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Short Communication

The effect of chamfer angle of polycrystalline cubic boron nitride cutting tool on the cutting forces and the tool stresses in finishing hard turning of AISI 52100 steel

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Abstract

Cutting experiments and finite element analysis (FEA) using ANSYS software have been carried out in this paper in order to investigate the effects of chamfer angle on the cutting forces and the cutting tool stresses, principal and von Mises stress, of polycrystalline cubic boron nitride (PCBN) cutting tools in finishing hard turning of AISI 52100 bearing steel. The obtained cutting force measurement tests and FEA results showed that the chamfer angle has a great influence on the cutting forces and tool stresses, especially in the passive force and von Mises stress distribution. From the present work, it can be drawn that critical chamfer angle is 20° in finishing hard turning of AISI 52100 bearing steel

Keywords: Finite element analysis; Finishing hard turning; Tool stress; Chamfer angle; PCBN

1. Introduction

In conjunction with the development of new cutting tool materials, such as polycrystalline cubic boron nitride (PCBN), the precision and rigidity of machine tools have been improved to allow hard turning, in which the hardness of work piece up to 60–65 HRC in automotive and bearing industries and super alloys, to become a viable process. The cost of PCBN insert is somewhat higher than either cemented carbide or ceramic tools, but the tool life may be 5–7 times that of a ceramic tool [1].

Hard turning differs from conventional turning of softer materials in several key ways. Because the material is harder, specific cutting forces are larger than in conventional turning, and thus the engagement between cutting tools and the work piece must be limited. Because of that the small cutting depths required, cutting takes place on the nose radius of cutting tools, and the tools are prepared with chamfered or honed edges to provide a stronger edge geometry that is less prone to premature fracture. Cutting on a chamfered or honed edge equates to a large negative effective rake angle, while neutral or positive rake angles are typical in conventional machining. The large negative rake angles yield increased cutting forces compared to machining with positive rake tools, and also induce larger compressive loads on the machined surface [2].

Theile et al. [3,4], presented research results of an experimental investigation of effects of cutting edge geometry and work piece hardness on residual stresses in finish hard turning of AISI 52100 steel. They showed that large hone radius tools produce more compressive stresses. Özel [5] investigated the influence of edge geometry in CBN tools with respect to stress and temperature development through finite element simulations in hard turning. Zhou et al. [6] presented a study of the effect of

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Nomenclature

r_ε	nose radius (mm)	σ	normal stress (MPa)
α	flank angle (°)	τ	shear stress (MPa)
$l_{\gamma n}$	chamfer width (mm)	N_r	normal force on rake face (N)
γ_n	chamfer angle (°)	N_f	normal force on flank face (N)
r_h	honing edge radius (mm)	T_r	shear force on rake face (N)
F_C	primary cutting force (N)	T_f	shear force on flank face (N)
F_p	passive force (N)		

chamfer angle on tool wear of PCBN cutting tool in the super finishing hard turning and investigated the correlation between cutting force, tool wear and tool life. Yen et al. [7], investigated the effects of edge preparation of the cutting tool (round/hone edge and T-land/chamfer edge) upon chip formation, cutting forces, and process variables (temperature, stress, and strain) in orthogonal cutting as determined with finite element method (FEM) simulations.

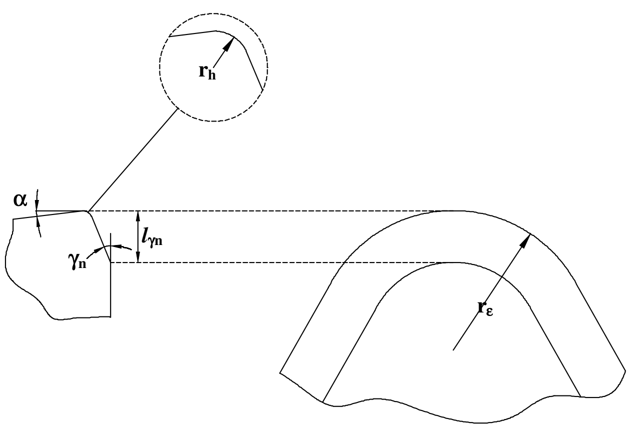

Fig. 1. Geometry parameters of PCBN insert used in the tests.

Table 1
Test parameters

Work piece material	AISI 52100 (60 HRC)
Dimensions (mm)	Outer diameter 120 and inner diameter 100
Cutting tool	PCBN (DCMW 11T308)
Nose radius, r_ε (mm)	0.8
Flank angle α (°)	7
Chamfer width, $l_{\gamma n}$ (mm)	0.1
Chamfer angle, γ_n (°)	0, 10, 20, 30
Honing edge radius, r_h (mm)	0.01
Tool holder	SDJCL 2020K11
Cutting parameters	
Cutting speed (m/min)	150
Feed rate (mm/rev)	0.03
Depth of cut (mm)	0.05

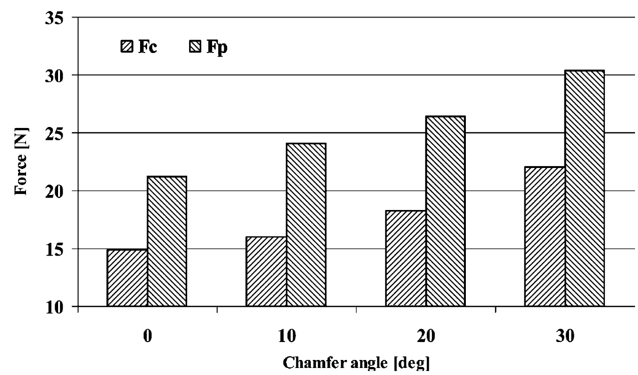

Fig. 2. Correlation of cutting forces and chamfer angle.

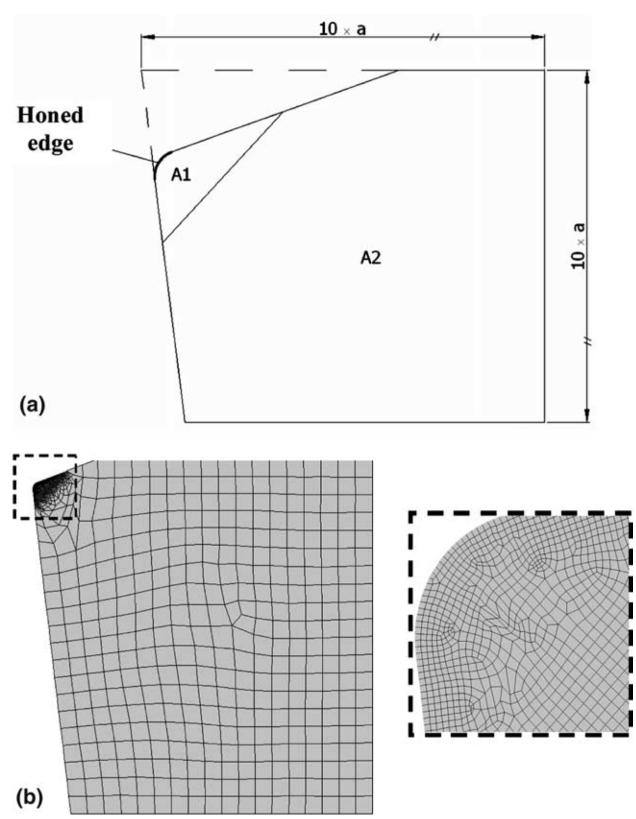

Fig. 3. PCBN insert model for FEA.

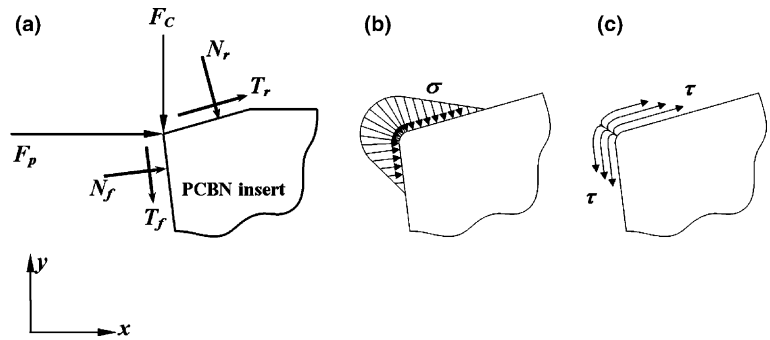

Fig. 4. Normal and tangential load distributions on PCBN insert.

In this study, the effects of chamfer angle on the cutting forces and the cutting tool stresses of PCBN cutting tool in finishing hard turning of AISI 52100 steel were investigated. Because of that AISI 52100 steel selected as the work piece material for all testing due to its widespread use in the bearing industry.

2. Experimental study

In cutting experiments, PCBN inserts have geometry as illustrated in Fig. 1 were used. Insert shape is 55° diagonal and have ISO designation, DCMW with nose radius (r_ε) 0.8 mm, flank angle (α) 7° and chamfer width

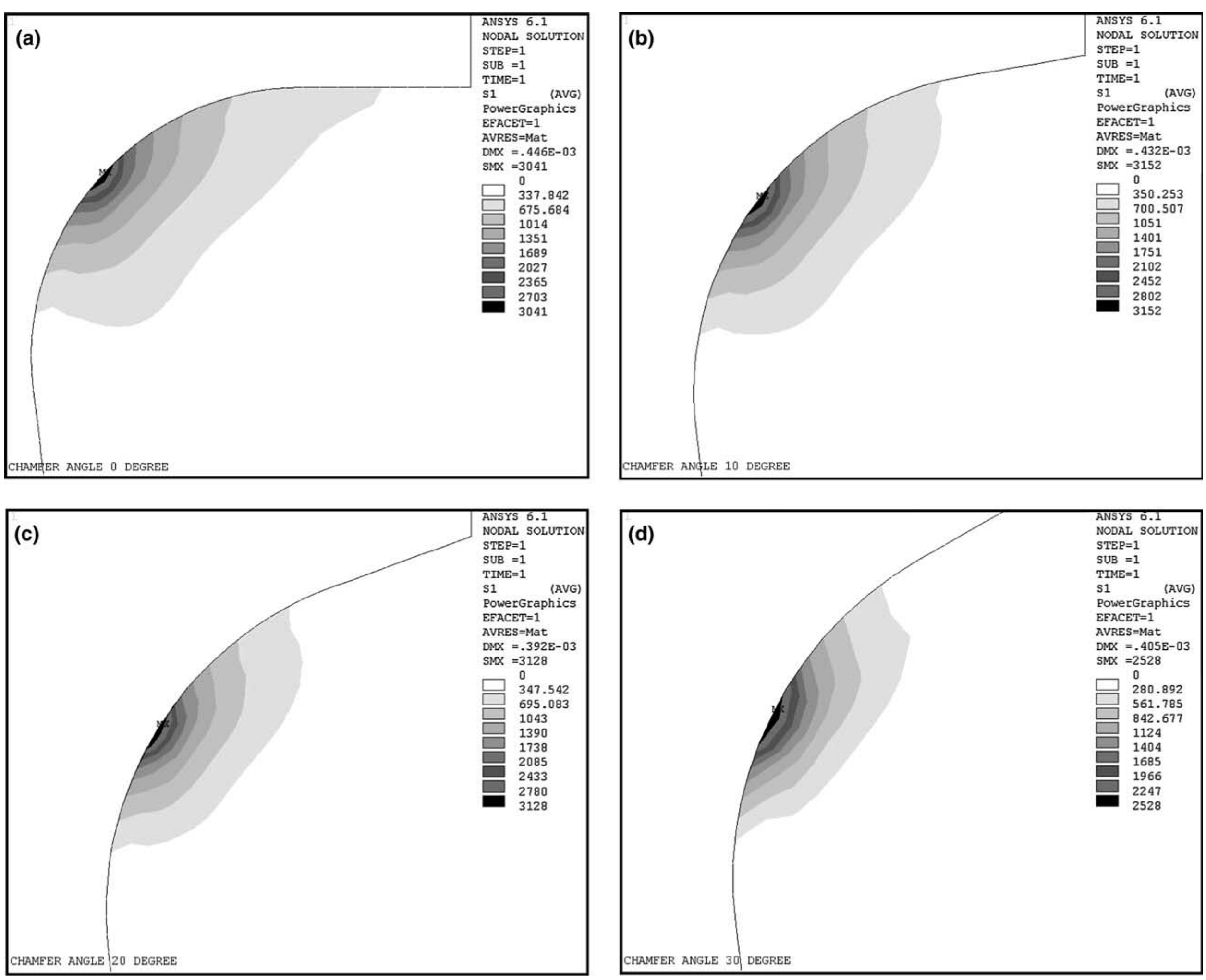

Fig. 5. Maximum principal stress distributions on PCBN insert.

($l_{\gamma n}$) 0.1 mm. Four values of chamfer angle (γ_n) 0°, 10°, 20° and 30° with honing edge radius (r_h) 0.01 mm were used for cutting experiments. The inserts mounted on a tool holder with an ISO designation, SDJCL 2020K11.

AISI 52100 bearing steel with outer diameter 120 mm, inner diameter 100 mm and hardness of 60 HRC was used as the work piece material all tests. All turning operations carried out on a Johnford T35 CNC Lathe. Cutting speed was selected as 150 m/min and due to finishing operation feed rate and depth of cut were used with 0.03 mm/rev and 0.05 mm, respectively (Table 1). Tests were carried out until the tool flank wear reached 0.2 mm. Cutting forces were measured using Kistler 9257B dynamometer and the mean values of stationary forces during the whole cutting process were used in the finite element analysis (FEA).

3. Cutting forces

Because of very small feed rate and depth of cut were used in finishing hard turning of AISI 52100 steel, cutting area is concentrated on a small area in the front tip of the cutting edge, or in the area of chamfer zone. According to the cutting force measurement test results, cutting forces increase with the increase of the chamfer angle, as shown Fig. 2. As all cutting conditions are identical, exclude the chamfer angle, the increase in the cutting forces is mainly due to forces contributed by chamfer zone. The passive forces (F_p) in the passive direction are higher than the primary cutting forces (F_C) in cutting direction and increase more rapidly with the increase in chamfer angle.

4. Finite element analysis

Stress distributions on the cutting tool was analysed by finite element method using ANSYS 6.1 software. The cutting force measurement test results were used in analysis. In order to reduce computational time, the PCBN insert was modelled 10 times of depth of cut ($10 \times a$, mm), as shown Fig. 3(a). In modelling process,

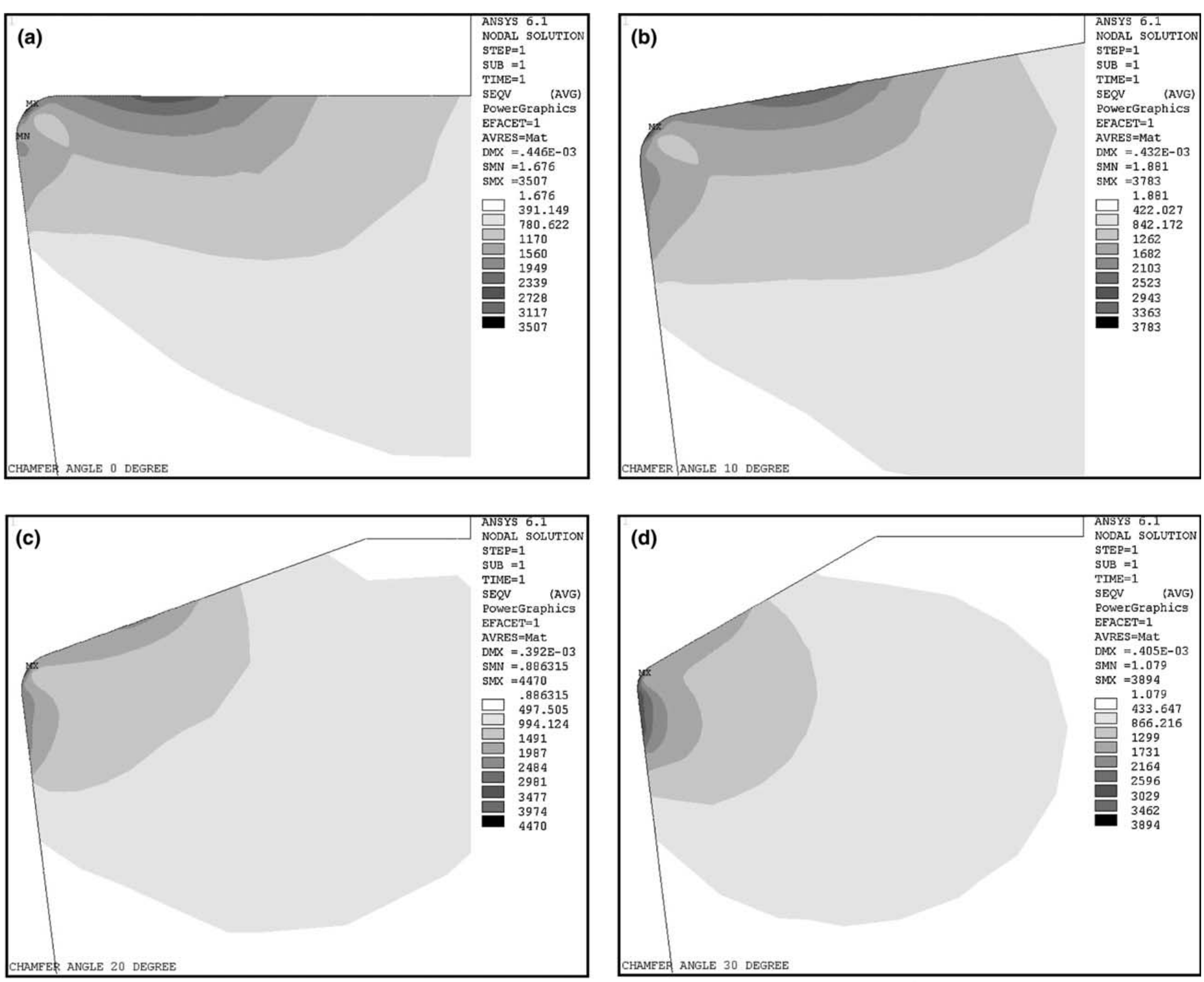

Fig. 6. von Mises stress distributions on PCBN insert.

at first, insert's model has been built using Mechanical Desktop 6 Power Pack software depend on the cutting tool's geometrical properties (flank angle, chamfer angle etc.) and then, it has exported to ANSYS in "*.iges*" format. For areas A1 and A2, and in order to apply the primary cutting force and passive force on the rake face and flank face as a normal and tangential load, 8-node quadrilateral PLANE82 and SURF153 was selected as the element type, respectively. In the insert model, honed edge on area A1 was divided 25 elements and in other section (area A2), element size was selected as 0.025 mm (Fig. 3(b)).

4.1. Load distribution on PCBN insert

The primary cutting force and passive force effect as normal and tangential load on the rake face and flank face (Fig. 4(a)). According to the primary cutting force, the passive force, the chamfer angle and the flank angle, normal and tangential load components on the rake face and flank face as follows:

$$N_r = F_C \cos\gamma_n - F_p \sin\gamma_n, \quad (1)$$

$$N_f = F_p \cos\alpha - F_C \sin\alpha, \quad (2)$$

$$T_r = F_p \cos\gamma_n - F_C \sin\gamma_n, \quad (3)$$

$$T_f = F_C \cos\alpha - F_p \sin\alpha. \quad (4)$$

Normal and tangential load components calculated by Eqs. (1)–(4) were applied to the rake face and flank face as triangular normal and shear stress distribution, as shown Fig. 4(b) and (c). Elastic modulus and Poisson's ratio for the PCBN insert is 588 GPa and 0.17, respectively [8].

4.2. Principal and von Mises stress distribution on PCBN insert

According to loading conditions in Fig. 4(a) and (b), FEA was carried out for chamfer angle 0°, 10°, 20° and 30°. von Mises stresses (or equivalent stress) was used to as failure criteria in analyses. Obtained maximum principal stress and von Mises stress distributions by ANSYS have been seen in Fig. 5 and 6, respectively.

The obtained results from FEA indicate that maximum principal stress (S1, in Fig. 7) acting on cutting edge with chamfer angle 30° has the smallest value, but on the other von Mises stress (SEQV, in Fig. 7) with 20° has the biggest value compared to other chamfer angles. Fig. 7 indicates that the variation of maximum principal stresses is very small. Generally the FEA results show that chamfer angle has a great influence on von Mises stress than the maximum principal stress (Fig. 7).

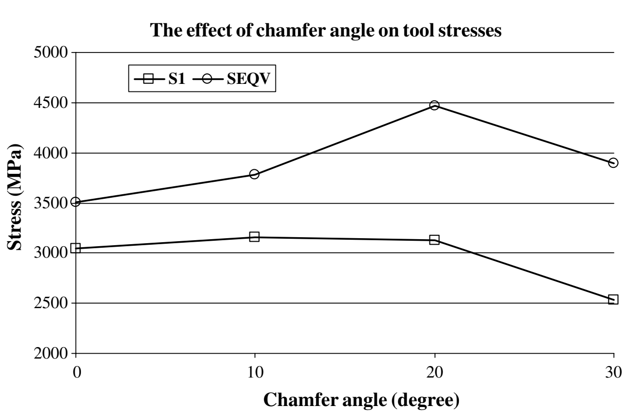

Fig. 7. The effect of chamfer angle on the cutting tool stresses.

5. Conclusions

Cutting experiments and FE analysis have been carried out in this study in order to investigate the effects of chamfer angle on the tool stresses of PCBN cutting tool in finishing hard turning of AISI 52100 bearing steel. The chamfer angle has a great influence on the cutting force and tool stresses. All cutting forces' components increase with an increase of the chamfer angles, especially in the level of passive force.

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Acknowledgements

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