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EXPERIMENTAL SELECTION OF SPECIAL GEOMETRY CUTTING TOOL FOR MINIMAL TOOL WEAR

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Abstract:
A major problem in achieving high production rates in metal cutting industry is Tool Wear. Prolonged tool life has gained significance with the discovery of materials like hard steels, and the urge to maintain tighter geometric tolerances and improved surface finish. Strengthening of the edge and prevention of its deterioration is achieved by the several edge geometries that have been proposed; the most prominent being chamfered tools and honed tools. But, the investigation of the effect of different chamfer angles and honed radii on the machining parameters and tool life is not much done. The present work is an attempt to study the influence of these variables on tool wear. EN-8 steel with sharp tool and different chamfered and honed tools has been machined and experimental investigations have been carried out. Variations in cutting forces, tool wear, and thus tool life, have been observed for all the cases. Inferences drawn are validated and the performance of the tools for workpieces with different hardness is assessed by machining EN-9 under similar cutting conditions using similar tools as in the previous case. Results obtained in both the cases are analogous, thus validating the conclusions made. The work can be extended by considering more values chamfer angle and honing radii.

Key Words: Chamfered Tool, Honed Tool, Metal Cutting, Tool Wear

1. INTRODUCTION

The present day cutthroat competition prompts towards developing processes and materials that perform satisfactorily, in prolonged usage. Production costs and times need to be minimized to achieve the goals. Undesirable effects such as tool wear and tool breakages not only result in deterioration in surface finish and dimensional accuracy of the finished parts, possible damage to the workpiece and machine, but also increase production times. For modern machine tools, a major portion of downtime is attributed to tool failure. Hence new strategies to reduce tool wear, thus improve tool life, are under research and are being developed.

Understanding tool wear mechanism/phenomenon is essential to devise new methodologies for enhancing tool life. Various mechanisms simultaneously contribute to tool wear. Due to the constant rupture of the cutting tool with hard particles in the workpiece, the cutting edge of the tool deforms. This mechanism is known as Abrasion wear and is a major cause of tool failure. Due to the high temperatures and pressures prevalent at the cutting tool-workpiece junction, the tip of the cutting tool gets adhered to the workpiece. The process is similar to welding and this mechanism is known as Adhesion wear. Diffusion wear occurs due to the high temperatures at the cutting edge of cutting tool; as material transfer takes place from the tool tip to the chip, tool cutting edge loses hardness. Due to the combination of aforementioned different mechanisms, tool wear occurs in various forms that include Flank wear, Crater wear, Notch wear and Nose wear.

Tool wear rarely occurs in an isolated form and is a combination of different mechanisms. It is relatively rare to find pure adhesive wear, as the material transferred during adhesive wear often causes abrasive wear. Abrasive wear involves loss of material by formation of chips as in abrasive machining. A convenient way of studying abrasive wear is in terms of specific energy, required to remove a unit volume of material [1].

During continuous machining, a wear land develops at tool flank, known as Flank wear. Flank wear is caused by constant rupture of cutting tool against just-machined surface due to adhesive and abrasive wear mechanisms. It is measured by the width of wear land and results in changes in the mechanics of the cutting process. Flank wear increases with progress in machining time and results in increased tendency for chatter and changes in the dimensions of the product.

Crater wear results from a combined evolution of high cutting temperatures and high shear stresses creating a crater on the rake face some distance away from the tool edges, quantified by depth and cross-sectional area of the crater. Crater wear arises due to combination of different wear mechanisms: adhesion, diffusion or thermal softening and plastic deformation. Crater wear changes the effective rake angle and the chip-tool contact length and also reduces the amount of force that the tool can withstand. Normally, limiting value of flank wear is reached before that of crater wear and hence the study of flank wear is more critical.

One of the challenges posed lies in devising methods for the classification/estimation of cutting tool wear. This seemingly simple task has proved to be rather difficult probably due to the fact that tool wear introduces small changes in a process with a very wide dynamic range. The task can be subdivided into a number of stages, generation of a feature or set of features indicative of tool condition, corresponding sensor selection and deployment and finally analysis of the collected and processed information so as to determine tool wear.

1.1 Tool wear monitoring

Conventionally, based on his experience, knowledge and expertise, an operator judges the condition of the cutting tool [1-3]. Sensory information like presence of smoke, smell, etc. is used to arrive at this decision. In many cases, information from a single sensor may not be sufficient and hence more sensors may be employed. The idea pursued in this anticipates learning, pattern recognition and sensor fusion abilities of human operators. With advent of unmanned industries, on-line monitoring systems are used to replace human operators.

Techniques for on-line tool wear monitoring can be grouped into two main categories: direct sensing and indirect sensing techniques [2]. Both the direct and indirect methods of tool wear sensing techniques are reported to be attempted extensively. However, direct methods are less beneficial as the cutting area is largely inaccessible, and hence on-line monitoring of tool condition becomes difficult.

The indirect methods include, touch trigger probes, optical, radioactive, proximity sensors and electrical resistance measurement techniques. These methods involve in recording one of the process variables that can be correlated to tool wear. The usual cutting parameters measured are cutting forces, acoustic emission, temperature, vibration, spindle motor current, torque and strain.

1.2 Chamfered tools and honed tools

As optimizing cutting conditions is little in control of the operator, new strategies are devised to restrict tool wear progression. Application of lubricants, though advantageous, is not of much use in high speed machining operations. Cutting tools with coatings and special edge geometries have emerged as a promising solution. Edge preparation of the tools is critical for acceptable tool life in turning. Due to the brittle nature of the materials used to machine steel, strong edge geometries help to prevent premature tool failure or accelerated tool wear by edge chipping. The problem is magnified by the large cutting load and negative rake angles typically used for hard turning. Thus, tool manufacturers have developed the practice of preparing cutting edges with a honed radius or edge chamfer to strengthen the edge. These tools have shown improved tool life compared to unprepared (or up-sharp) tools.

Single point cutting tools are characterized by the loss of tool tip in the initial stages of wear. Deterioration of the tip weakens the tool and results in the loss of its functionality [4,5]. Research to strengthen the tool tip has engendered tools of special geometry like chamfered and honed tools [4,6]. Ren at al [6] proposed an analytical model based on tool geometry, cutting conditions and steady state temperatures in shear and chip rake face contact zones to estimate influence of chamfer angle on cutting forces and temperatures. applied the minimum energy principle to total energy and calculated the shear angle. Corresponding shear strain and stresses were estimated. Zhou et al [7] studied the effect of chamfer angle on tool wear of PCBN cutting tool in super finishing hard turning. The correlation between cutting force, tool wear and tool life were investigated. The optimized cutting angle of chamfer for PCBN tools is suggested as 15°. Movahhedy et al [8] carried out numerical analysis of metal cutting with chamfered as well as blunt tools. It was concluded that though chip formation process is not much affected, cutting forces have increased with chamfered tools. It is generally agreed that chamfered tools increase tool life but lead to increased cutting forces. Though work is reported in PCBN tools, the behaviour of chamfered HSS tools is not studied.

When the cutting tool is relatively brittle or subjected to a hard workpiece, the very tip of the tool is rounded off to prevent chipping. This has been attracting the researchers of late. A lightly honed edge has a radius of about 0.03mm while a heavily honed tool has a radius of about 0.125mm. Mayer et al [9] measured machining forces in virgin and worn out tool. They proposed a combination of chamfered and honed tools for better tool life. Kountanya [10] studied the tool wear progression with honed tools and concluded that though cut-in wear is more for honed tools, wear growth gets stabilised later on and is less on further rise in machining time compared to sharp tools. They reported an increase in the cutting forces with increase in honed radius. Fang et al [11] studied the effect of chamfered and honed tools in machining three aluminium alloys 7075-76, 6061-T6 and 2024-T351. Cutting forces, thrust force, their ratios and chip thickness were measured. A model was proposed to predict chip formation characteristics. Cemented carbide tools were used in the study.

Majority of the works reported on the subject do not deal with the popular HSS tools and also the proposed models are for chip flow characteristics or cutting forces. Tool wear models are not proposed. Also the performance of chamfered tools and honed tools is not compared; both are dealt with separately. The present work investigates the effect of tool tip geometry on tool wear and cutting forces, considering chamfered and honed HSS tools. Cutting force is chosen as a parameter to estimate tool flank wear. Turning of EN-8 steel using H.S.S tool under constant cutting conditions is carried out. A lathe tool dynamometer is used to find out radial force data. The tool profile has been analyzed under an optical projector to estimate the growth of flank wear under progressive machining [12]. The projected profile of the tool in different stages of machining is compared with that of virgin tool and width of flank wear land is measured. Limiting value of 0.6mm of maximum flank wear width is considered. The performance of both tools is compared. A mathematical model is proposed for tool wear based on regression. To validate the results obtained, another material, typically a harder one; EN-9 is turned with tools of similar geometry.

2. EXPERIMENTAL SET-UP AND PROCEDURE

EN-8 steel is turned under constant cutting conditions. To validate the conclusions drawn and to study the influence of workpiece hardness on the behaviour of the tool, turning of EN-9 (carbon-0.5%) is carried out. Workpieces of diameter 50mm and 915 mm length are machined.

A 3 HP lathe of make Madras Machine Tool Manufacturer's Ltd., Coimbatore, India is used for the experimentation. H.S.S tool is used for machining. The nomenclature of the tool is 0^0-5^0-30^0-15^0-10^0-10^0-0 as per ISO specifications.

Figure 1 shows the chamfered tool. Chamfer angles are varied from 5 to 20^0 in steps of 5^0. Chamfer width is kept constant at 0.9 mm. The remaining geometry is same as the sharp tool. Figure 2 shows the honed tool. Radius of honing is varied as 0.03, 0.05, 0.1, 0.12

mm. Tools are honed using a tool end cutter and are verified with the tool maker's microscope. Cutting forces are measured using a lathe tool dynamometer (Make : Lakshmi Controls and Instrumentation Controls, Measuring range : 0-2000 N, Type : Cantilever type strain gauge dynamometer, Accuracy : ± 2% , Sensitivity : 1 N).

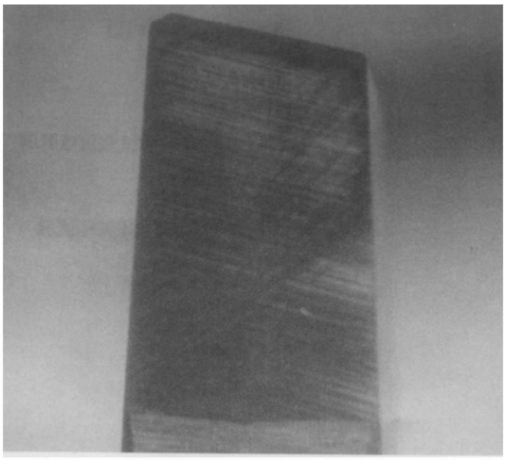

Figure1: Chamfered Tool.

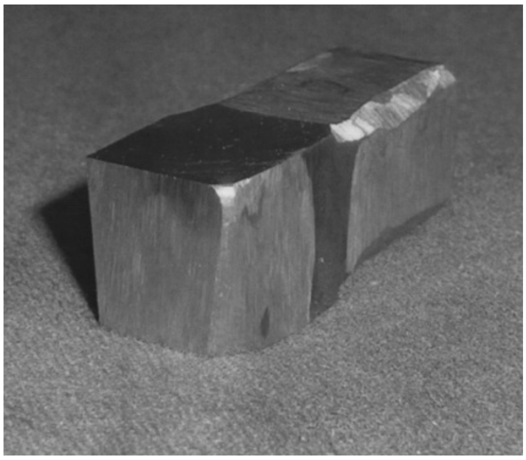

Figure 2: Honed Tool.

At regular intervals of machining, cutting tool is analysed under an optical projector to measure tool flank wear.

A lens of magnification 20 is used to analyse tool profile. Optical projector has provisions for rectangular movement of the table on which tool is placed. To make tool flank parallel to table a wooden rest is prepared.

Machining is performed on a lathe with specifications mentioned above. EN-8 and EN-9 steel are selected as workpiece. A H.S.S cutting tool is used for machining. Constant cutting conditions are maintained. An average Cutting speed of 100 m/min, feed rate of 0.2514 mm/rev and depth of cut of 1 mm is maintained.

Machining is carried out and in intervals (one minute initially up to 3 min and 5 min thereafter, up to 40 min) tool profile is analysed under an optical projector. Tool profiles obtained after machining are compared with initial tool profile and flank wear is determined.

3. RESULTS AND DISCUSSIONS

3.1 Radial cutting force

In the present work radial component of cutting force is chosen as a parameter to estimate tool flank wear. A lathe tool dynamometer is used to measure radial force component of cutting force. Measurements are taken with progress in machining time. Figure 3 shows variation of radial force with machining time for chamfered and sharp tool. Cutting forces are consistently higher for the chamfered tool. The forces increase with the chamfer angle; the obvious reason being the increase in the contact area of the tool and workpiece, resulting in increased friction. In all the cases, for chamfered as well as sharp tool, it can be seen that radial force increases with progress in machining time. Initially, rise in radial force is high and gradually gets slowed down. After sometime, rise in cutting force is low.

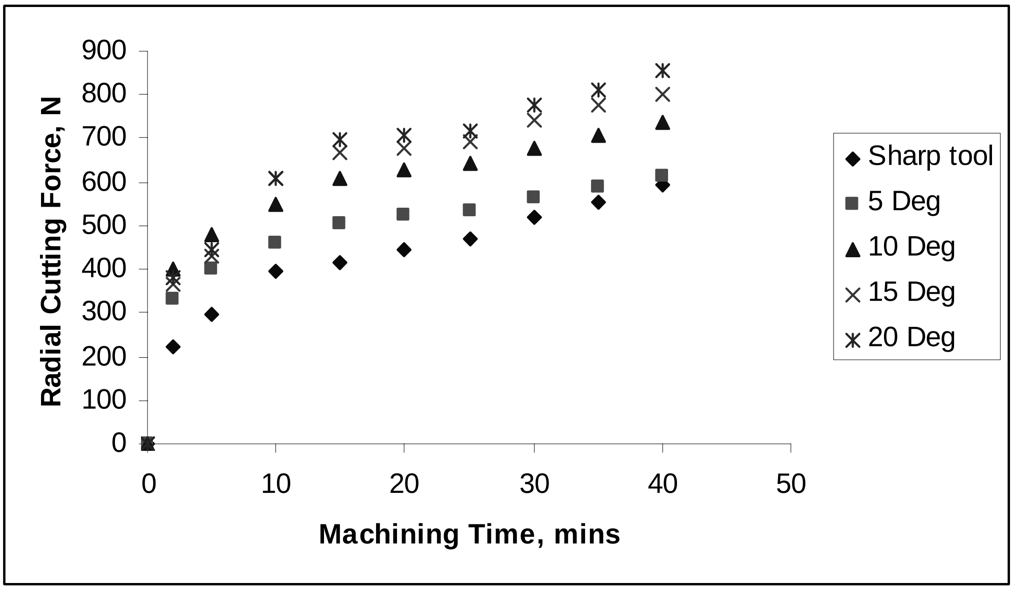

Figure 3: Variation of radial force with machining time for chamfered and sharp tool (EN-8).

Figure 4 shows the variation of cutting force with machining time for honed tools with different honing radius and sharp tool. Cutting forces are consistently higher for honed tools. The forces increase with the honing radius. It can be seen that in both honed and chamfered tools, the cutting forces are much higher compared to sharp tools. However, cutting forces are higher in chamfered tools compared to the honed tools. This may be attributed to the fact that chamfered tools have an area contact with the workpiece, while the rounded honed tool has point, at the maximum a line contact. As the contact is less, the cutting forces are less in honed tools compared to the chamfered tools.

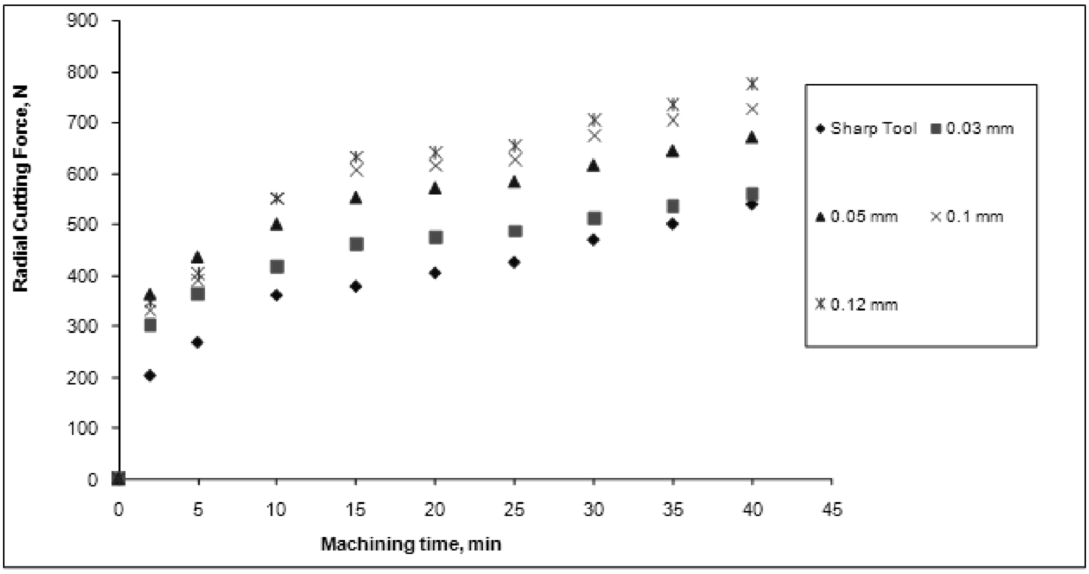

Figure 4: Variation of radial force with machining time for honed and sharp tool (EN-8).

3.2 Tool flank wear

Tool flank wear is measured at different instances of machining with progress in machining time. Figure 5 shows variation of flank wear with progress in machining time for chamfered and sharp tool.

Figure 5 shows that growth of flank wear is initially high and slowly gets constant for some time. On further machining, rise in flank wear is accelerated. Tool wear in case of sharp tool is highest. It is interesting to note that tool wear decreases with chamfer angle up to 15° and then raises. Hence minimum tool wear is observed for 15° chamfer angle. For better understanding of the implication of the chamfer angle, Figure 6 plots tool life (extrapolated values) versus chamfer angle. Chamfer angle of 0° represents a sharp tool. The results clearly demonstrate that tool life tends to increase with chamfer angle up to 150 and then decreases. One possible reason for this could be that while chamfering strengthens the tool tip, excessive chamfering may lead to increased tool-workpiece contact and damage the tool.

Figure 7 shows the growth of flank wear is for honed and sharp tools. It may be observed that the tool wear progression follows a similar trend as in case of chamfered tool. The influence of honing radius is interesting to note. The tool with honing has lesser tool wear compared to the sharp tool. However, honed tools do not show initially high wear. This stage is reached by the honed tools after machining for about 10 min. The possible reason maybe that machining causes the rounded portion of the tool to be lost by sharpening it. The tool then becomes analogous to a sharp tool and then the tool wear takes place just as in a sharp tool. In other words, the tool wear mechanism is postponed for sometime in the honed tools. It may be observed that honed tools have considerably less wear compared to the sharp tool and tool wear decreases with honing radius.

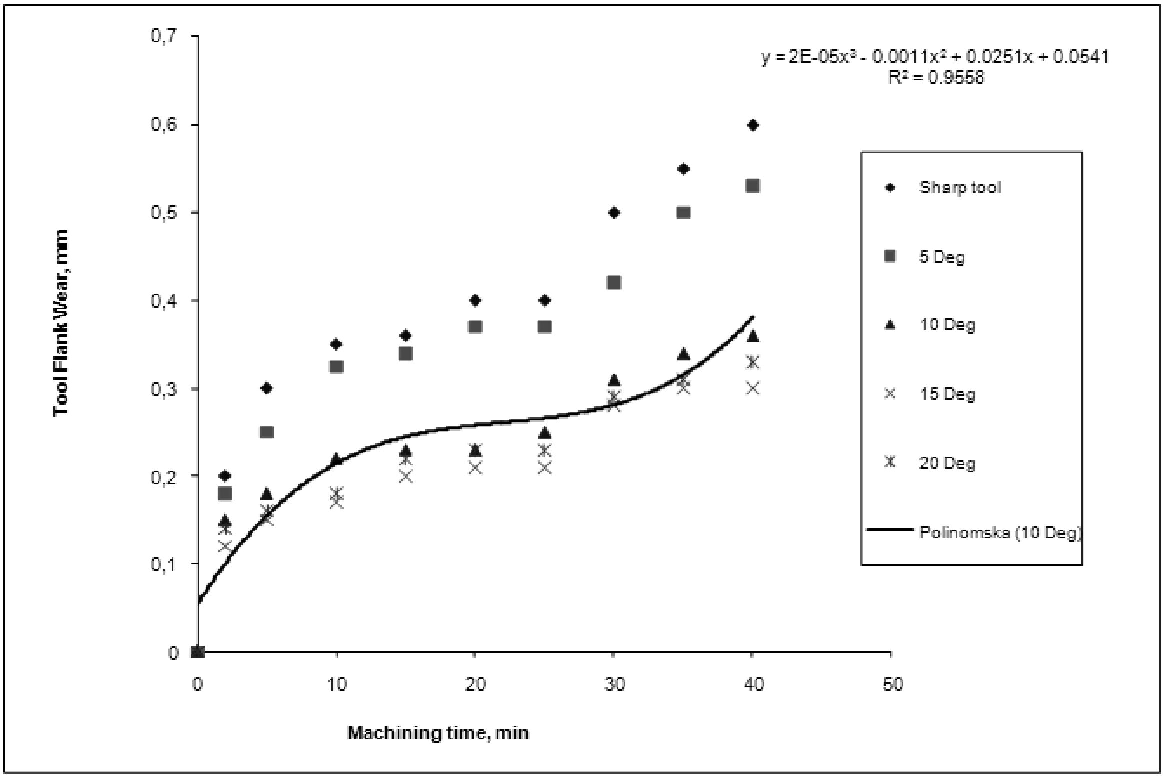

Figure 5: Variation of flank wear with machining time for chamfered and sharp tool (EN-8).

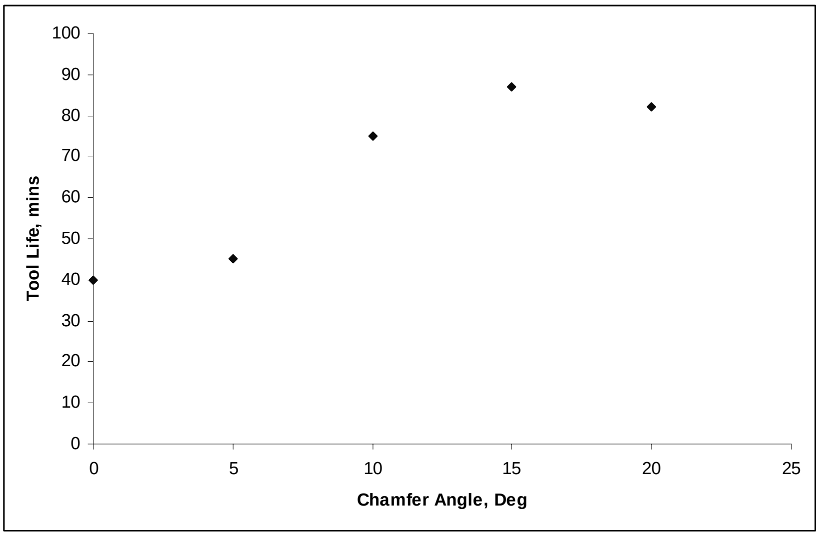

Figure 6: Variation of tool life with chamfer angle (EN-8).

For clarity, tool life is plotted against honing radius in Figure 8. As in the above case, sharp tool is taken as a tool with zero honing radius. It may be inferred from the results that cutting tools with honed edge has lesser tool wear, thus longer tool life, compared to the chamfered tools. Though honed tools with larger honing radius demonstrate higher tool life, providing much honing radius may result in excessive ploughing and may be disastrous to the tool. Results suggest that tool life for honed tools is much longer compared to the chamfered tools.

Cutting tool wear trends in both honed and cutting tools follow a curve of third degree of the form:

$$Y=AX^3 + BX^2+CX+D \tag{1}$$

where, Y represents Tool Flank Wear, X represents machining time and A, B, C, D are constants that depend on the tool, workpiece and other machining parameters. The individual equations are shown in the figures.

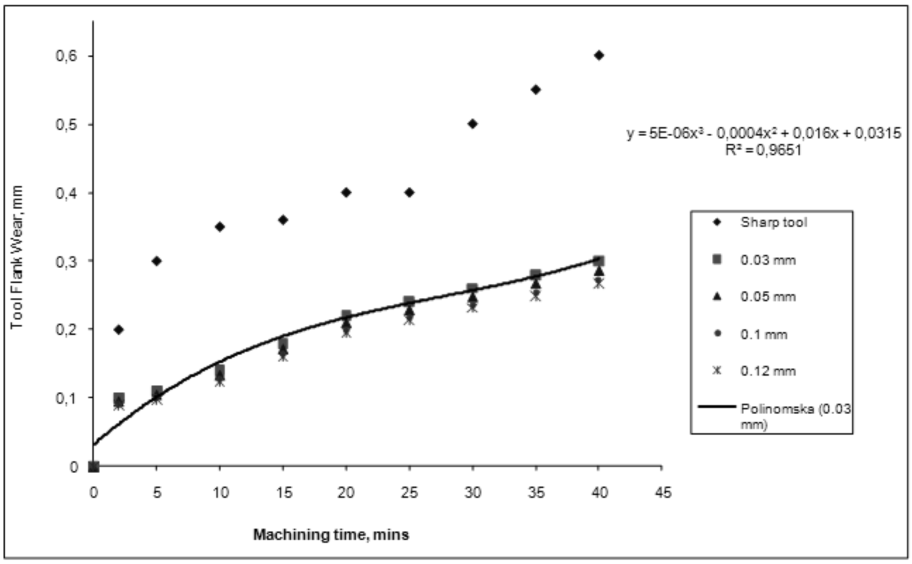

Figure 7: Variation of flank wear with machining time for honed and sharp tool (EN-8).

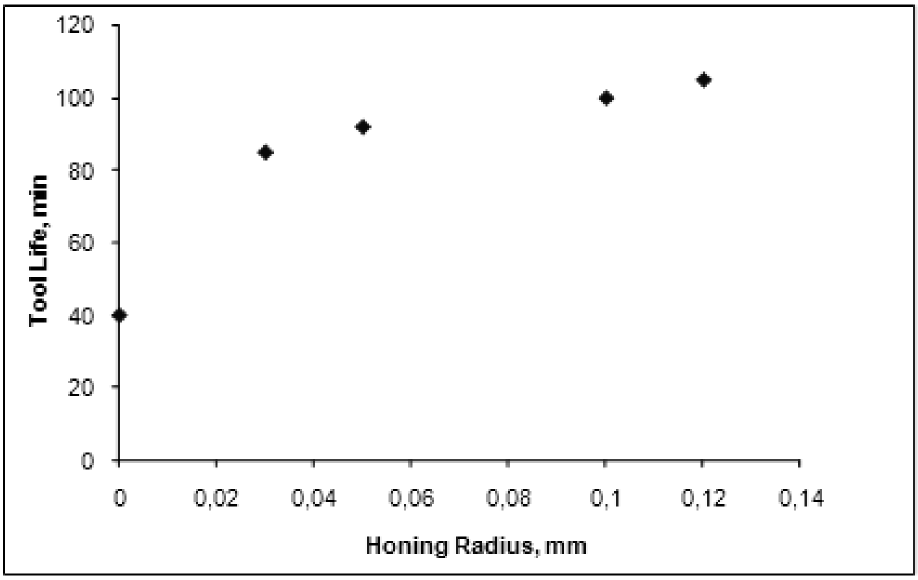

Figure 8: Variation of tool life with honing radius (EN-8).

An average regression above 0.95 is observed in both the cases. To validate the inferences drawn from the above work, another material, EN-9 is taken and is machined using tools of similar geometry.

The results show that the forces obtained in machining EN-9 are considerably higher, due to higher content of carbon that leads to hardness of the material, however, the cutting forces follow the same pattern as in case of machining EN-8 (Figure 9-10). The results are similar to those obtained by machining EN-8. Honed tools produce higher cutting forces compared to the sharp tools. It is interesting to note that in both cases, chamfered tools produce higher cutting forces.

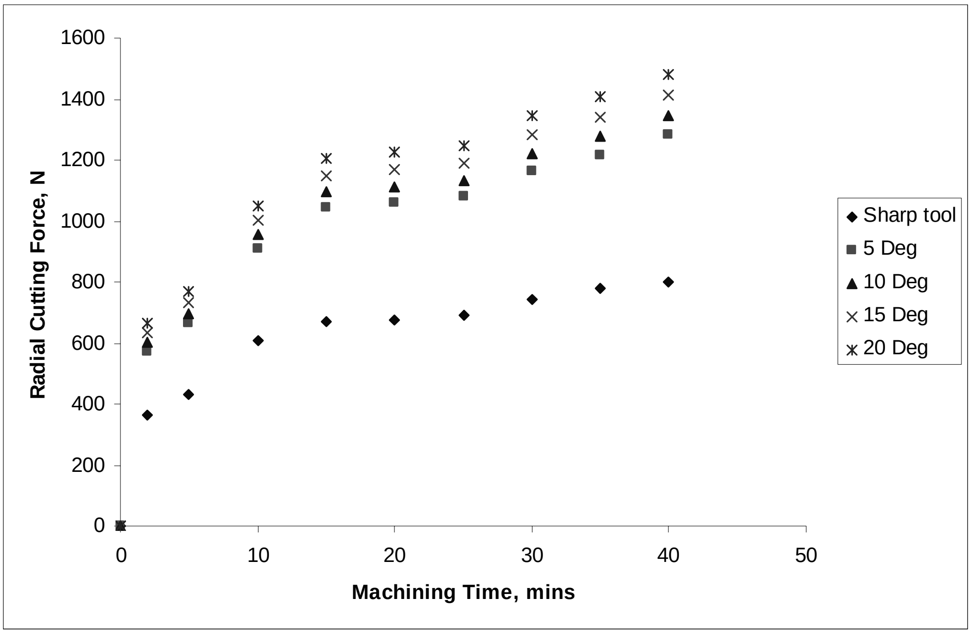

Figure 9: Variation of radial force with machining time for chamfered and sharp tool (EN-9).

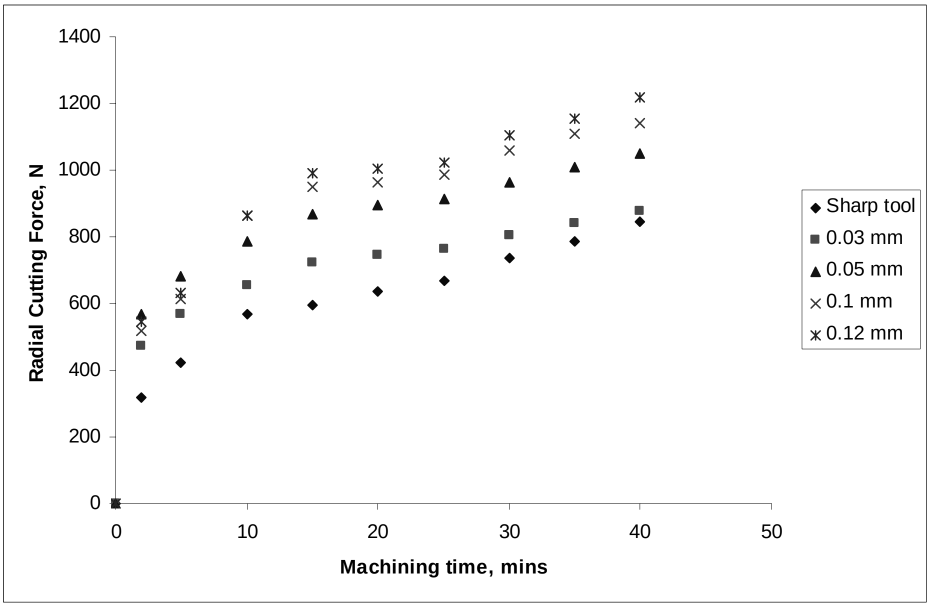

Figure 10: Variation of radial force with machining time for honed and sharp tool (EN-9).

Figure 11 shows the growth of tool flank wear in case of machining EN-9 with chamfered and sharp tools. It can be noted that tool wear is much less in chamfered tools compared to the sharp tool. Also the difference between the sharp tool wear and the chamfered tool wear is very large. This clearly indicates the better suitability of chamfered tools for machining hard materials. Further, even in this case, as in case of machining EN-8 steel, the tool with 15° chamfer angle has minimum tool flank wear.

Figure 12 presents tool flank wear growth in honed and sharp tools while machining EN-9 steel. The presented results show that tool wear is less for honed tools compared to the sharp tool. Also, tool wear is found to decrease with increase in honing radius. Further, it may be noted that difference in tool flank wear for honed tools and sharp tool is much more than in case of machining EN-8. Thus, in both the cases of chamfered and honed tools, it is evident that these tools are best suited for machining harder materials.

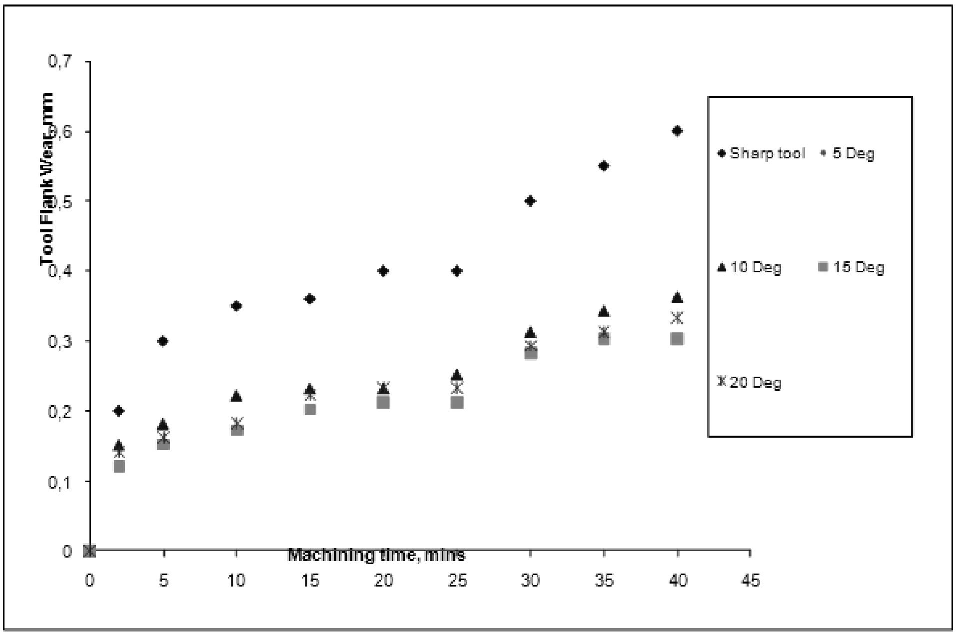

Figure 11: Variation of flank wear with machining time for chamfered and sharp tool (EN-9).

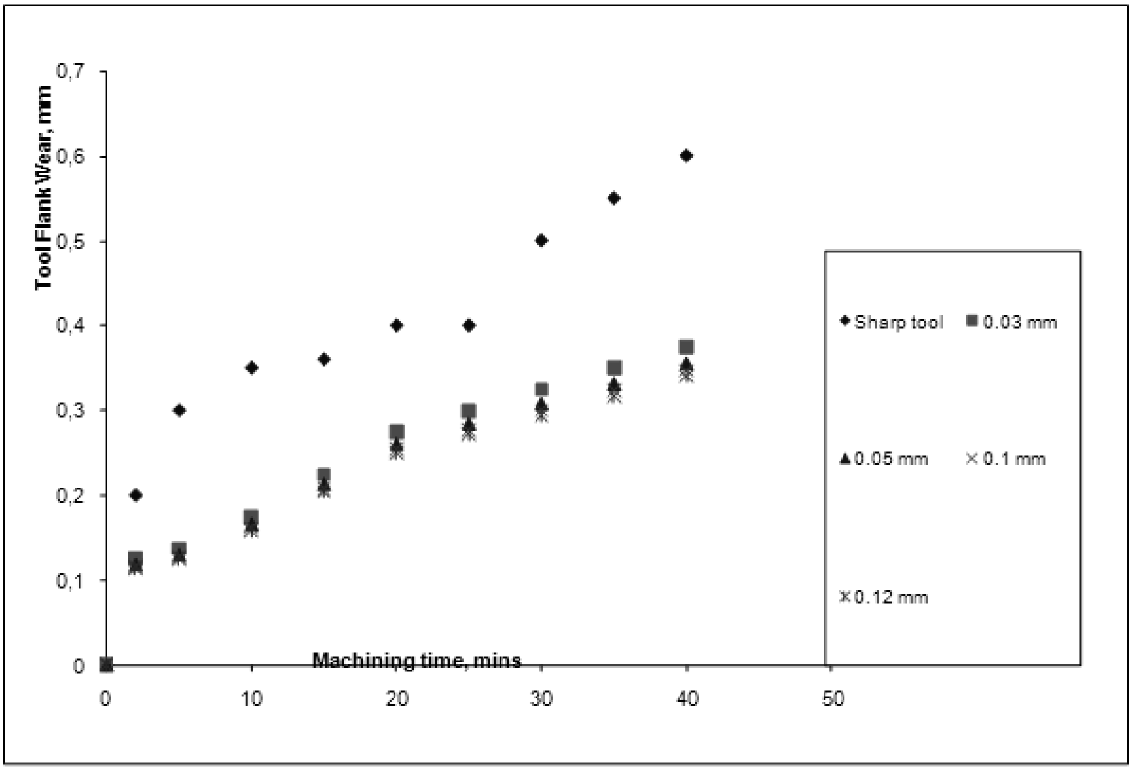

Figure 12: Variation of flank wear with machining time for honed and sharp tool (EN-9).

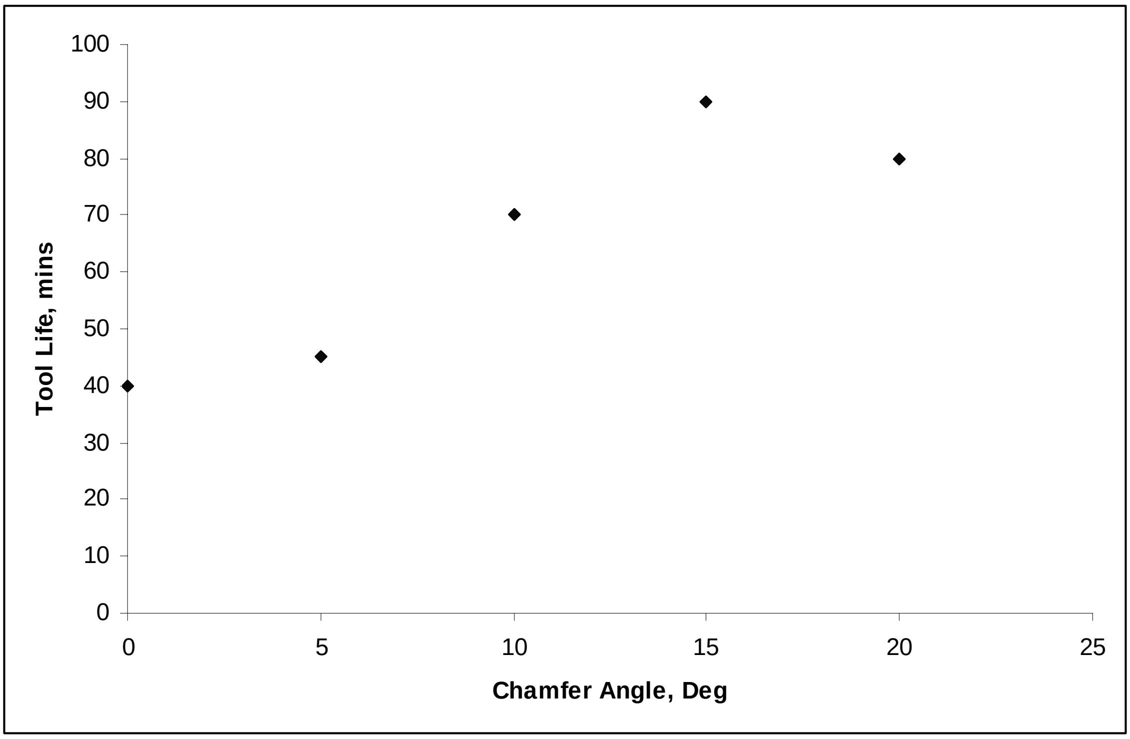

Figure 13: Variation of tool life with chamfer angle (EN-9).

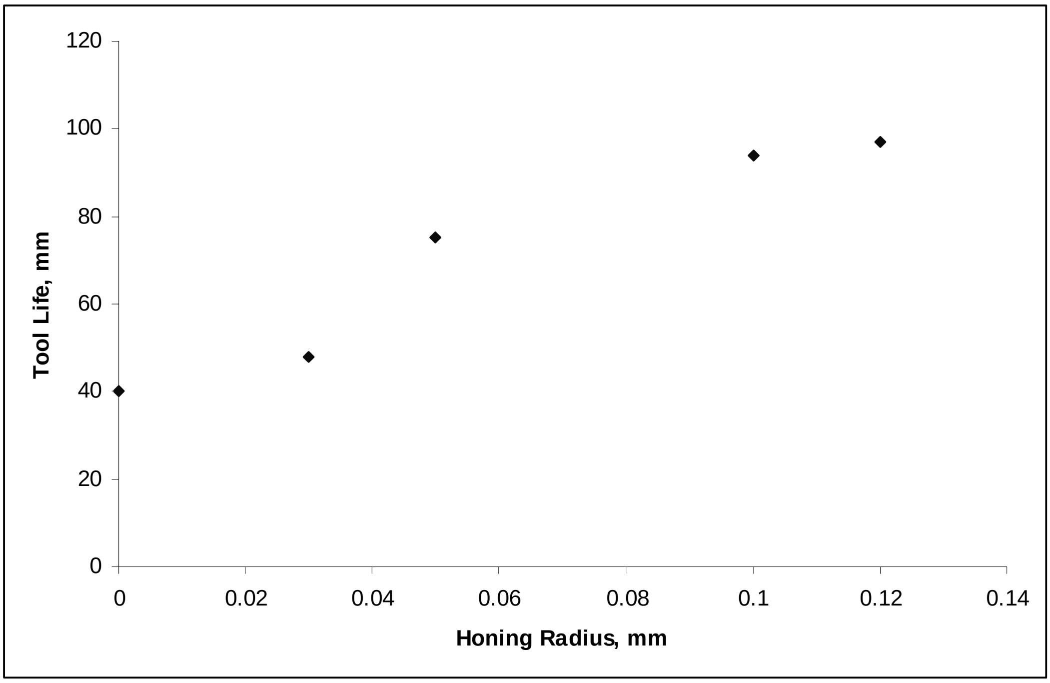

Figure 14: Variation of tool life with honing radius (EN-9).

In case of machining EN-9, it can be noted that in both chamfered and honed tools, tool wear tends to follow a third degree polynomial curve, similar to the machining of EN-8 steel. Regression coefficient is found to be 0.96. As in the previous case, tool life is evaluated for both chamfered and honed tools (Figure 13, Figure 14).

It is noteworthy that results are synonymous is both combinations of tool and workpiece thus validating the findings.

4. CONCLUSIONS

Chamfered tools and honed tools are subjected to lesser tool wear compared to sharp tool, since initial cut phase of tool flank wear is postponed in them. However, cutting forces are higher in chamfered and honed tools compared to sharp tool. Compared to chamfered tools, honed tools showed less tool wear. Chamfered tool with 15° chamfer angle is subjected to minimum tool wear, as this is a break-even between the increased strength and the increased tool-workpiece contact area. However, in honed tools, tool wear is low for higher honing radius. The major limitation of the work is that experimentation is carried out only for a set of chamfer angle and honing radii, in view of the practical difficulties; this can be extended and future work may be carried with finer tunings of the values to identify more optimal chamfer angle and honing radius.

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