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The Impact of Cutting Tool Materials on Cutting Force

M.A. Kamely, M.Y. Noordin

***Abstract*—**A judicious choice of insert material, tool geometry and cutting conditions can make hard turning produce better surfaces than grinding. In the present study, an attempt has been made to investigate the effect of cutting tool materials on cutting forces (feed force, thrust force and cutting force) in finish hard turning of AISI D2 cold work tool steel. In conclusion of the results obtained with a constant depth of cut and feed rate, it is important to note that cutting force is directly affected by cutting tool material.

***Keywords*—**hard turning, cutting force, cutting tool materials, mixed ceramic, cbn

I. INTRODUCTION

NEWLY developed cutting tool grades are intended to permit versatile use in roughing and finishing applications for a broader spectrum of workpiece materials. The new improvements and developments in coating technology have produced new and more wear resistant tool materials. Coated tools used for metal cutting must have a combination of abrasion wear resistance and chemical stability at high temperature to meet the demands of the application. The use of coated cutting tools to machine various materials now represents the state-of-the art technology. Manufacturing Industries are constantly focus for lower cost solutions with reduced lead time and better surface quality in order to maintain their competitiveness and efficiency.Cutting force is important in machining because they provide distinctive signature of the mechanics of machining. It plays a primary role in determining the energy consumed and machining power requirements of process, tool and workpiece deflections. In hard turning, because of the high hardness of the workpiece, it results in higher cutting forces than usual and this reduces the performance of the cutting tool. Lalwani et. al [1] investigated the influence of cutting parameters on cutting forces and surface roughness in finish hard turning of MDN250 steel. It shows that cutting forces and surface roughness do not vary much with experimental cutting speed in the range of 55–93 m/min.

Tool wear was found not only can reduce the part geometry accuracy but also increases the cutting forces drastically. The change in cutting forces also causes instability in the tool motion and contributes to more inaccuracy [2]. In conclusion of the results obtained with a constant cutting speed, it is important to note that a progressive degradation of the surface roughness corresponds to the rise in the specific cutting forces [3]. These loads are caused by thermal phenomena in the high speed cutting process. According to Molinari and Nouari [4], high temperatures can cause physical chemical phenomena which exacerbate tool wear at the rake. The tool material composition and properties are crucial to the behaviour of machining forces, which in turn affect tool life and surface roughness [5]. Therefore, performance of cutting tools is directly affected by process parameters such as forces. Traditionally, most ferrous metal parts are rough turned, heat-treated and finished by grinding. In recent years, hard turning which uses a single point cutting tool has replaced grinding to some extent for such applications. Cutting tools used for hard turning are typically hard and prepared with chamfered and/or honed edges to provide a stronger edge that is less prone to premature fracture. Cutting tools are insistently subject to pressure and opposing stresses during cutting while machining metallic and nonmetallic materials.Cutting performance such as surface accuracy, tool wear, tool breakage, cutting temperature, self-excited and forced vibrations, etc. correlates strongly with cutting forces [6]. There have been many studies concerning the effect of cutting parameters and tool geometry on the cutting forces. The influence of machining parameters such as cutting speed, feed rate, etc. for different materials [7,8,9,10]. All cutting operations require tool materials that can withstand the extreme conditions produced during machining. There are primarily three problems that all cutting tools face: wear at the cutting edge, heat generated during the cutting process, and thermo mechanical shock. Characteristics that allow tool materials to stand up during the cutting process include hardness, toughness, wear resistance, and chemical stability. Cutting force is important in machining because they provide distinctive signature of the mechanics of machining. It plays a primary role in determining the energy consumed and machining power requirements of process, tool and workpiece deflections. In hard turning, because of the high hardness of the workpiece, it results in higher cutting forces than usual and this reduces the performance of the cutting tool.

II. EXPERIMENTAL DETAILS

Commercially available AISI D2 bars of diameter 90 mm and 200 mm length, hardened to a hardness of 60 HRC were used as a workpiece material. Typical composition of this special alloy steel is: 1.55% C, 0.4% Mn, 11.6% Cr, 0.8% Mo, 0.9% V and 0.3% Si. Before conducting the machining tests, a thin layer of 0.5 mm was machined with a new cutting edge

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in order to remove the uneven surfaces due to the previous operation and to ensure consistency.Cutting test was carried out on a 9.2 KW Harrison M500 lathe machine with induction-hardened bedway under dry conditions. The spindle rotation of the machine spindle ranges from 31 to 1600 rpm and 18 different spindle rotational speeds are selectable. The feed rates ranges from 0.04 to 0.71 mm/rev and 15 different feed rates are selectable. Three components of cutting force were measured throughout the cut. The tool forces were measured with a three-component force dynamometer (Kistler 9265B), mounted on the turret of the lathe. Measurements were made in the second measurement range of the device (of 0 to 1000 N). Cutting forces and their amplitudes were measured with an accuracy of ± 0.040 N, ± 0.021N and ± 0.010 N, for the Fc, Ff and Fr: constituents of the resultant force (G), respectively.

TABLE I
SPECIFICATIONS OF THE CUTTING TOOLS, CUTTING CONDITIONS AND TOOL HOLDER USED IN THIS STUDY

Cutting tool : CBN and Mixed ceramic
Tool holder : MCLNL 1616H 12
Insert : CNGA120408T01020
Nose radius : 0.8 mm
Chamfer angle : 20°
End cutting edge angle : 5°
Side rake angle :−5°
Side cutting edge angle :−5°
Rake angle :−5°
Inclination angle : 5°
Cutting speed : 100, 140, 200 m/min
Feed : 0.06mm/rev
Depth of cut : 0.4 mm
Coolant : dry

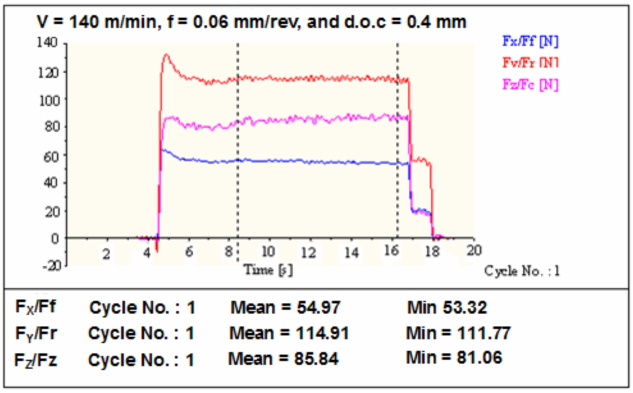
TABLE II
TYPICAL CUTTING TOOLS PHYSICAL PROPERTIES

	CBN-Low	CBN-High	Mixed Ceramic
Density (g/cm^3)	4.37	3.34	4.26
Thermal conductivity (W/mK)	44	100	24
Hardness (HV)	2549	4589	1800

III. RESULTS AND DISCUSSION

A. Cutting Force Measurements

The three cutting force namely tangential force (Fc), radial force (Fr) and feed force (Ff) were measured during hard turning of AISI D2 cold work tool steel of 60 HRC. In each experiment, a fresh cutting tool was used and the experiments were repeated twice at each cutting condition in order to keep experimental error at a minimum. Figure 1 shows that each force trace exhibits an initial overshoot which corresponds to the entry of the cutting tool into the workpiece and the subsequent, relatively constant force corresponds to the steady state force. The steady state force condition is maintained until the tool exits from the workpiece.



F_X/Ff Cycle No. : 1 Mean = 54.97 Min 53.32
F_Y/Fr Cycle No. : 1 Mean = 114.91 Min = 111.77
F_Z/Fz Cycle No. : 1 Mean = 85.84 Min = 81.06

Fig. 1 Sample output from Dynoware software

Figures 2 to 4 shows the relationship between each of the three component forces and cutting speed for all cutting tools used. These results were average values at the early stage of the turning process during the initial cutting process where the depth of cut is 0.4 mm and feed is 0.06 mm/rev. All three component forces shows similar trends where the use of CBN-Low coated with TiAIN obtained the higher value while the mixed ceramic tools coated with TiN obtained the lower value. The lower cutting forces obtained by mixed ceramic explains why this cutting tool has higher tool life compared to the other cutting tools. This lower cutting force results in lowest shear work and friction work. In contrast CBN-Low coated with TiAIN obtained the largest of the three force components for all cutting speeds. This can be related to the low tool life compared to CBN-Low coated with TiN/AI_2O_3/TiCN and CBN-High coated with TiN/AI_2O_3/TiCN. Figure 2 shows the evolution of Ff (feed forces) to cutting speed at the earlier lifetime of cutting tools. At low cutting speed, there is no significant different in values between the uncoated and coated CBN. Mixed ceramic obtained a lower value (35.89 N). At cutting speed of 140 m/min and 200 m/min, it shows some variations where CBN-Low coated with TiAIN still keep the higher value (177.6 N). However, CBN-High coated with TiN/AI_2O_3/TiCN shows a different behaviour where from lower cutting speed to medium cutting speed it shows a decreased in value but increased at high cutting speed.

At low cutting speed, there is no significant difference in value between the uncoated CBN-High and CBN-High coated with TiN/AI_2O_3/TiCN. This is due to both insert has a same composition and the influence of temperature at low cutting speed is not significance. CBN-Low coated with TiAIN obtained higher value (165.12 N) whereas the mixed ceramic obtained a lower value (97.77 N). This shows that there is significant influence of thermal conductivity of the cutting tools and coatings. Combining effect of the low thermal conductivity of TiN coating and mixed ceramic cutting tools compared to CBN with TiAIN coating increased localized temperatures in the tool-workpiece which decreases the workpiece material strength and thus decreased its cutting force. At medium cutting speed of 140 m/min, radial force of uncoated CBN-High increased but decreased as the cutting speed increased to 200 m/min. Coated CBN-Low and CBN-High with the same coating TiN/AI_2O_3/TiCN showed the increased trend.

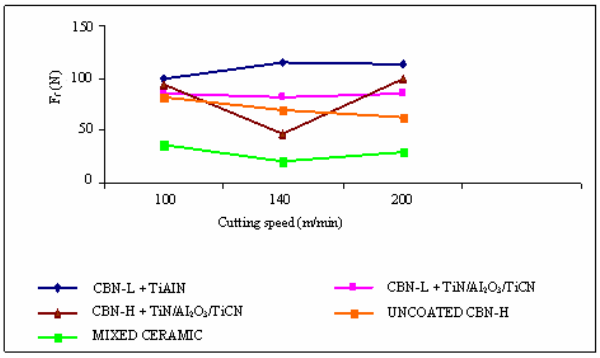


Fig. 2 Feed force and cutting speed relationship

The increased in F_r at high cutting speed explain why the tool life of CBN-High coated with TiN/AI_2O_3/TiCN has a similar tool life of uncoated CBN-High at a particular cutting condition. Once again mixed ceramic coated with TiN obtained the lowers value. The effect of cutting speed on the tangential force (Fc) is shown in Figure 4. Tests were conducted at cutting speeds in the range from 100 to 200 m/min with new sharp cutting tool. At low cutting speed, higher tangential force was obtained with CBN-Low coated with TiAIN, followed by CBN-High coated with TiN/AI_2O_3/TiCN and uncoated CBN-High. Mixed ceramic and CBN-Low coated with TiN/AI_2O_3/TiCN obtained lower value. As the cutting speed increased CBN-Low coated with TiAIN and uncoated CBN-High show slightly decreased in tangential force. In the other hand the use of CBN-High coated with TiN/AI_2O_3/TiCN and mixed ceramic show an increased in tangential force from medium to high cutting speeds. Mixed ceramic obtained the lowers value at medium and high cutting speed.

The general trends for higher cutting forces at all cutting speeds and TiAIN coating were observed. On the other hand lower cutting forces at all cutting speeds was obtained with mixed ceramic (AI_2O_3 + TiCN). From the graph it is observed that Fc decreased with the increase in cutting speed. This can be attributed to the drop in the shear strength in the flow zone as the tool temperatures rises as well as to the decrease in contact area due to the more intense deformation at the shear plane [11]. The three forces do not change much with increasing cutting speeds from 100 to 200 m/min, which agrees with the experimental observations reported in the literature that forces do not change with cutting speed within the recommended cutting speed range [12]. Radial trust force were found to be the largest force and this is an agreement with the result by [13] in his study using CBN cutting tools when finish hard turning using workpiece material GB 699-88 55 steel (45-55 HRC) who found that the radial thrust force became the largest among the three cutting force components.

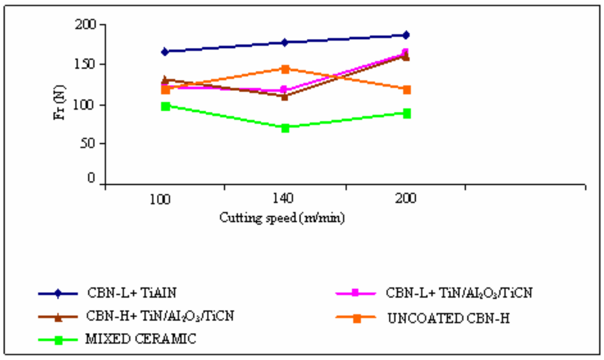


Fig. 3 Radial force and cutting speed relationship

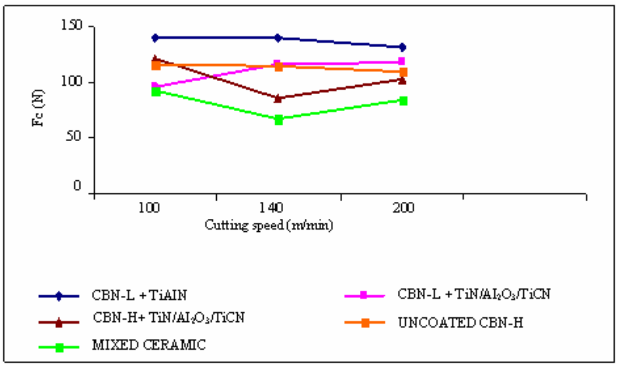


Fig. 4 Tangential force and cutting speed relationship

IV. CONCLUSION

Force difference is observed when using the same type of tools, but with different thermal properties. For example, under the same cutting condition there is force difference between using low CBN content tools coated with TiAIN and CBN-Low coated with TiN/AI_2O_3/TiCN. This was the case when turning with uncoated CBN-High and CBN-High coated with TiN/AI_2O_3/TiCN. This can be due to the influence of material composition and thermal properties of the tool. The material properties of the cutting tools have a greater influence on the feed force and thrust force than on the principal force. The radial force was found to become the largest of the three force components at all cutting conditions. Results also shows that the decreased of the three component forces by using mixed ceramic (AI_2O_3 + TiCN) coated with TiN compared to the CBN cutting tools for all cutting conditions.

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