PERFORMANCE ANALYSIS OF CERAMIC AND CARBIDE CUTTING TOOLS IN MACHINING OF EN36

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Abstract: The aim of this research is to compare ceramic and carbide cutting tools in milling EN36. The hardness of the workpiece material was measured and found to be 62 HRC. In the present work a series of tests were conducted in order to evaluate the tool performances by adopting tool life. In all experiments cutting forces, flank wear and surface roughness values were measured throughout the tool life. No cutting fluid was used during the milling operations. Study of the tool life and failure modes shows that tool life was determined by the flank wear and surface roughness generated on the workpiece. The main conclusion is that tool life of ceramic insert was longer than the carbide insert although much higher cutting speeds were used.

Keywords: ceramics, wear, tool life, cutting force.

1. INTRODUCTION

Ceramic cutting tools in recent years have been sought in many applications due to their improved properties like good thermal shock resistance, good high-temperature strength, creep resistance, low density, high hardness and wear resistance, electrical resistively, and better
They have unique chemical and mechanical properties and these tools can offer increased metal removal rates, extended tool life and have the ability to machine hard workpiece materials like stainless steel and hardened steel. These properties have now enabled the ceramic tools to be used in the machining of various types of steel, cast iron, non-ferrous metals and refractory nickel based alloys at high speeds.

For machining on EN36, the most widely used ceramic class is the alumina-based class. There are different classes of ceramic materials for cutting tools, each with different properties. The two main classes of ceramic for cutting tools are aluminum oxide (Al₂O₃)- based, and silicon nitride-based (Si₃N₄). The Si₃N₄-based ceramics are formed by crystals of Si₃N₄ with an intergranular phase of SiO₂. Compared to the Al₂O₃ class, the Si₃N₄-based ceramic has a higher toughness, greater hardness, increased thermal shock resistance, but lower chemical stability with respect to iron.

The wear behaviour of ceramic cutting tools has to be properly understood for their effective utilization in machining hard materials. Varieties of researches have been carried out focusing on the ceramic cutting tool materials in machining different work materials. The material fabrication and its cutting performance of Al₂O₃/TiC ceramic tool observed that the occurrence of plastic deformation of the ceramic cutting edge, triggered surface roughness deterioration, and eventually, edge fracture, while machining hardened steel using ceramic cutting tool materials which carried out machining experiments with cast iron using several types of ceramic and carbide tools. Their results showed that the dominant wear mechanism for aluminum oxide-based ceramics was abrasion, while for silicon nitride-based ceramics the basic mechanism was diffusion. This comparison was made in terms of tool and workpiece surface roughness and to understand the wear mechanism of silicon nitride-based ceramic tools and carbide tools in milling of EN36.

Nowadays, most carbide tools used in the machining of EN36 have microscopic layers. The main materials are titanium carbide, aluminum oxide (Al₂O₃), titanium nitride (TiN) and titanium carbonitride (TiCN). The chief purpose of these increase wear resistance of the tool external layers which have contact with chips and workpiece, while the tool substrate keeps the toughness of the regular cemented carbide. Most of the carbide tools inserts used to machine on EN36 are using the chemical vapour deposition (CVD) technique.

The main goal of this research is to compare two different tool materials (ceramic and carbide) in the milling operation of EN36. Some experimental results on the cutting performance of ceramic and carbide tool materials are reported and wear mechanisms are analyzed with microstructural observation.

2. MATERIALS AND METHOD

2.1. Material Properties
Rectangle EN36 bars in 50 mm diameter and 40 mm length that were EN36 at constant temperatures and times were used as base materials. EN36 samples were hardened at particular temperature. Before hardening
treatment, the bar ends were cut off and the casting skin was removed leaving 50 mm of diameter and 40 mm of length for the workpiece. The hardness of the work-piece material was measured and found to be 62HRC.

2.2. Machinability test

Machining tests were carried out according with Standard ISO 3685 (ISO, 1993) which involves milling of a bar at a constant cutting speed (V) and the identification of the cutting time (Tc) necessary to obtain a specific value of tool flank wear. The experimental conditions have been given in Table 2. Since conventional 5.5 KW TOSS lathe was used in the tests.

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Table 2. Experimental condition

| Machine tool                  | Milling, 5.5 KW, CNC |
| Work specimen’s materials    | EN36                |
| Size                        | (Rectangle bar workpiece 50×40 mm) |
| Cutting tools               | Ceramic Tool and Carbide Tool |

| Tool holder                  | CDBNR 2525 M12      |
| Working tool geometry        | Inclination angle:6, rake angle:6, clearance angle:6, edge angle:75 |
| Principal nose radius        | 0.8 mm              |
| Force dynamometer            | Kyowa TD-500        |
| Microscope                   | Nikon104 with a magnification of X10 |
| A profilometer               | Taylor Hobson Talysurf 10 |
| Process parameters           |                     |
| Cutting velocity, V          | 128 m/min for carbide, 192 m/min for ceramic inserts |
| Feed rate, f                 | 0.12 mm/rev         |
| Depth of cut, a              | 1.0 mm              |
| Environment                  | Dry                 |

Table 3. The composition and properties of cutting tool materials

<table>
<thead>
<tr>
<th>Details of tool material</th>
<th>Unit</th>
<th>Carbide tool</th>
<th>Ceramic tool</th>
</tr>
</thead>
<tbody>
<tr>
<td>Composition</td>
<td></td>
<td>90% W, 6% Ni, 4% Cu</td>
<td>Al:Oxygen:70% TiN 22.5% TiC 7.5%</td>
</tr>
<tr>
<td>Insert specification</td>
<td></td>
<td>DNMG 15 06 08 T01020</td>
<td>DNMG 15 06 08 T01020</td>
</tr>
<tr>
<td>Density</td>
<td></td>
<td>11.6</td>
<td>4.26</td>
</tr>
<tr>
<td>Vickers hardness</td>
<td></td>
<td>1500</td>
<td>1800</td>
</tr>
<tr>
<td>Transverse rupture Strength</td>
<td></td>
<td>2150</td>
<td>550</td>
</tr>
<tr>
<td>Young’s modulus</td>
<td></td>
<td>530</td>
<td>400</td>
</tr>
<tr>
<td>Fracture toughness</td>
<td></td>
<td>13</td>
<td>4.0</td>
</tr>
<tr>
<td>Thermal conductivity</td>
<td></td>
<td>42</td>
<td>24</td>
</tr>
<tr>
<td>Coefficient of thermal</td>
<td></td>
<td>12.4</td>
<td>8.6</td>
</tr>
<tr>
<td>Expansion</td>
<td></td>
<td>10^12 x10^-12</td>
<td></td>
</tr>
</tbody>
</table>
In all experiments, depth of cut (a) was 1.0 mm, feed rate (f) was 0.12 mm and cutting speeds (V) were 128 m/min for carbide tool and 192 m/min for ceramic tools (which is an acceptable cutting speed for EN36 materials. It was obvious that the ceramic tool would present very long tool life, if the same cutting speeds were used for both tool materials. This is why the different cutting speeds were used.

As the tool life criteria, a value of 0.3 mm of average flank wear land (VBₘ) that was clamped on tool holder CDBNR 2525 M12 was used in the tests. Cutting forces, flank wear and surface roughness values were measured until the tool expires. The cutting forces were measured by a three-dimensional force dynamometer, Kyowa TD-500, the flank wear of the tool was measured by Nikon104.
3. RESULTS AND DISCUSSIONS

3.1. Flank wear

Flank wear is a major form of tool wear in metal cutting. When machining using tools under typical cutting conditions, the gradual wear of the flank face is the main process by which a cutting tool fails (Luo et. al., 2005, Haron et. al., 2001 and Arsecularatne et. al., 2006). The flank wear in the ceramic cutting tools is a mechanically activated wear usually by the abrasive action of the hard workpiece material with the ceramic cutting tools. It occurs on the relief face of the cutting tool and is generally attributed to the rubbing of the tool along the machined surface and high temperatures causing abrasive and/or adhesive wear, thus affecting tool materials properties as well as work piece surface Seker et. al., 2006 and Sornakumar et. al., 1995).

Tool life estimation involves a number of tests to be carried out at constant cutting conditions till the failure of the cutting tool. In general, as the tool life criterion, amount of flank wear is used. The cutting test was started with a new cutting tool, and the machining process was stopped at certain intervals of cutting length in order to measure the width of flank wear. Flank wear curve of the ceramic and coated carbide tools in machining EN36 is shown in Figure 4. It indicates that ceramic tool material has good wear resistance. Under the experimental conditions, and ceramic tool has uniform flank wear.

3.2. Surface finish

One of the important parameters in evaluating the performance of a cutting tool is the surface quality. Theoretically, surface roughness is a function of feed rate and nose radius. But in practice; cutting speed, cutting depth and tool wear have influence on surface roughness as well. The advantage of machining using ceramic cutting tools is generally seen in higher levels of surface finish obtained compared to that of other conventional tools such as cemented carbides (Seker et. al., 2006).
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Surface finish is one of the most stringent requirements placed on finish operations; its degradation is usually due to the tool wear. For this reason, the workpart surface finish and the tool flank wear were used to evaluate the tool performance. In particular, the wear criterion adopted in the finish turning tests was based on a maximum allowed value imposed to the average surface roughness.

Surface roughness values that were measured by a profilometer 10 mm from the chuck first, in every 75 mm, were compared. Figure 5 depicts the surface roughness values of each one. In X axis of the diagram the distance from the chuck of lathe is given in millimeters, and in Y axis surface roughness values (Ra) in microns.

The values in the roughness figures of this work are an average values obtained throughout the whole experiment. Figure 5 shows the flank wear versus surface roughness for different cutting inserts. It can be observed that surface roughness values for workpieces machined by ceramic tools were somewhat lower. Since cutters, carbide and ceramic had the same cutter geometry and the same cutting edge microgeometry, the lower roughness obtained with ceramic tools must be attributed to the higher cutting speed used when ceramic tools were employed. The surface quality gets worse not only as the tool wears but also as the tool moves away from the chuck, therefore this should be considered in surface quality evaluations.
3.3. Cutting forces

The magnitude of the cutting forces is one of the most important machinability indices as it plays vital roles on power and specific energy consumption, product quality and life. Force signals are highly sensitive carriers of information about the machining process. The force displays were also reported to provide evidence of the nature of the relationship between force and wear which means the increase in cutting force indicates the increase of wear on the tool. Tangential cutting force versus cutting time is shown in Figure 6. The tangential cutting force values at the beginning of the cut and at the end of the tool life when the tool wear reaches to its critical value were used in comparisons.
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In tool life evaluation milling processes were paused in every 75 milimetres and the average flank wear was measured. If the tool was not expired (which means it does not reach to a value of 0.3 mm of average flank wear land) at the end of the first bar, second bar of the same structure was used for the rest of the process. This was necessary for the constant cutting speed as explained previously. The ends of bars were chamfered to ease the entry of the tool to the workpiece. Machined workpieces (50x40 mm) are heavy. No matter how well they were supported by the tailstock, the stability problem was encountered in some cases which affect the surface quality. This means the surface quality gets worse not only as the tool wears but also as the tool moves away from the chuck, therefore this should be considered in surface quality evaluations.

Figure 8 shows the average chip volume removed per tool life in the experiments. As can be seen in this figure, the ceramic tool attained a much longer tool life than carbide tool, even under higher cutting speed. It must be remembered that the cutting speed used for ceramic tools was 1.5 times higher than for carbide tools, making cutting 1.5 times faster too. Thus, in this kind of operation, ceramic tools are much more suitable than carbide tools.

Figure 7:
Tangential cutting force vs. cutting time $V=128$ m/min (carbide tool), $V=192$ m/min (ceramic tool), $f=0.12$ mm/rev, $a=1$ mm

Figure 8:
Chip volume removed per tool life for each tool material $V=128$ m/min (carbide tool), $V=192$ m/min (ceramic tool), $f=0.12$ mm/rev, $a=1$ mm
4. CONCLUSIONS

The paper describes a machinability evaluation of EN36 with ceramic tool and carbide tool. The experimental results showed that there are strong correlation between tool wear, cutting force, and surface finish. Tool life models were developed using the wear data. Based on the results obtained in this work, it can be concluded that:

(a) Flank wear increase over tool life influence surface roughness, which remained nearly constant throughout tool lives, especially for the experiments with alumina-based ceramic tool.
(b) Ceramic cutting tool presented longer tool lives than carbide tool although much higher cutting speeds were used.
(c) Machining with ceramic tools presented average surface roughness values lower than those obtained with carbide tools and also with smaller dispersion.
(d) Ceramic cutting tool material has good wear resistance in dry machining of EN36.
(e) Ceramic cutting tool is lower than carbide cutting tool on machining EN36.

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REFERENCES


