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Machining with chamfered tools

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Abstract

The application of chamfered tools in metal cutting is yet very much limited. Despite their better edge strength, relatively little research have been done so far to understand the effect of tool geometry on cutting variables and the mechanics of chip formation. The present study focuses on the performance of chamfered tools during continuous and interrupted turning of medium carbon low alloy steel. Several cutting tests were conducted in turning on a conventional lathe machine with cemented carbide chamfered solid tools and its performance with respect to cutting force, tool life and chip formation have been investigated. The tools were ground to different chamfer widths varying from 0.10 to 0.40 mm at a constant chamfer angle of 45° and to a varying main cutting edge chamfer angles ranging from 15° to 35° at a constant chamfer width of 0.20 mm. For the purpose of interrupted turning, four axial slots were milled on the cylindrical work material.

It has been observed that both in continuous and interrupted turning, with the increase chamfer width, both the main cutting force and feed forces increases and the effect on the feed force is more significant. With the increase of chamfer angle, cutting forces increased but at the maximum chamfer angle, both main cutting force and feed force were low. The chip thickness was observed to decrease with increasing chamfer width. However the effect of chamfer angle on the chip thickness was insignificant. Shear angle increased with the increase of both width and angle of the chamfer.

Keywords: Interrupted turning; Chamfered tools; Tool wear; Surface roughness

1. Introduction

In practice, the machining process is optimized based on certain output variables, such as tool wear, cutting forces, surface finish, chatter, cutting temperature etc. The performance of a cutting tool is evaluated in terms of tool life, surface finish, cutting forces, power and metal removal rate. These depend on the tool geometry, feed, cutting speed, depth of cut and work material and tool material properties [1].

Research on metal cutting mainly focuses on machining with sharp edge inserts/tools. The investigation of tool geometry focuses on categories such as (i) the tool edge geometry and (ii) the tool rake geometry. Tools with chamfered edge are used for machining hard materials due to their edge strength. Chamfered cutting tool traps the work material over the chamfered edge and the formed dead metal acts like a cutting edge, which increases the tool edge strength and reduces the tool wear. Some researchers have found that the chamfered cutting edge is almost completely filled by a dead metal zone and the chamfer has more influence on the feed force than the tangential (main cutting force) force [2,3]. When a chamfer is introduced to the tool edge, the chamfered edge acts as the primary rake of the tool with a limited length and at a large negative rake angle. The main rake of the tool becomes the secondary rake at a positive, neutral or slightly negative rake angle. The chamfer enhances the performance of the tool by strengthening the tool edge and reducing the possibility of breakage. Cutting tools with a negative chamfered edge and positive rake face traps the work material over the chamfered edge and the dead metal formed acts like a cutting edge that increases the strength and reduces the tool wear. However, cutting with dead metal zone on the chamfered edge are that forces on the tool are increased and the dimensional accuracy may be compromised as the size of the dead metal zone may vary during cutting [4].

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The mechanics of machining with chamfered tools have been analyzed by Zhang et al. [5]. They considered the primary, dead metal, and deformation zone separately and concluded that existence of dead metal zone was not dependent on the cutting speed, tool main rake angle or the chamfer angle. They observed that shear angle due to chamfer decreased by about 2°–3° compared to that for cutting with sharp edge tools under the same cutting conditions. Fuh et al. [6] have modeled three dimensional geometry and mechanics of tools with a chamfer and predicted cutting forces using shear laws governed by minimum energy principle. Researchers have also investigated the effect of tool edge geometry on the chip removal process. Previous research on the fundamental of mechanics of cutting suggests that chip is formed by a shearing process along a shear plane ahead of cutting edge toward a free surface of the work material. [7,8]. It is believed that the edge or the ploughing force influences the surface integrity and residual stresses in the machined surface rather than contributing directly to the chip removal process. Since there is no direct measurement technique for the ploughing force, it is indirectly estimated from the total cutting force by extrapolating the forces at various uncut chip thickness to zero thickness [9]. This however may over predict the ploughing forces in some cases when the variation of strain, strain rate, and temperature are taken into account at different feed rates [10,11]. Chang and Fu [12,13] presented a force model for single point chamfered tools to predict the cutting force. They also suggested that with main cutting edge chamfer tools could improve cutting efficiency [14].

Relatively little research have been done toward better understanding of the influence of chamfered edge tool on the output variables in continuous and interrupted turning. In this study, tools with various chamfered widths on the main cutting edge have been used both in continuous and interrupted turning. The objectives are to determine the effect of chamfer width on the cutting force, surface roughness, chip thickness, and tool life. Experiments were conducted on a medium carbon, low alloy steel (ASSAB 760) using solid cemented carbide-cutting tools having various chamfer widths.

2. Experimental method and procedure

In continuous turning, a series of experimental run were conducted on a 140 mm diameter cylindrical bar under different cutting conditions. While in interrupted turning, work piece diameter was 80 mm with four 6 mm wide slots made along the longitudinal direction. The solid tools were specifically ground according to the required geometry.

2.1. Cutting tools and tool geometry

2.1.1. Cutting tool

Solid cemented carbide tools of square cross section (8 mm × 8 mm) and 75 mm long were ground at the desired tool geometry in a tool grinder. The various angles were; main rake angle = 5°, side clearance angle = 5°, back clearance angle = 8°, and minor tool cutting edge angle = 10°. Table 1 shows the values of different chamfer angles and widths. The composition of the tool is 55% WC, 10% Co, and 35% TaC + TiC with hardness HRA equal to 90.5.

Table 1
Chamfer dimensions of the tool

Tool #	Chamfer angle (°)	Chamfer width (mm)
First set of experiment		
1	45	0.10
2	45	0.14
3	45	0.20
4	45	0.28
5	45	0.40
Second set of experiment		
1	15	0.20
2	25	0.20
3	30	0.20
4	35	0.20

2.2. Workpiece

The work piece used was Assab steel 760 (HV 221) with C = 0.45% and Mn = 0.70% for both continuous and interrupted turning. For interrupted turning, four axial slots as shown in Fig. 1 were milled.

2.3. Experimental conditions and setup

All the experiments were run dry in a conventional lathe machine. The engine lathe was equipped with a three-component Kistler dynamometer in conjunction with a multi channel charge amplifier. Force signals were recorded in a Yokogawa DL 1540 Digital Oscilloscope. Surface roughness was measured by a portable surface roughness tester while tool wear was measured in a Toolmaker's microscope. The specifications of the equipments and instruments used in the experiment are as follows:

(i) A Cholchester Master versus 3250, 7.5 kW conventional lathe with maximum spindle speed of 2500 rev/min and feed range of 0.036–1.2 mm/rev.

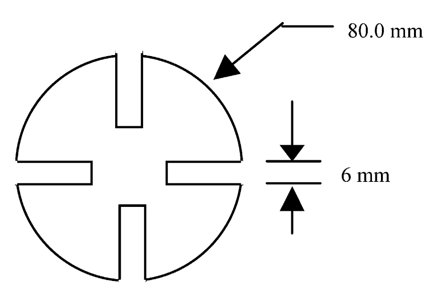

Fig. 1. Work piece with four axial slots.

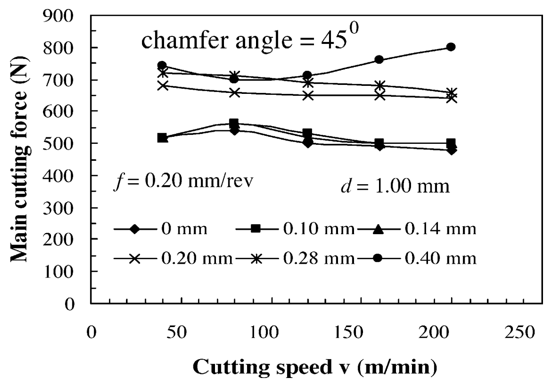

Fig. 2. Effect of chamfer width on the main cutting force at different cutting speed.

(ii) Kistler piezo-electric dynamometer: Model 9257A with a multi-channel Kistler charge amplifier and a Yokogawa DL 1540 digital oscilloscope.
(iii) A portable Perthometer (Mahr) for measuring surface roughness.
(iv) A Toolmaker's microscope and a high magnification microscope (OPITIHOT 100S) for measuring and observing tool wear.

2.4. Cutting force tests

For continuous and interrupted turning, cutting conditions were; cutting speed $v = 40$, 80, 120, 160, and 200 m/min, feed rate $f = 0.08$, 0.10, 0.12, 0.16, and 0.20 mm/rev, and depth of cut $d = 1.0$ mm. Five tools with different chamfer width and one with no chamfer were used in continuous turning and forces were recorded. In the case of interrupted turning, both the chamfer width and the angle were varied and force signals were recorded. For each experimental run, three measurements were made and average value has been considered.

2.5. Chip thickness ratio and shear angle

Chips were collected at each cutting condition and measured by a dial gage. Chip thickness and the tool-chip contact length were also measured and the chip thickness ratios and shear angles were calculated for different cutting conditions.

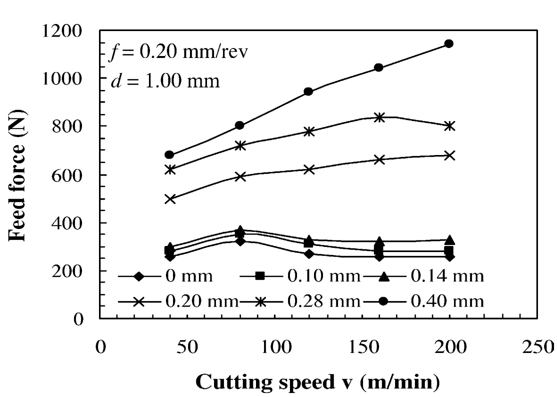

Fig. 3. Effect of chamfer width on the feed force at different cutting speed.

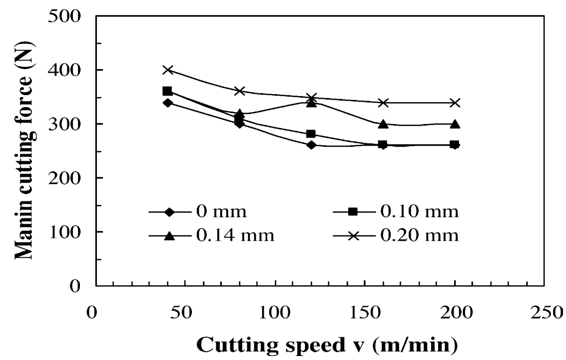

Fig. 4. Effect of chamfer width on the main cutting force at different cutting speed.

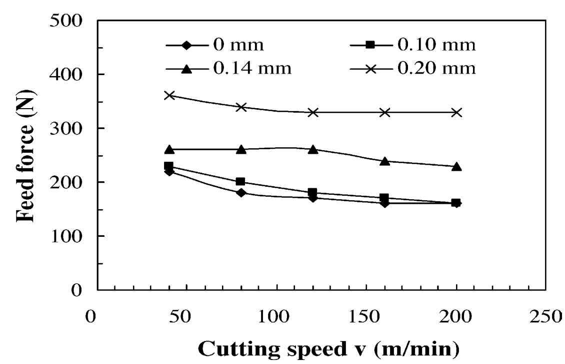

Fig. 5. Effect of chamfer width on the feed force at different cutting speed.

2.6. Tool life tests

The tool life tests were conducted only in interrupted turning with chamfered tools of different angles at a constant chamfer width of 0.20 mm. The speed, feed, and depth of cut were 120 m/min, 0.12 mm/rev, and 1 mm, respectively. Chamfer angles were 15°, 20°, 30°, and 35°.

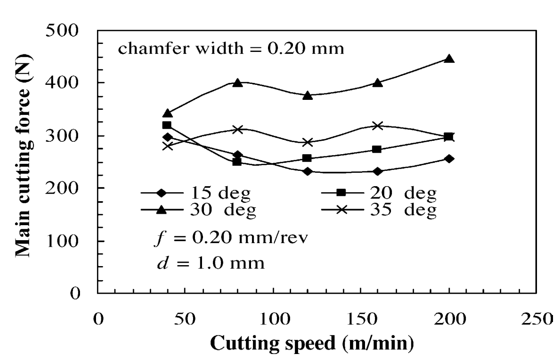

Fig. 6. Effect of chamfer angle on the main cutting force at different cutting speed.

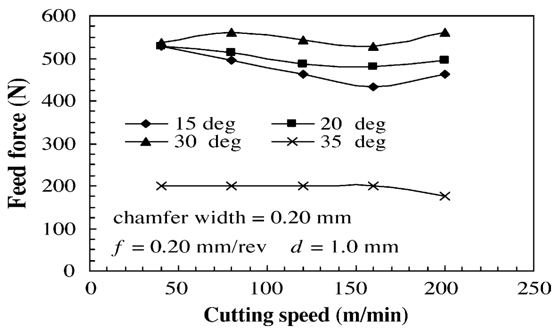

Fig. 7. Effect of chamfer angle on the feed force at different cutting speed.

3. Results and discussions

3.1. Cutting forces

3.1.1. Continuous turning

The effect of chamfer width on the main cutting force and feed force were recorded at various speeds and plotted in Figs. 2 and 3. Feed and depth of cut were kept constant at 0.20 mm/rev and 1.0 mm, respectively. From the Fig. 2, it was observed that at constant chamfer width, main cutting force remains almost unchanged with the increase of speed. At lower widths (0.10 and 0.14 mm), chamfered and non-chamfered tools produced almost identical forces. However, at the larger widths (0.20 mm and above), force magnitude was higher although it did not change much with respect to the increase of speed. With respect to the feed force, larger width tools produced higher forces and the magnitudes were observed to increase with the increase of speed. The reason for higher forces at higher widths may be due to the formation of a dead metal zone [4], which is trapped under the chamfer edge but this may protect the tool from wearing under heavy cutting conditions.

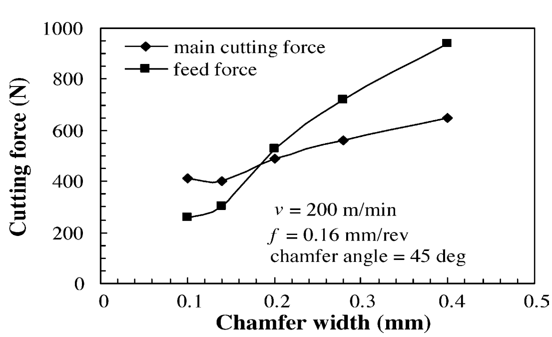

Fig. 8. Effect of chamfer width on the cutting force components.

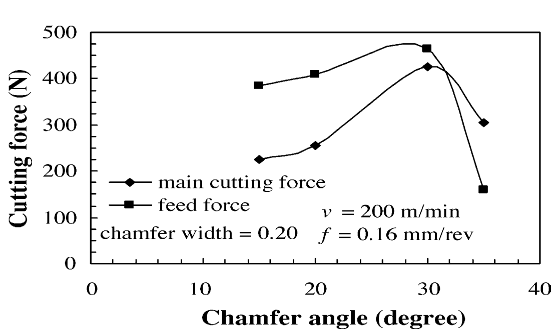

Fig. 9. Effect of chamfer angle on the cutting force components.

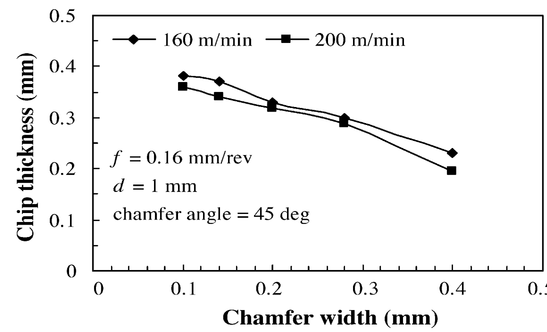

Fig. 10. Effect of chamfer width on chip thickness.

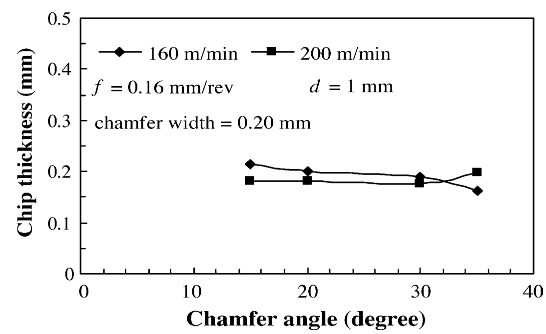

Fig. 11. Effect of chamfer angle on chip thickness.

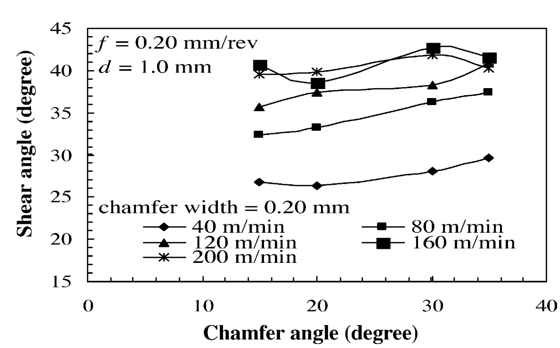

Fig. 12. Effect of chamfer angle on shear angle.

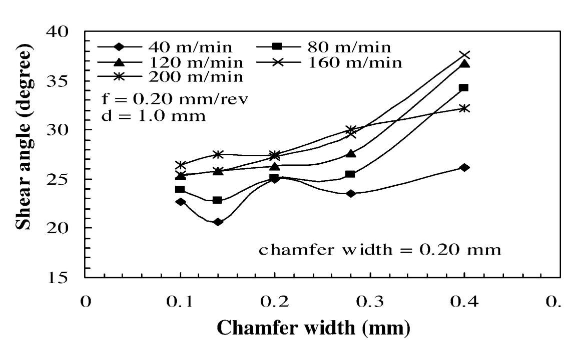

Fig. 13. Effect of chamfer width on shear angle.

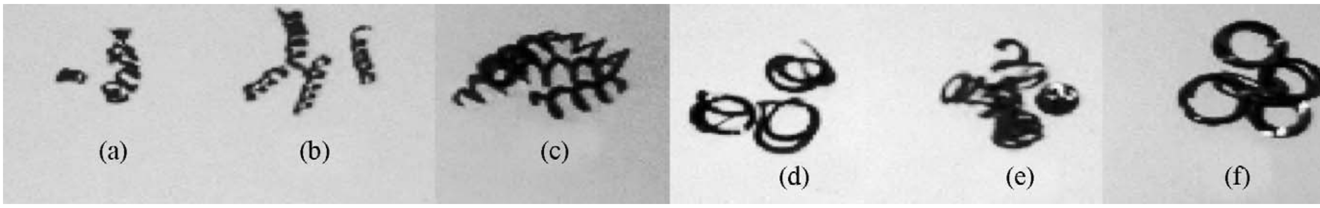

Fig. 14. Chip formation (a) chamfer angle 20°, $f = 0.08$ mm/rev and $v = 40$ m/min, (b) chamfer angle 15°, $f = 0.08$ mm/rev and $v = 40$ m/min, (c) angle 15° and $f = 0.16$ mm/rev, $v = 200$ m/min, (d) chamfer angle 30°, $f = 0.10$ mm/rev and $v = 80$ m/min, (e) chamfer angle 15°, $f = 0.08$ mm/rev and $v = 200$ m/min, (f) chamfer angle 35°, $f = 0.08$ mm/rev and $v = 80$ m/min, all at $d = 1.0$ mm.

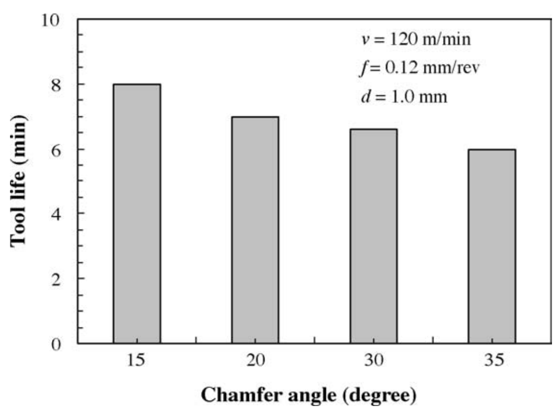

Fig. 15. Tool life values at different chamfer angles.

3.1.2. Interrupted turning

Figs. 4 and 5 shows the effect of chamfer width (0.10, 0.14, 0.20 mm) on the main cutting force and feed force at different speeds for feed $f = 0.12$ mm/rev and depth of cut $d = 1$ mm. Here the trend is also similar like in continuous turning although feed force did not change much with the speed. The tool without any chamfer resulted in the lowest cutting force. Figs. 6 and 7 show the effect of chamfer angle on the cutting and feed forces at various speeds. When the chamfer angle was 35°, the magnitude of main cutting force was lower that that at angle of 30°. While in the case of feed force, chamfer angle 35° produced the lowest than all other angle tools. Figs. 8 and 9 show the effect of chamfer width and angle on the main cutting force and feed force. It has been observed that the width and angle effects are more pronounced on the feed force than on the main cutting force.

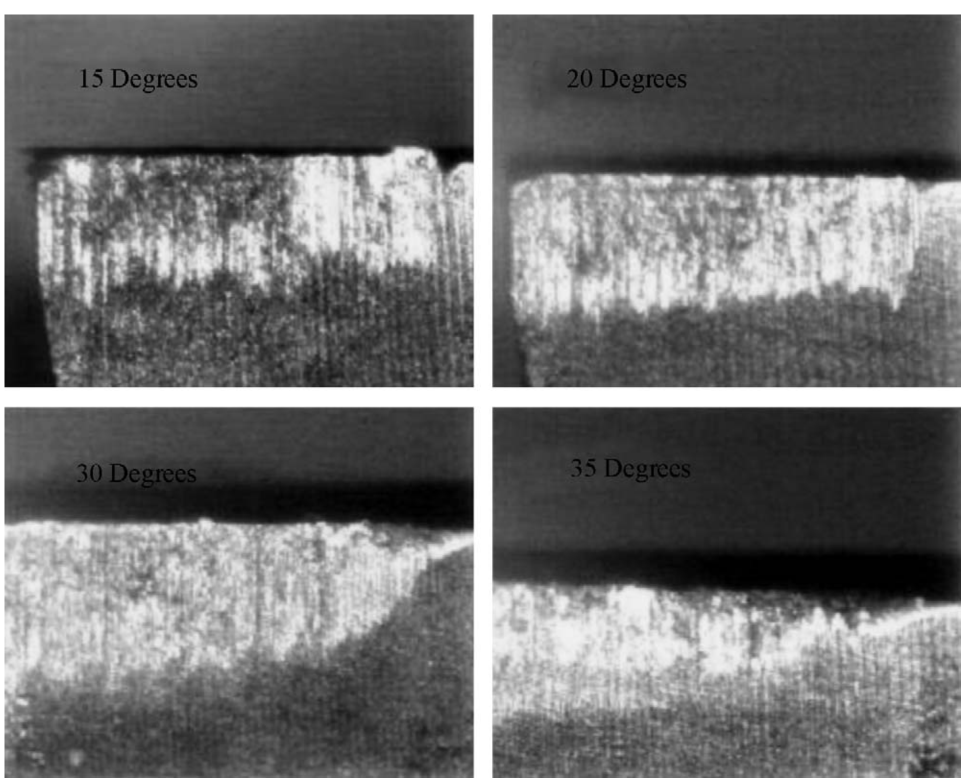

Fig. 16. Tool wear observed after seven minutes cutting time under a high magnification microscope at $v = 120$ m/min/in, $f = 0.12$ mm/rev, and $d = 1.0$ mm.

These observations are consistent with the research reported in the literatures [2,3].

3.2. Chip thickness and shear angle

Figs. 10 and 11 show the variation of chip thickness with the width and angle, respectively while Figs. 12 and 13 show the variation of shear angle at different chamfer angle and widths, respectively. As the width of chamfer increases, there has been a decrease in chip thickness resulting in the increase of chip thickness ratio. This leads to an increase in chip velocity. However as the chamfer angle increases, chip thickness remains unchanged and this supports the previous work by other researchers [5]. From Figs. 12 and 13, shear angle increases with the increase of chamfer width or angle at a constant speed. However, the increase is only 2°–5° for width variation. The increasing shear angle means chip becomes thinner and thinner and comes off at a higher speed. As the speed increases for a constant chamfer width or angle, shear angle also increases. The observation does not support the view of research reported in the literature [5]. Chips produced at different chamfer angles are shown in Fig. 14. At all angles, chips produced are spiral which may attribute to the presence of the dead metal zone that fills the chamfer and makes the cutting process almost identical for different chamfer angles.

3.3. Tool life

The tool life tests were conducted only at one chamfer width (0.20 mm) with four different chamfer angles and average flank wear values were recorded under a microscope. Tool failure time was calculated from the plot of wear against cutting time for different chamfer angles. Fig. 15 shows the life of tools having different chamfer angles. Tool having the lowest chamfer angle produced the highest tool life and it is clear that as the chamfer angle increased, tool life decreased. However, notch formation was observed on 15° and 20° chamfer angle tools after 5 min of cutting. Chipping phenomena was not at all observed in any of the chamfer angle tools. Fig. 16 shows high magnification picture after 7 min of cutting. The flank wear progression seems to be uniform.

4. Conclusions

In this paper, experimental studies have been conducted towards better understanding of the performance of chamfered tools.

- Either in continuous or interrupted turning as the speed increases, main cutting force remains almost the same at a constant chamfer width or angle. However with the increase of chamfer width, main cutting force increased at a constant speed.
- Effect of width or angle is more pronounced on the feed force than the main cutting force. The largest chamfer angle tool resulted in the lowest feed force indicating the absence of any dead metal zone. When the chamfer width is relatively low (≤0.14 mm), there is no significant difference between a chamfered and a non-chamfered tool with respect to the cutting force magnitude. The sharp tool (width = 0 mm) produced the smallest force.
- Chip thickness does not change with chamfer angle. However with the increase of width, chip thickness decreases and at high cutting speed, chip thickness was lower.
- There has been a steady increase in shear angle either with the increase of width or angle. The shear angle however increased only by 2°–5° when width was increased. The increase in the shear angle was even more when the chamfer angle increased.
- Almost identical chip were produced irrespective of chamfer angles and at all cutting conditions indicating the presence of dead metal zone on the face of the chamfer.
- When the chamfer angle was the smallest, tool life was maximum. The rapid flank wear at the increasing chamfer angle may be due to the high feed force and consequently the higher stresses in the thrust direction.

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