/M steel V4 (**b**).

2.2 Investigation Method and Tools

Machining was done with the following cutting parameters: $V_c = 160$ m/min, $a_p = 0.2$ mm, $f_{1-5} = 0.05; 0.075; 0.1; 0.125; 0.15$ mm/rev. The cutter PDJNR2020K11 ($\kappa_r = 93°$, $\alpha = 6°$, $\gamma = -6°$) with replaceable plates DNGA 110408 ($r_\varepsilon = 0.8$ mm) was used in the study. Dry machining was performed. Machining was done using new cutting blades for each variable. Characteristics of the cutting blades are presented in Table 1.

Scanning microscope JEOL JSM-6400 was used for metallographic studies. The chip thickness was measured ten times using ball micrometer with a measuring error of ±0.004 mm.

Table 1. Characteristics of the cutting blades taken for the study

Material type	CBN 7025	CBN 7015	CBN 020
Machining type	Continuous and semi interrupted	Continuous	Continuous
PCBN structure	60% CBN (1.3 μm) in ceramic binder	50% CBN in ceramic binder	50% CBN in ceramic binder
Coating	NONE	TiN	TiAlN
Chamfer	BN = 0.1 mm GB = 20°	BN = 0.1 mm GB = 30°	BN = 0.13 mm GB = 25°
Cutting edge radius (r_n)[a]	21.7 μm	17.17 μm	25.26 μm

[a]Average of 3 measurements

3 Results and Discussion

3.1 Chip Shape

Change of the chip shape during machining of alloy steel SV21 (a) and P/M steel V4 (b) depending on the type of cutting blade and feed rate f is shown in Fig. 2.

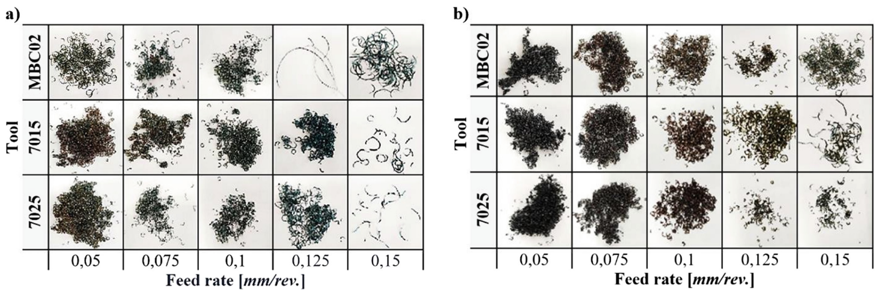

Fig. 2. Chip shape depending on the type of cutting blade and feed rate f for: **a** SV21; **b** V4.

Analysis of changes in chip characteristics during turning of both materials (Fig. 2) shows that the shape of chips is more advantageous in case of machining P/M steel V4. For this material, the range of feed rate f for which the chip is obtained as short spirals or separate short fragments is large and applies to all studied cutting blades at feed rate above 0.1 [mm/rev.]. Such chip shape, according to [21], is easy to remove from the cutting area and does not damage the surface of the machined material during machining. In case of alloy steel SV21, advantageous shape of chips was obtained during machining using the blade MBC020 at feed rate $f = 0.05$ and 0.075 [mm/rev.], and using the blades 7015 and 7025 during machining at feed rate $f = 0.15$ [mm/rev.]. The least advantageous shape of chips in the form of long spirals, strips, or long straight segments was obtained mainly during machining of P/M steel V4 at feed rate below 0.1 [mm/rev.]

and during machining of alloy steel SV21 using the blades 7015 and 7025 at feed rate below 0.15 [mm/rev.], and for the blade MBC020 during machining at feed rate above 0.075 [mm/rev.]. Such chip shape can damage the machined surface, resulting in increase of surface roughness and change of performance properties.

3.2 Characteristics of the Chip Formation Zone

The main parameters describing the process of chip formation include:

- Average chip thickening coefficient K_h, determining the speed of the chip along the surface of the blade advance,
- Sliding angle Φ determining the changes occurring on the surface of the material and tool wear,
- Coefficient of friction μ on the rake face determining, in particular, temperature in the cutting area.

Figure 3, 4 and 5 shows in succession the values of coefficient K_h, sliding angle Φ, and coefficient μ during machining of alloy steel SV21 (a) and P/M steel V4 (b).

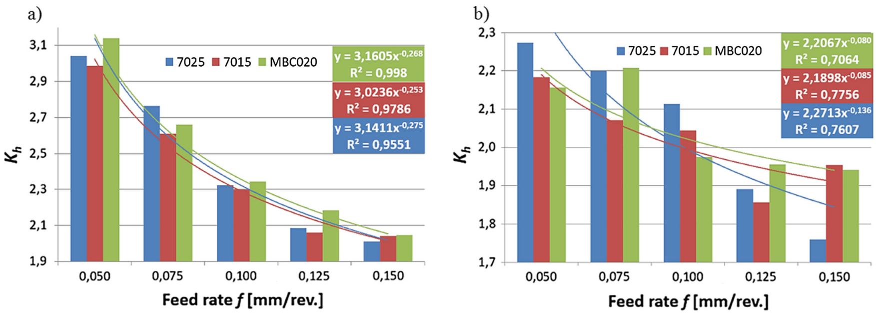

Fig. 3. Values of average chip thickening coefficient K_h depending on the cutting blade and feed rate f for: **a** SV21; **b** V4.

The smallest value of average chip thickening coefficient K_h over the entire range of studied feed rates f and for all studied cutting blades was obtained during machining of P/M steel V4 (Fig. 3b). Depending on the value of feed rate f, it was, at the average, by 10–26% smaller than during machining of alloy steel Sv21 (Fig. 3a). The smallest change in the intensity of the analyzed parameter depending on the increase of feed rate f for P/M steel V4 was obtained during turning by blades 7015 coated with TiN, the largest change—during machining by uncoated blades 7025. For SV21 material, the intensity of change in the value of this parameter depending on increase of feed rate f was similar for all types of blades.

The smallest value of sliding angle Φ over the entire range of studied feed rates f and for all studied types of the cutting blade was obtained for machining of alloy steel SV21 (Fig. 4a). Depending on feed rate f, it was, at the average, by 6–24% smaller as compared to machining of P/M steel V4 (Fig. 4b). The smallest change in the intensity

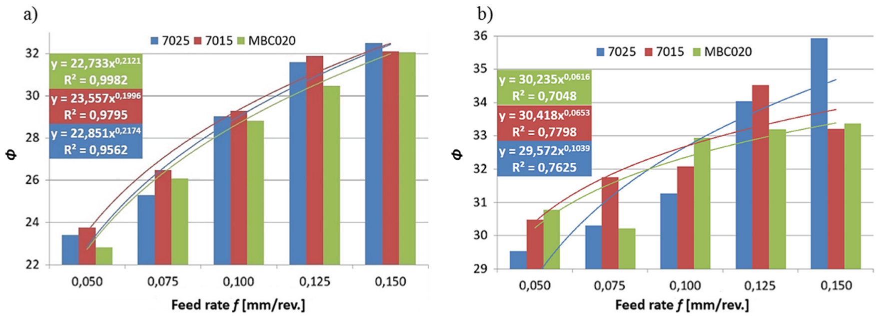

Fig. 4. Value of sliding angle Φ depending on the type of the cutting blade and feed rate f for: **a** SV21; **b** V4.

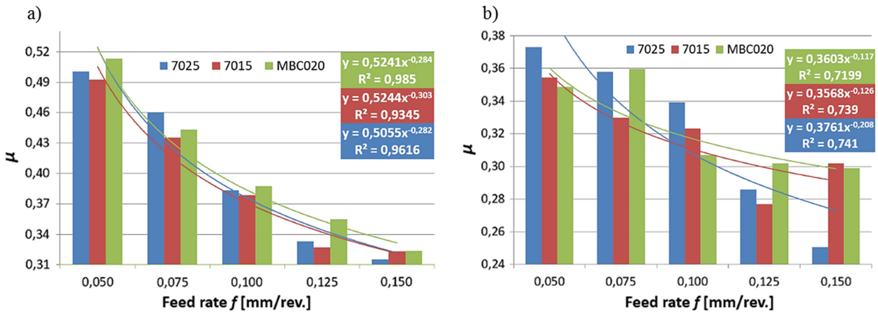

Fig. 5. Value of the friction coefficient μ depending on the type of the cutting blade and feed rate f for: **a** SV21; **b** V4.

of the analyzed parameter depending on the increase of feed rate f for P/M steel V4 was obtained during turning by blades MBC020 coated with TiAlN, the largest change—during machining by uncoated blades 7025. For SV21 material, the intensity of change in the value of this parameter depending on increase of feed rate f was similar for all types of blades.

The smallest value of friction coefficient μ over the entire range of studied feed rates f and for all studied cutting blades was obtained during machining of P/M steel V4 (Fig. 5b). Depending on the value of feed rate f, it was, at the average, by 10–28% smaller than during machining of alloy steel SV21 (Fig. 5a). The smallest change in the intensity of the analyzed parameter depending on the increase of feed rate f for P/M steel V4 was obtained during turning by blades 7015 coated with TiN, the largest change—during machining by uncoated blades 7025. For SV21 material, the intensity of change in the value of this parameter depending on increase of feed rate f was similar for all types of blades.

4 Conclusions

Basing on the analysis performed, the authors formulated the following conclusions:

- The most advantageous shape of chips is obtained during machining of P/M steel V4 at feed rate f in the range of 0.1–0.15 [mm/rev.] regardless of the type of cutting blade used.
- The value of average chip thickening coefficient K_{h} and friction coefficient μ over the entire range of studied feed rate and for all types of studied cutting blades was the smallest during machining of P/M steel V4.
- The smallest value of sliding angle Φ over the entire range of studied feed rate and for all types of studied cutting blades was obtained during machining of alloy steel SV21.
- The largest intensity of change of the values of studied parameters was obtained for uncoated blades 7025 during machining of P/M steel V4.

References

1. Obikawa T, Ohno T, Yamaguchi M et al (2012) Wear characteristics of cutting tools in turning of sintered steel under different lubrication conditions. Key Eng Mater 523–524:13–18
2. Shvartsburg LE, Butrimova EV, Yagolnitser OV (2017) Energy efficiency and ecological safety of shaping technological processes. Procedia Eng 206:1009–1014. https://doi.org/10.1016/j.proeng.2017.10.586
3. Shvartsburg L, Yagolnitser O, Butrimova E (2018) Integrated approach to providing for environmental friendliness and safety of the technological processes. MATEC Web Conf 224:01090. https://doi.org/10.1051/matecconf/201822401090
4. Zaborowski T, Shvartsburg L, Ivanova N, Ryabov S (2018) Ecoenergetic cutting techniques. Manag Prod Eng Rev 9(4):70–75. https://doi.org/10.24425/119547
5. Senthur Prabu S, Choudhary A et al (2014) Experimental study od dry sliding wear behaviour of sintered Fe-C-W P/M low alloy steels. Procedia Mater Sci 5:809–816
6. Nizam Khan M, Narayan S, Rajeshkannan A (2019) Influence of process parameters on workability characteristics of sintered Al and Al-Cu composites during cold deformation. AIMS Mater Sci 6(3):441–453
7. Shvartsburg LE, Butrimova EV, Yagolnitser OV (2017) Quantitative evaluation of the effectiveness of best available technologies of form-shaping. MATEC Web Conf 129:01027. https://doi.org/10.1051/matecconf/201712901027
8. M'Saoubi R, Czotscher T et al (2014) Machinability of powder steels using PCBN inserts. Procedia CIRP 14:83–88
9. Selvakumar N, Mohan Raj A, Narayanasamy R (2012) Experimental investigation on workability and strain hardening behaviour of Fe-C-0.5 Mn sintered composites. Mater Des 41:349–357
10. Erden MA, Gunduz S et al (2017) Wear behaviour of sintered steels obtained using powder metallurgy method. Mechanika 23(4):574–580
11. Alizadeh E (2008) Factors influencing the machinability of sintered steels. Powder Metall Met Ceram 47(5):304–315
12. Salak A, Vasilko K et al (2006) New short time face turning method for testing the machinability of PM steels. J Mater Process Technol 176:62–69

13. Slipchenko K, Turkevich V et al (2018) Superhard pcBN materials with chromium compounds as a binder. Procedia Manuf 25:322–329
14. Ociepa M, Jenek M, Feldshtein E (2018) On the wear comparative analysis of cutting tools made of composite materials based on polycrystalline cubic boron nitride when finish turning of AISI D2 (X153CrMoV12) steel. J Superhard Mater 40(6):396–401
15. Arsecularatne J, Zhang L, Montross C (2005) Wear and tool life of tungsten carbide, PCBN and PCD cutting tools. Int J Mach Tools Manuf 46:482–491
16. Slipchenko K, Petrusha I et al (2018) Investigation of the mechanical properties and cutting performance of cBN-based cutting tools with Cr3C2 binder phase. Procedia CIRP 72:1433–1438
17. Sivaraman V, Prakash S (2017) Recent developments in turning hardened steels—a review. In: IOP conference series: materials science and engineering, pp 197
18. Ociepa M, Jenek M, Leksycki K (2019) The phenomenon of material side flow during finish turning of EN X153CrMoV12 hardened steel with tools based on polycrystalline cubic boron nitride. J Superhard Mater 41(4):265–271
19. Uhlmann E, Braeuer G et al (2004) CBN coatings on cutting tools. Res Dev Germany: Ann German Acad Soc Prod Eng 11:45–48
20. Zlamal T, Mrkvica I, Szotkowski T, Malotova S (2019) The influence of the surface treatment of PVD coating on its quality and wear resistant. Coatings 9(7):439
21. Maruda RW, Krolczyk GM et al (2016) Chip formation zone analysis during the turning of austenitic stainless steel 316L under MQCL cooling condition. Procedia Eng 149:297–304