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A Comparative Study on Flank Wear of Ceramic and Tungsten Carbide Inserts during High Speed machining of Stainless Steel

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Abstract

To meet the challenge of higher speeds for higher production rates, carbides (also known as cemented or sintered carbides) were introduced in the 1930s. Tungsten carbide (WC) is a composite material consisting of tungsten-carbide particles bonded together in a cobalt matrix; an alternate name for WC is cemented carbides. As the cobalt content increases, the strength, hardness, and wear resistance of WC decrease, while its toughness increases because of the higher toughness of cobalt. Alumina based ceramic tools consist primarily of fine-grained, high-purity aluminum oxide. They are cold-pressed into insert shapes under high pressure and sintered at high temperature. Additions of titanium nitride and zirconium oxide help improve properties such as toughness and thermal-shock resistance. However, ceramics are very brittle, and their use may result in premature tool failure by chipping of the cutting edges or catastrophic failure. Due to their brittleness they are effective in high-speed, uninterrupted cutting operations. Because of their high hardness over a wide range of temperatures, high elastic modulus and thermal conductivity, and low thermal expansion, carbides are among the most important, versatile, and cost-effective tool and die materials for a wide range of applications.

In the present research work a study has been done to compare the flank wear of ceramic and tungsten carbide inserts during high speed machining. As flank wear increases, friction between the tool and the workpiece also increases. This results poor work surface finish and increase in cutting force and consequently more flank wear. It was found that for both ceramic and tungsten carbide tools flank wear increases with increase in cutting speed, feed rate and depth of cut. But cutting speed is the most significant factor resulting flank wear. The results of the investigation shows that flank wear is more for ceramic tools compared to that of carbide tools for most of the experiment runs. The reason behind it is, with increase in cutting parameters like cutting speed, feed rate and depth of cut, vibration during machining increases that results microchipping of the cutting edge resulting higher flank wear. But when the cutting parameters are low, then less vibration occurs and ceramic tools shows better performance than carbides in terms of flank wear.

Keywords: Ceramic, Carbide, Flank wear, Cutting speed, Feed rate, Depth of cut.

INTRODUCTION

Now-a-days most of the metallic parts are made by machining. During machining tool wear is of great concern because it affects the quality of machined surface. Both dimensional accuracy and surface finish of the machined surface depend on tool condition. In order to reduce tool wear new tool materials are developing very fast. Starting from carbon steel tools (around 1895), high speed steel (around 1905), cast cobalt alloys (around 1915), cemented carbides (around 1930), improves carbide grades (around 1955), first coated grades (around 1970), first double coated grades (around 1973), first triple coated grades (around 1985) cubic boron nitride (around 1950) were introduced for machining. During the period from 1900 to 1990 productivity of machining was increased to almost 150 times due to improved capabilities of tool materials to machine at high cutting speed. High hardness, especially at elevated temperature, chemical stability and high resistance to wear make the tool materials capable of machining at high speed. Accuracy of machining is the key aspects that influence the quality of machined parts. Accuracy of machining mainly depends on tool wear. Both ceramic and carbides are extensively used in machining for their wear resistance.

Metal cutting industries are using ceramic cutting tools for over 100 years [1]. Ceramic cutting tools are constructed mainly from alumina (Al_2O_3) and silicon nitride (SiN). Recent advances have also introduced the use of silicon carbide (SiC) and ceramic matrix composites (CMCs) in order to enhance the performance of the cutting tools. The ceramic cutting tools have their own benefits to the manufacturing industries. The most common benefits of using ceramic cutting tools are increasing productivity and efficiency in machining process. They have high hardness, good wear resistance and chemical stability. But ceramic tools are very brittle. Al_2O_3 based ceramic cutting tools are widely used in dry cutting and high-speed machining of hardened workpiece materials due to their unique intrinsic properties. Even so, it also has a setback where the friction coefficient under dry cutting condition of hard materials will become relatively high. This will surely cause increasing tool wear and reduced tool life. Various new tools and methods were developed to reduce friction and wear and extend the tool life. One of the effective ways to improve the tribological performance and wear resistance of materials is surface coating, which includes hard-coatings and soft-coatings [2]. Ceramic tools are characterized by high hardness, great heat resistance, good wear resistance, and chemical stability. They are one of the most important ideal choices in machining ultra-high-strength steels [3]. Optimization of cutting parameters was also investigated to reduce tool wear and improve work surface finish [4]. To meet the challenge of higher speeds for higher production rates, carbides (also known as cemented or sintered carbides) were introduced in the 1930s [5].

Because of their high hardness over a wide range of temperatures, high elastic modulus and thermal conductivity and low thermal expansion, carbides are among the most important, versatile, and cost-effective tool and die materials for a wide range of applications. The two basic groups of carbides used for machining operations are tungsten carbide and titanium carbide.

In the present work a comparative analysis has been done on wear resistance of ceramic and tungsten carbide inserts.

METHODS

Experiment Setup

Experiments were conducted on a lathe machine as shown in Figure 1.

Figure 1: Lathe machine

Workpiece and tool materials

In the present work SUS 304 stainless steel cylinder was used as the workpiece with dimension 39 mm diameter, and 450 mm length. The chemical composition and mechanical properties of SUS 304 are shown in Table 1. Figure 2 shows the inserts used for the experiments. The properties of inserts are presented in Table 2. Selection of machining parameters was done based on previous experiments and literature review. Experimental plan was done using DOE software. After each of the run flank ware was measured using Mitutoyo microscope TM-500.

Table 1: Properties of SUS 304 stainless steel

Chemical composition (%)					
Chromium	Silicon	Manganese	Sulfur	Nickel	Carbon
18-20	1.0	2.0	.03	18-20	.08
Mechanical properties					
Yield strength (ksi)	Tensile strength (ksi)	Elongation (%)	Reduction of area (%)	Brinell hardness (HB)	
30	75	40	60	187	

(a) (b)

Figure 2: Inserts used (a) ceramic; (b) carbide

Table 2: Properties of Tungsten Carbide and Ceramic tools

Properties	Tungsten carbide	Ceramic
Hardness RA	90-95	91-95
Compressive strength MPa	4100-5850	2750-4500
Transverse rupture strength MPa	1050-2600	345-950
Impact strength J	0.34-1.35	<0.1
Modulus of elasticity GPa	520-690	310-410
Density kg/m3	10,000-15,000	4,000-4,500
Thermal conductivity W/mK	42-125	29

Results and Discussions

Flank wear of ceramic tools and carbide tools are shown in Table 3 and table 4 respectively. After each of the experiments flank wear was measured and the results were analyzed using DOE. 3D model graph of flank wear of carbide tools are presented in Figure 3 and Figure 4. On the other hand flank wear of ceramic tools depending on cutting speed, feed rate and depth of cut is presented in Figure 5 and Figure 6.

Table 3: Flank wear of ceramic tools

Run	**Speed (rpm)**	**Feed rate (mm/rev)**	**Depth of cut (mm)**	**Flank wear (mm)**
1	470	0.1	0.50	0.081
2	1120	0.2	1.00	0.319
3	470	0.1	1.00	0.159
4	1120	0.2	0.50	0.302
5	470	0.2	0.50	0.182
6	470	0.2	1.00	0.197
7	1120	0.1	1.00	0.291
8	1120	0.1	0.50	0.287

Table 4: Flank wear of carbide tools

Run	Speed (rpm)	Feed rate (mm/rev)	Depth of cut (mm)	Flank wear (mm)
1	470	0.1	0.50	0.121
2	1120	0.2	1.00	0.211
3	470	0.1	1.00	0.139
4	1120	0.2	0.50	0.176
5	470	0.2	0.50	0.146
6	470	0.2	1.00	0.159
7	1120	0.1	1.00	0.163
8	1120	0.1	0.50	0.158

It clear from Figure 3 and Figure 5 that increase in cutting speed results intensive tool wear for both carbide and ceramic tools. As cutting speed increases, more energy will be required for machining and more heat is generated. As a result of more heat, tool becomes softer and results more abrasion wear of the tools. From Figure 4 and Figure 6 it can be observed that increase in feed rate and depth of cut results more flank wear. Higher values of depth cut and feed rate results more heat and the tool is more loaded. As a result tool wear becomes more [6,7].

A comparison of flank wear between ceramic tools and tungsten carbide tools is presented in Figure 7. It can be found from the Figure that in almost all runs wear of ceramic tools is higher than tungsten carbide tools. The reason behind is that ceramic tools are more brittle compared to carbides. At a higher cutting conditions as cutting speed, feed rate and depth of cut are increased, higher is the cutting force and more is the vibration. As a result microchipping of cutting edges occurs in ceramic tools resulting more flank wear. But in the first run all the cutting parameters are low; therefore, cutting force is low, vibration is also low and ceramic tools demonstrate better performance [8].

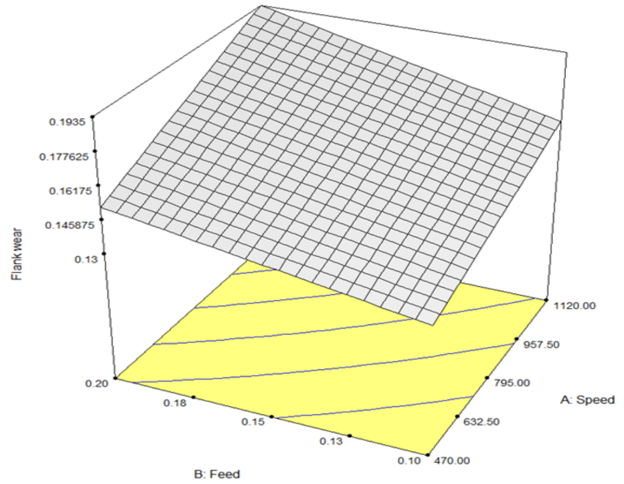

Figure 3: Flank wear of carbide tools depending on cutting speed and feed rate

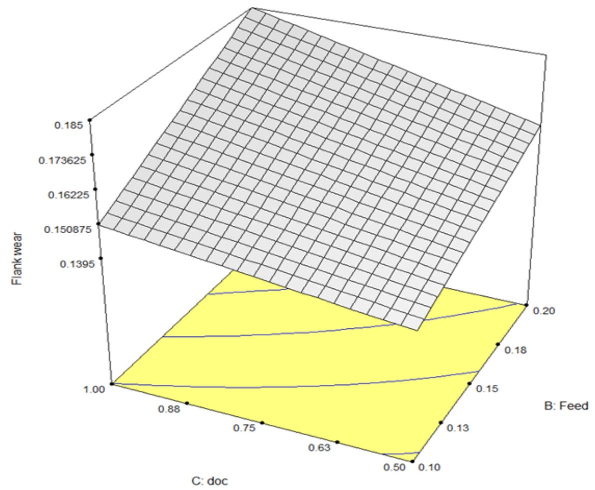

Figure 4: Flank wear of carbide tools depending on feed rate and depth of cut

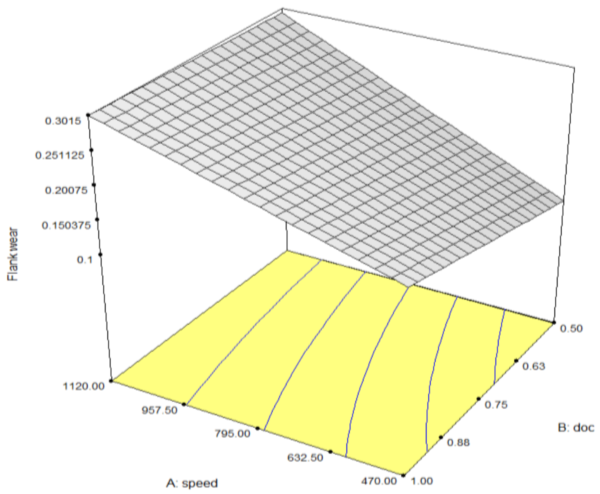

Figure 5: Flank wear of ceramic tools depending on cutting speed and depth of cut

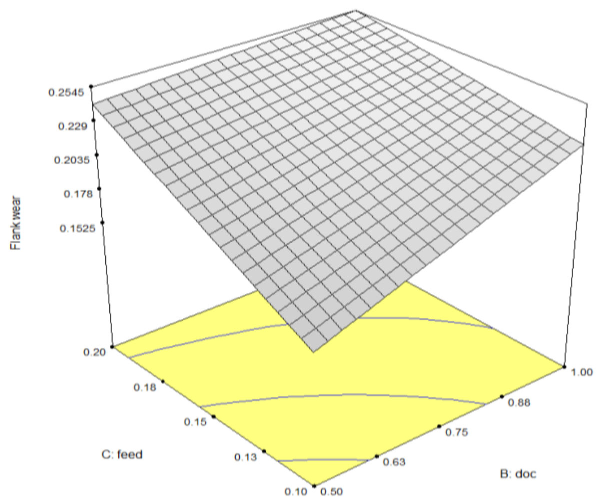

Figure 6: Flank wear of ceramic tools depending on feed rate and depth of cut

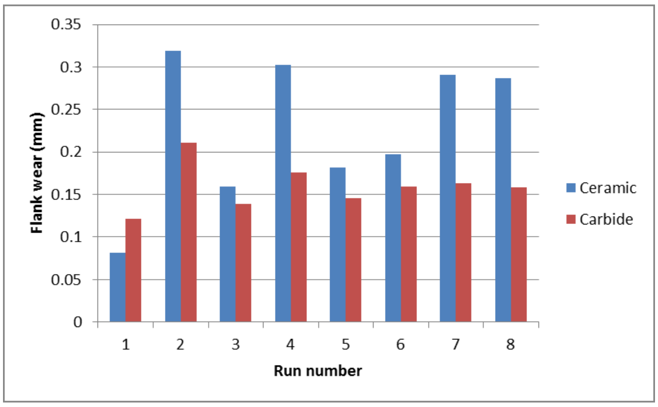

Figure 7: Comparison of flank wear between ceramic and tungsten carbide tools.

CONCLUSION

In the present work, machining performance of ceramic and tungsten carbides cutting tool has been investigated. The cutting parameters are the platform to evaluate the machining performance and flank wear of the cutting tools. The experimental plan was done using Design of Experiments (DOE) version 6.08. All the data was analyzed using that software.

It was found that cutting speed is the most significant factor responsible for flank wear. At a higher cutting speed more heat is generated in the shear plane and also due to friction of the tool with the workpiece and chips. More heat means higher temperature of the tool. As a result tool material becomes softer and abrasion wear occurs. Similarly, depth of cut and feed rate also influence on flank wear. Increase in feed rate and depth of cut cause more heat resulting more wear of tools.

It was found that in almost all runs flank wear of ceramic tools is higher than that of tungsten carbide tools. The reason behind is that ceramic tools are more brittle compared to carbides tools. At a higher cutting conditions, as cutting speed, feed rate and depth of cut are increased, higher is the cutting force and more is the vibration. Vibration results microchipping of cutting edges in ceramic tools resulting more flank wear. But if the cutting condition is mild; that is cutting speed, feed rate and depth of cut are low, then cutting force is also low and less will be microchipping of the cutting edges. That results less tool wear.

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