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Surface Roughness in High Feed Turning with Wiper Insert

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Abstract. Surface roughness in a turning operation is affected by a great number of factors. Two of the most important factors are feed rate and the size of the corner radius. Surface roughness can be roughly determined to increase with the square of the feed rate and decrease with increased size of the corner radius. However, wiper insert geometries changed this relationship with the capability to generate good surface roughness at relatively higher feeds by transferring small part of the round insert edges into the straight cutting edges of the pointed insert. The principle of how wiper inserts behave different from conventional inserts as to the effects on the surface roughness is explored in this paper. Experimental study of the surface roughness produced in the turning of hardened mild steels using coated carbide tools with both conventional and wiper inserts is conducted. The test results prove the effectiveness of the wiper inserts in providing excellent surface roughness. The results also suggest that the use of the wiper insert is an effective way that significantly increases cutting efficiency without changing the machined surface roughness in high feed turning operations.

Introduction

Machining operations are utilized in view of the better surface roughness that could be achieved by it compared to other manufacturing operations. Thus it is important to know what could be the effective surface roughness that can be achieved in a machining operation. The surface roughness in a turning operation is affected by a great number of factors such as: (1) the geometry of the cutting tool; (2) the cutting process parameters, such as speed, feed rate and depth of cut; (3) application of cutting fluids or not; (4) workpiece and tool materials characteristics; (5) rigidity of the machine tool and the consequent vibrations [1].

The major two of the above important factors are feed rate and the size of the tool nose radius. Surface roughness can be roughly determined to increase with the square of the feed rate and decrease with increased size of the tool nose radius. A large feed will give poorer surface roughness but shorter cutting times while a large nose radius will generate a better surface roughness and provide more strength. However, an excessively large nose radius can lead to vibration tendencies, unsatisfactory chipbreaking and shorter tool-life because of insufficient cutting edge engagement [2, 3]. Therefore, the size of the insert nose radius and the feed may be limited in a practical operation. To upset this relationship – to achieve a better surface roughness at a higher feed, the wiper technology for the indexable insert nose-radius has been developed [4].

The wiper inserts are a recent development in edge preparations, which is designed with modified nose radii with larger corners or flatter forms into the straight minor cutting edge to wipe the surface smooth. The corner or flatter form of the wiper insert indicates that it takes off more material with the back of the insert as it cuts (wipes). As a rule of thumb, the surface finish produced by the wiper insert is twice as good as it would be with the conventional insert for a given feed rate. Alternately, the feed rate can be approximately doubled while maintaining a similar surface finish [5, 6]. However, little work has been done to theoretically evaluate the mechanism of the wiper inserts effect on the surface roughness. The remainder of the paper is organized as follows. Section 2 theoretically explores the wiper geometry effects on surface roughness, while Section 3 gives an experimental study of the wiper geometry effects on surface roughness produced in the turning of hardened mild steel. Finally, conclusions will be presented in Section 4.

Wiper Insert Effect on Theoretical Surface Roughness

Under ideal conditions the relevent tool cutting part profile will be reproduced on the component to form the machined surface which will exhibit the characteristic feed marks. A graphical representation of the feed mark is shown in Fig.1 for conventional insert and wiper insert. It is noted that the cusp areas are reproduced on the turned surafce by the turning inserts. The theoretical surface roughness can be expressed in terms of standard indices such as the peak to valley height R_t (R_{tw} and R_{tc} for wiper insert and conventional insert, respectively). The peak to valley height R_t is dependent on the tool nose radius r_ε, the minor cutting edge angle $\kappa_r^{'}$, and the feed rate f. It is apparent that R_{tc} will additionally be dependent on the modified nose raius r_w for wiper insert.

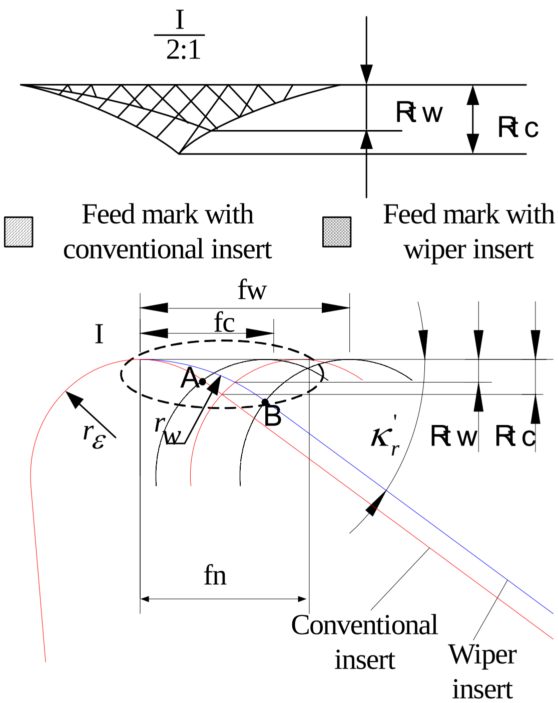


Fig.1 Feed marks for conventional insert and wiper insert

In Fig.1, point A is the intersection between conventional insert nose and straight minor cutting edge, while point B is the intersection between wiper nose and straight minor cutting edge. f_c and f_w are the feed rates when the major cutting edge transverses the points A and B, respectively. From the geometry of Fig.1,

$$f_c = 2 r_\varepsilon \sin\kappa_r^{'} \tag{1}$$

$$f_w = r_w \sin\kappa_r^{'} + \sqrt{r_\varepsilon^2 - [r_\varepsilon - r_w(1-\cos\kappa_r^{'})]^2} \tag{2}$$

Derivation of the peak to valley height R_t requires classification of the feed marks into three cases depending on the feed rate f_n applied in turning operations – small feed, transitional feed, and large feed. The relationships among peak to valley heights R_{tw} as well as R_{tc}, tool nose radius r_ε, the minor cutting edge angle $\kappa_r^{'}$, the applied feed rate f_n, and the wiper nose raius r_w are given as follows for these three cases with wiper insert and conventional insert,respectively.

Case of small feed ($f_c > f_n$):

$$\sqrt{r_\varepsilon^2 - (r_\varepsilon - R_{tw})^2} + \sqrt{r_w^2 - (r_w - R_{tw})^2} = f_n \quad \text{(for wiper insert)} \tag{3}$$

$$R_{tc} = r_\varepsilon - \sqrt{r_\varepsilon^2 - f_n^2/4} \quad \text{(for conventional insert).} \tag{4}$$

Case of transitional feed ($f_c < f_n < f_w$):

$$\sqrt{r_\varepsilon^2 - (r_\varepsilon - R_{tw})^2} + \sqrt{r_w^2 - (r_w - R_{tw})^2} = f_n \text{ (for wiper insert).} \tag{5}$$

$$\sqrt{r_\varepsilon^2 - (r_\varepsilon - R_{tc})^2} + (r_\varepsilon - R_{tc})\tan\kappa_r^{'} + \frac{r_\varepsilon}{\sin\kappa_r^{'}} - \frac{r_\varepsilon - R_{tc}}{\sin\kappa_r^{'}\cos\kappa_r^{'}} = f_n \text{ (for conventional insert).} \tag{6}$$

Case of large feed ($f_n > f_w$):

$$\sqrt{r_\varepsilon^2 - (r_\varepsilon - R_{tw})^2} + (r_w - R_{tw})\tan\kappa_r^{'} + \frac{r_w}{\sin\kappa_r^{'}} - \frac{r_w - R_{tw}}{\sin\kappa_r^{'}\cos\kappa_r^{'}} = f_n \text{ (for wiper insert).} \tag{7}$$

In the case of large feed, the relationship among peak to valley heights R_{tc} with conventional insert, tool nose radius r_ε, the minor cutting edge angle $\kappa_r^{'}$, and the applied feed rate f_n is the same as in the case of transitional feed, which can also be expressed using Eq. (6).

Turning Tests for Insert Geometry Effect on Surface Roughness

Turning Experiment Setup. The workpiece material was 45# mild steel (0.45% carbide) barstock with a hardness of 30 HRC~35 HRC. The Kennametal coated carbide grade KC9110 (MT-CVD-TiCN/Al_2O_3/TiN, Fig.2) with conventional insert geometry CNMG120408FN and wiper insert geometry CNMG120408FW were used. The corner radius was 0.8 mm for both insert types. The wiper radius r_w was 5 mm for the wiper insert. The toolholder PCLNR2020K12 was selected. The minor cutting edge angle $\kappa_r^{'}$ was 5° as shown in Fig.3.

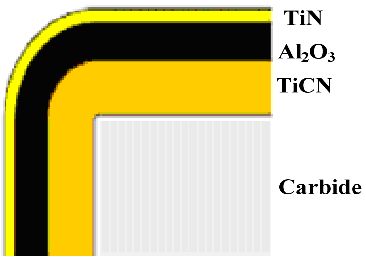


Fig.2 Kennametal coated carbide tool

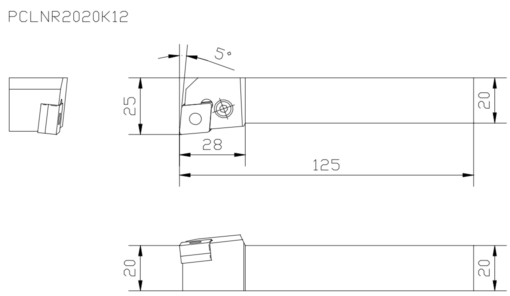


Fig.3 Kennametal toolholder PCLNR2020K12

Tests were conducted at six feed rates 0.1, 0.2, 0.3, 0.4, 0.5, and 0.6 mm/r. These feeds were in line with those covering small and transitional feed rate cases that affect the peak to valley height. Each test was repeated three times. All tests were performed at fixed cutting speed 170 m/min and depth of cut 0.5 mm. In order to measure the peak-to-valley roughness of the turned parts, a surface profiler tester with a resolution of ±8μm/1nm was employed.

Comparisons for Theoretical and Experimental Results of Surface Roughness. For these selected toolholder and insert geometries, f_c and f_w are 0.1395 mm and 0.6092 mm by calculating with Eq. 1 and Eq. 2, repepectively.

Fig.4 shows that the feed rate affects the theroretical surface roughness R_t for the selected tool geometries and cutting conditions. The values of R_t are directly calculated using Eq. 3 ~ Eq. 7, depending on the insert type and feed rate f_n applied. Both insert types present the same trend of surface roughness increasing with the feed rate. It is noted, for example, that the turned surface roughness 11.41 μm at feed rate of 0.3 mm/r with conventional insert is more than twofold of the surface roughness 4.6 μm with wiper insert. For the surface roughness 8.2 μm, the feed rate required is 0.23 mm/r for conventional insert, while 0.4 mm/r for wiper insert.

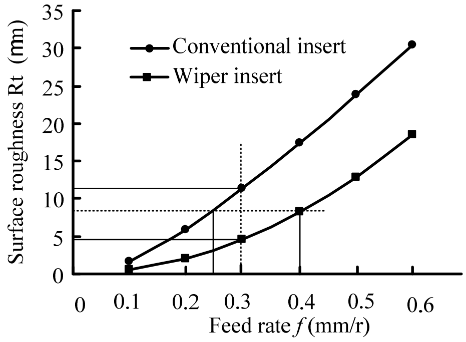
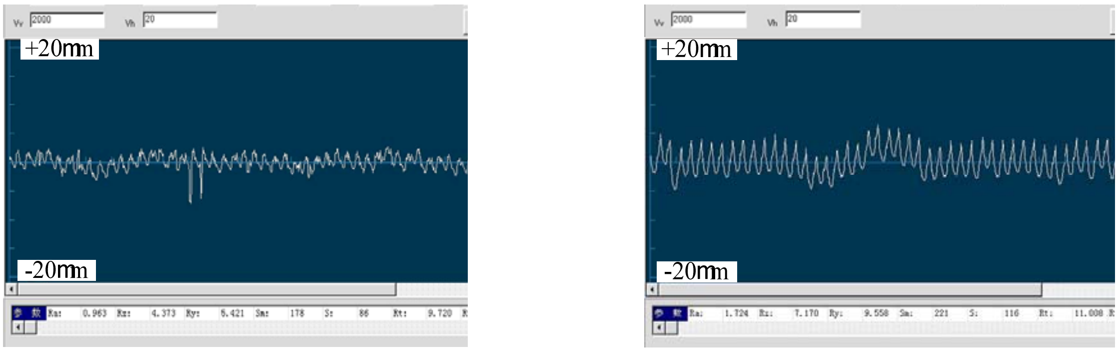


Fig.4 Feed rate effect on theoretical surface roughness



(a)With wiper insert (b) With conventional insert

Fig.5 Measured surface profile for the turned workpiece at the feed rate 0.2mm/r

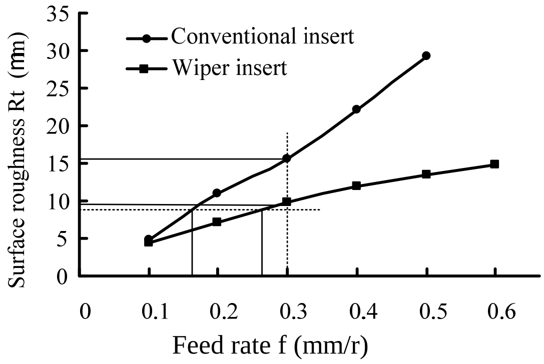


Fig.6 Measured values of surface roughness for turning with conventional and wiper inserts

Fig.5 shows the measured surface profile for the turned workpiece with conventional insert and wiper insert at the feed rate 0.2mm/r, respectively. The comparison between the turned surface roughness obtained using the wiper inserts and those obtained with conventional inserts at all six tested feed rates is shown in Fig.6. These test results prove the effectiveness of the theoretical analysis results and the wiper inserts in providing excellent surface roughness. In particular, turning using the wiper inserts with a doubled feed rate with respect to the conventional ones provides machined surface with lower roughness values.

Conclusions

The conclusions of this study can be summarized as follows:

Without changing cutting conditions, up to two-times better surface roughness was achieved with wiper insert in turning operations. In this investigation this fact was proved through theoretical analysis and experimental study when turning mild steel with conventional inserts and wiper inserts, respectively. For example, keeping the same feed rate of 0.3 mm/r in Fig.6, the surface roughness R_{tc}15.52 μm was achieved when turning with conventional insert, while surface roughness R_{tw} 9.95 μm was obtained with wiper insert.

Without sacrificing finish requirements, one can double the feed rates to obtain the same surface roughness. For the surface roughness 9 μm in Fig.6, the feed rate required was 0.17 mm/r for conventional insert, while 0.28 mm/r was for wiper insert.

Both using conventional insert and wiper insert presented the same trend of surface roughness increasing with the feed rate.

Acknowledgements

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