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A NOTE ON THE INFLUENCE OF CUTTING SPEED ON CUTTING FORCES AND SURFACE FINISH DURING PRECISION TURNING OF AISI 1045 STEEL

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ABSTRACT:
The miniaturization of components and systems is advancing steadily in many areas of engineering. Micro-machining is becoming an important manufacture technology due to the increasing demand for miniaturized products in recent years. The purpose of this study is to investigate the influence of cutting speed on cutting forces and surface roughness when dry precision turning AISI 1045 steel using uncoated and coated cemented carbide tools. The results indicated that, in general, the turning force components tend to decrease or remain practically stable as cutting speed increased. The specific cutting force presents a similar behaviour as long as feed rate is kept unaltered. The surface roughness produced by the two cutting tools was significantly affected by cutting speed within the range tested.
KEYWORDS:
Precision turning, micro-turning, cutting forces surface roughness, AISI 1045 steel

1. INTRODUCTION

The miniaturization of components and systems is advancing steadily in many areas of engineering. Micro-machining is becoming an important manufacture technology due to the increasing demand for miniaturized products in recent years. This trend is mainly driven by the needs for appreciable reductions in size and weight, better efficiency regarding power consumption and higher portability in commercial and non-commercial applications. Many industrial sectors require micro-components, for instance, telecommunication, biomedical and micro-intelligent technology. Micro-machining by shearing is capable of attaining high dimensional and geometric accuracy, surface finish quality and sub-surface integrity at reasonably low costs. Thus, it should be the first choice amongst various manufacturing processes. Furthermore, conventional machining processes such as turning, milling and grinding have already been well established [1, 5, 6, 11].

Micro-machining imposes high demands on machine behaviour since the workpiece contour is determined both by the technological parameters and by the geometric characteristics of the machine. Most of the experimental research in micro-machining has been conducted on either conventional precision machine tools or dedicated machine tools built by researchers. Conventional precision machine tools have been greatly improved with respect to motion accuracy, stiffness, and capability. In general, micro-machining is performed on precision machine tools with conventional dimensions. According Nakazawa

[10], in order to achieve high precision, a small machining unit is a necessary condition. The machining unit, by definition, must be the minimum controllable amount of material that can be removed. Furthermore, a small machining unit minimizes deflections in both the workpiece and the machine tool due to the extremely low cutting forces involved.

However, the work size and the required power for processing are comparatively lower for micro-machining [2, 4, 11]. Transferring the knowledge acquired on traditional machining operations to micro-processes is critical when considering both the efficient development of practical micro-processes and the understanding of the limitations of its application. The material removal using carbide tools can produce a number of feature shapes and sizes. The micro-cutting process is challenging, however, the experiences learned from traditional processes provide a valuable resource for future micro-machining research [2]. In general, the cutting mechanism in macro-machining is mainly shearing of the material ahead of the tool tip and forming a chip. Micro-machining relies on more complicated mechanisms depending on the level of the size effect, which is the dramatic increase in material shear flow stress as the uncut chip thickness decreases. Therefore, characteristics such as grain boundaries, crystal defects, and impurities play a critical role during plastic deformation and chip formation.

The study of the dynamics of the cutting forces and surface roughness in any machining operation is critical for the proper process planning and control and for the optimization of the cutting conditions aiming minimal production costs and times. The cutting force analysis plays a vital role in studying the various characteristics of a machining process, for instance, the dynamic stability, positioning accuracy of the tool, roughness of the machined surface and form errors of the machined component. On the other hand, surface roughness is predominantly considered as the most important feature of engineering surfaces due to its crucial influence on the mechanical and physical properties of a machined part.

The effects of the cutting parameters on cutting forces and surface roughness have been extensively investigated. Kang et al. [7] presented a cutting force model and predicted the cutting force in micro-end milling of aluminium with a 200 μm diameter end mill. Their model took into account the tool edge radius effect, which is a relevant characteristic of the micro cutting mechanism. Lima et al. [9] studied the machinability of hardened steels at different levels of hardness and using a range of cutting tool materials. More specifically, the machinability of hardened AISI 4340 high strength low alloy steel and AISI D2 cold work tool steel was investigated. The results indicated that when turning AISI 4340 steel the surface roughness of the machined parts was improved as cutting speed was elevated and deteriorated with feed rate. Depth of cut presented little effect on the surface roughness values. Kim et al. [8] showed analytically the differences in cutting forces produced by traditional machining and micro-machining processes. In the macro-model, shear takes place along a shear plane, whereas in micro-machining the shear stress rises continuously around the cutting edge. The orthogonal micro-cutting force analytical model considered the elastic recovery of the workpiece along the clearance face of the tool and the plowing effect as a result of the tool edge radius action. Davim [3] studied the influence of the cutting parameters on the surface finish obtained by turning. An experimental planning based on the Taguchi technique was undertaken aiming to establish a correlation between cutting speed, feed rate and depth of cut with the roughness evaluating parameters R_a and R_t. The results indicated that cutting possesses larger influence on the roughness values, followed by feed rate.

The purpose of this study is to investigate the influence of cutting speed on the cutting forces and surface roughness when dry precision turning AISI 1045 medium carbon steel using uncoated and coated cemented carbide tools.

2. EXPERIMENTAL PROCEDURE

The experimental procedure was conducted with the purpose to study the influence of cutting speed (v_c) on machining forces (cutting, feed and radial forces) and surface roughness (R_a and R_t parameters). The workpiece material used was AISI 1045 medium carbon steel. Bars with 20 mm diameter and 5mm cutting length were turned with ISO grade

K15 uncoated cemented carbide without chip breaker (geometry code DCMW 11T3 04) and grade P25 coated (Al_2O_3 on the rake face + TiCN on the flank face) cemented carbide coded DCMT 11T3 04PF. The tools were mounted on a tool holder with geometry SDJCL 2020 K11, resulting in the cutting tool angles indicated in Table 1. Tool wear was considered negligible throughout the experimental program.

TABLE 1. Cutting tools geometry

Tool	Rake angle γ_n (º)	Clearance angle α_n (º)	Cutting edge angle χ_r (º)	Cutting edge inclination angle λ_s (º)	Tool nose radius r_ε (mm)
Coated ISO P25 carbide DCMT 11T3 04 PF	6	7	93	0	0.4
Uncoated ISO K15 carbide DCMW 11T3 04 H13A	0	7	93	0	0.4

Dry turning tests were performed on a Kingsbury MHP 50 CNC lathe with 18 kW spindle power and a maximum spindle speed of 4500 rpm. Preliminary tests were undertaken in order to check the accuracy of the machine tool. A Kistler® piezoelectric dynamometer model 9121 with a load amplifier connected to a computer was used for the acquisition of the cutting force (F_c), feed force (F_f) and radial force (F_r). The set up for measuring the turning forces is shown in Figure 1. Kistler Dynoware® software was used for data acquisition. The equipment, provided with a static and dynamic calibration record presents a working range from 0 to 600 N to F_c and from 0 to 300 N to F_f and F_r. Moreover, the dynamometer possesses natural frequency of 1kHz, linearity lower than 1% and sensitivity of -3,8 pC/N for F_c and -7,9 pC/N for F_f and F_r.

The specific cutting force (K_s) was calculated with the obtained results by cutting force for following Eq. (1):

$$K_S = \frac{Fc}{S} \tag{1}$$

Where: Ks = Specific cutting force (N/mm²)
F_c = Cutting force (N)
S = Shear plane area (mm²)

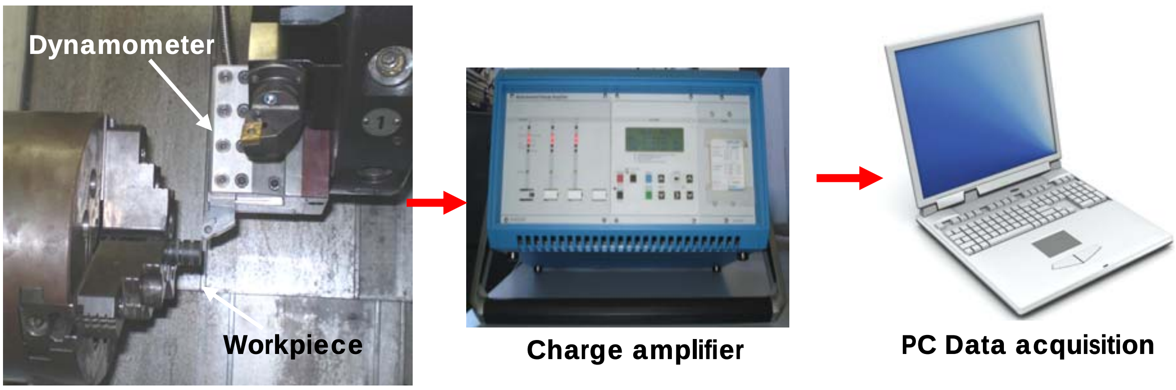


FIGURE 1. Set up for measuring three component turning forces

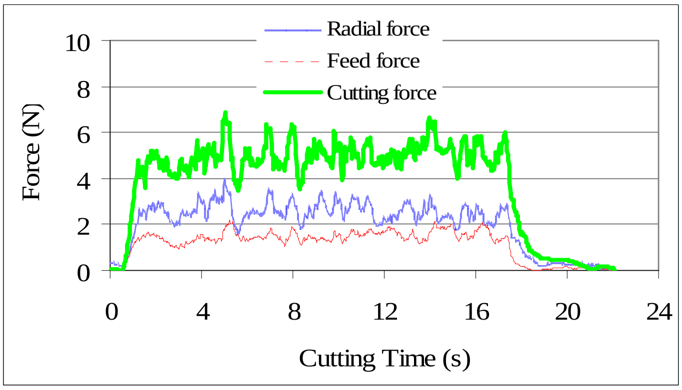
The surface roughness parameters R_a and R_t were assessed in accordance to ISO 4287/1 standard using a Hommeltester T1000 profilometer connected to a computer with Hommeltester Turbo-Datawin software. An average of six measurements was used to represent the surface roughness under each cutting condition.

The experimental work was conducted at constant values of feed rate (f = 10 μm/rev) and depth of cut (a_p= 100 μm). The cutting speed (v_c) values tested were: 50, 100, 150 and 200 m/min. Owing to the fact that the experimental work was carried out on a conventional CNC lathe, preliminary tests were conducted in order to check the accuracy of the machine tool. These tests indicated a diameter repeatability of ±1μm (measured with a digital micrometer with 1μm resolution).

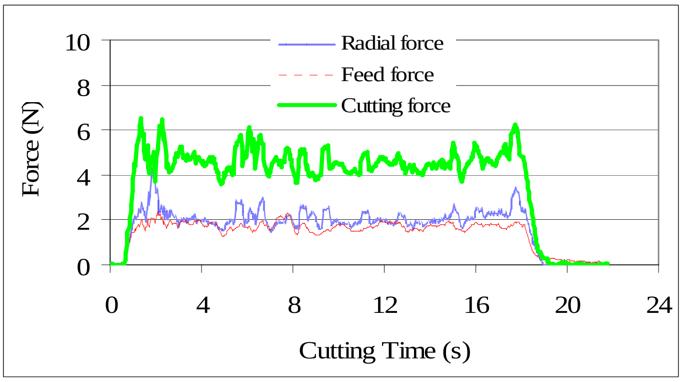
3. RESULTS AND DISCUSSION

Figure 2 illustrates typical results for the three forces (F_c - F_f - F_r) for each tool material as cutting time elapses, at a cutting speed of 100 m/min. In general, a distinct behaviour can be observed comparing both tool materials. Due to absence of tool wear, the forces remain unaltered during the test. It can be noticed that, in general, the cutting force presents the highest values, followed by the radial force and finally by the feed force.

The principal differences between the tool materials are related to tool material/coating, the rake angle value and the presence of a chip breaker. The coated cemented carbide tool was expected to provide lower force values owing to both its positive rake face angle (γ_n= 6º) and the presence of the MTCVD TiCN film, however, this was not the case. Although not represented all the graphs, the behaviour of forces for different cutting speeds values (50, 150 and 200 m/min) was similar to that recorded at v_c=100 m/min.



a) K15 uncoated carbide tool



b) P25 coated carbide tool

FIGURE 2. Turning forces evolution when cutting of AISI 1045 steel at v_c = 100 m/min, f = 10 μm/rev and a_p = 100 μm using uncoated (K15) and coated (P25) cemented carbide tools.

Figure 3 presents the evolution of the average cutting, feed and radial forces and specific cutting force as a function of cutting speed for both uncoated and coated carbide tools. The forces tend to decrease or remain steady with the increase of cutting speed. Figure 3d) shows the influence of cutting speed on the specific cutting force (K_s), where it can be seen that, similarly to the cutting force, the K_s value was not significantly affected by cutting speed. The surface texture of a machined part can substantially affect its performance, especially when the component is subjected to alternated stresses or to corrosive environments. Although many factors affect the surface texture of a machined part, the cutting parameters and tool nose radius have a significant influence on the surface roughness for a given machine tool and workpiece set-up. Figure 4 shows the evolution of surface roughness as a function of cutting speed and tool material, where Figure 4a) presents the results concerning the R_a values for the two tools materials and Figure 4b) shows these findings related to R_t parameter. The uncoated K15 tool provided lower R_a and R_t values at highest cutting speeds, whereas the coated P25 tool obtained better performance in lower speeds. In general, the surface roughness produced was considerably affected by the four cutting speeds, tending to improve as cutting speed was elevated.

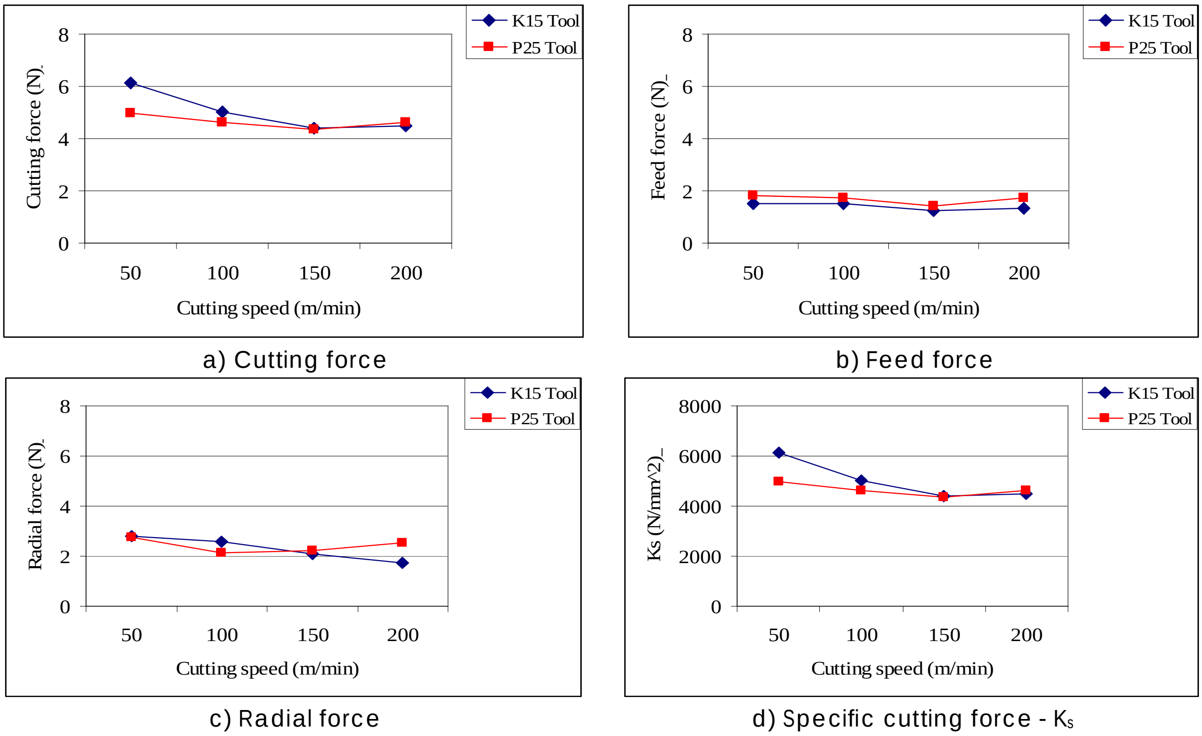


FIGURE 3. Effect of cutting speed on turning forces and specific cutting force when machining of AISI 1045 steel with f = 10 μm/rev and a_p = 100 μm using uncoated (K15) and coated (P25) cemented carbide tools.

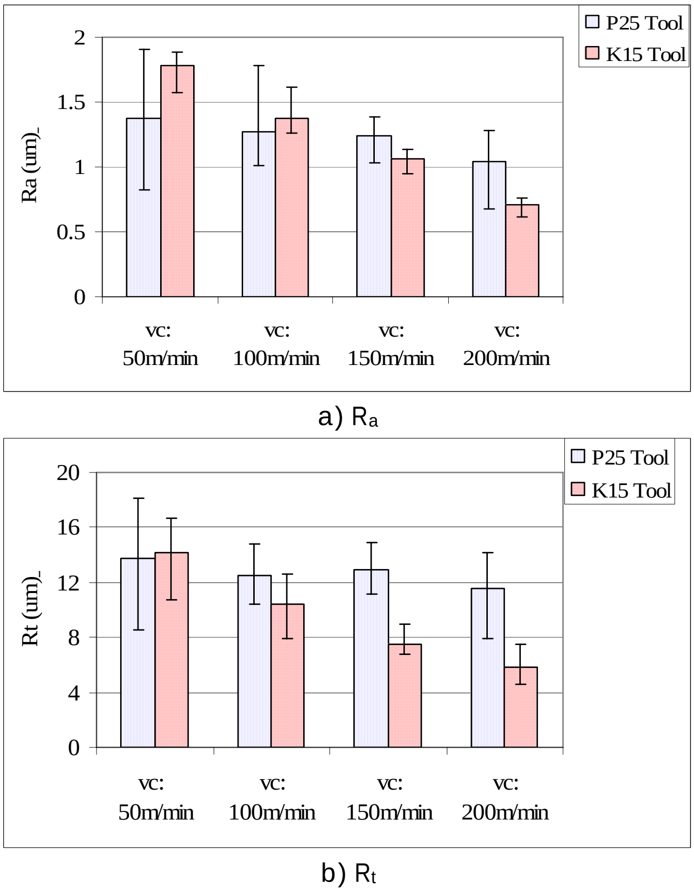


FIGURE 4. Surface roughness when turning of AISI 1045 steel with f = 10 μm/rev and a_p = 100 μm as a function of cutting speed and tool material.

4. CONCLUSIONS

Based on the experimental results presented, the following conclusions can be draw from precision turning of AISI 1045 steel at various cutting speeds with uncoated and coated cemented carbide tools:

- In general, the cutting force presented the highest values, followed by the radial force and finally by the feed force. The machining forces tend to decrease or remain unaltered as cutting speed was elevated;
- The specific cutting force was reduced as cutting speed increased;
- The surface finish produced was significantly affected by the four tested cutting speeds, tending to decrease as the speed was increased.

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