RESEARCH ARTICLE OPEN ACCESS

Improvement of Carbides Tool Based On Stress Rules

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Abstract
Machining is a common fabrication technique where material is shaved from a part using a tool with a small, hard tip. In order to quickly fabricate a part, a high cutting speed is desired. These higher speeds, however, lead to a faster degradation of the tool tip, which requires that the tool tip be replaced more frequently. Over the history of machining, guidelines and conventions have arisen based on empirical information of tradeoffs between cutting speed and tool replacement time. On the other hand, very little attention has been paid analytically to understanding the behavior of the tool, specifically with regard to extending its lifetime. This lack of numerical investigation of tool response is surprising, given the possible cost and time savings of extending the life of the tool, which allows either faster cutting speeds or a longer time between retooling. In this project it is to use the finite element analysis software and X-ray diffraction method to find the behavior of specific tool tips under controlled cutting conditions so as to optimize the residual stress in the tool which will allow to make recommendations for extending tool life based on understanding of tool failure mechanism
Index Terms : Tool geometry, Finite element analysis, Tungsten Carbide-Cobalt.

I. INTRODUCTION

Cutting tools must be able to resist high temperature and severe temperature gradients, thermal shock, fatigue, abrasion, attrition, and chemical induced wear [1, 2]. Thus materials for cutting tools and dies must have high hardness to combat wear, hot strength to overcome the heat involved, and sufficient toughness to withstand interrupted cuts or vibrations occurring during the machining process. Cutting tools are a two billion-dollar industry worldwide and form the backbone of manufacturing operations for metals, polymers, and advanced materials such as intermetallics and composites of all types [1, 2].

The Discovery of Tungsten Carbide

Henri Moissan (1852-1907), a Nobel Laureate (1906), is best known as the inventor of the electric furnace and for his unsuccessful attempts to prepare artificial diamonds. It was in his laboratory at the School of Pharmacy at the University of Paris, that the two carbides of tungsten were discovered, namely W2C (1896) by H. Moissan and WC (1898) by P. Williams [6].

The most suitable substrate materials for producing diamond-coated tools are SiC w7,8x, Si3N4 w9x or Cocemented tungsten carbide (WC-Co). However, ceramic substrates are too brittle and WC contains cobalt as a binder, which provides additional toughness to the tool but it is hostile to diamond adhesion w10–12x. As a consequence, it is impossible to deposit adherent diamond coatings onto untreated WC-Co tools and surface cobalt must be removed deep enough to avoid it reaching the surface by diffusing during the CVD process. However, a large cobalt depleted zone may make the cutting edges brittle. Therefore, substrate pretreatment represents a crucial step in the coating process. Its effectiveness in increasing adhesion and attaining desired functional properties of WC-Co coated parts might be strongly influenced by substrate microstructure. For this reason, we have studied the combined effect of substrate pretreatment and grain size on the wear resistance of diamond coated WC-Co inserts in the dry turning of aluminum-based metal matrix composites (MMC).

High speed machining (HSM) using ceramic or cubic boron nitride (CBN) tools is one possible alternative for improving productivity. HSM provides added advantages of workpiece softening and chip control . Ceramic and CBN tools have superior hot hardness and so could be used at speeds an order of magnitude higher than the coated carbide cutting tools. To date, there has been a considerable amount of research published on the performance of these tools in the machining of HRSA, which has been reviewed in great detail in references [3–6]. While trying to improve the productivity by using different cutting tools and parameters, it is essential that the quality of the machined surface is considered, as it can drastically affect component performance, longevity and reliability.

However, titanium alloys are difficult to machine due to their high temperature strength, low modulus of elasticity, low thermal conductivity and high chemical reactivity [1–3]. Cutting of titanium alloys has always been a topic of great interest for industrial production and scientific research worldwide. The chemical reactivity of titanium alloys with tool materials and their consequent welding by adhesion onto the cutting tool during machining leads to excessive chipping, premature tool failure, and poor surface finish. Titanium alloys can maintain their high strength levels at elevated temperature. These characteristics cause high temperatures at the tool–chip interface during machining. The maximum temperature between chip and tool can reach 1000 ◦C when machining Ti–6Al–4V at high cutting speed [4–7], high cutting temperature promotes thermally related wear phenomena, and is the principal reason for the rapid tool wear. The element diffusion from the tool to the titanium alloy (and vice versa) through the tool–chip interface leads to composition change of the tool substrate, which may increase the possibility of mechanical damage of the cutting edge.

II. RELATED WORD

2.1 Residual Stress

Compressive residual stresses have an extending effect on lifetime [6-8], as load induced stresses superimpose residual stresses. For PVD-coated cutting tools it could be shown by means of X-ray diffraction that the coatings possess strong, while the substrates show moderate compressive residual stresses.

Inconel 718 bars of diameter 100 mm and thickness 15 mm in solution treated and age hardened condition having a hardness of 36 HRC were used as work piece material. Before conducting the machining tests, a thin layer of 0.5 mm was machined with a new cutting edge from each sample in order to remove the uneven surfaces due to the previous operation and to ensure consistency. The face machining operations were carried out on a 15 kW rigid CNC lathe with a constant speed capability. All machining was performed with coolant except for the ones used to study the influence of dry cutting on the residual stresses and surface roughness. The two tool materials used in the study are pure CBN and mixed ceramic (Al_2O_3 and TiC). The specifications of the cutting tool materials, cutting conditions and tool holders. The cutting conditions used in this study are based on optimum tool performance investigated by the authors in a separate study . For the investigations on cutting speeds above 225 m/min, the cutting length was reduced, since after a certain length the rpm required to maintain that speed exceeded the maximum rpm (2000) of the machine. For each set of cutting conditions tested, two samples were prepared.

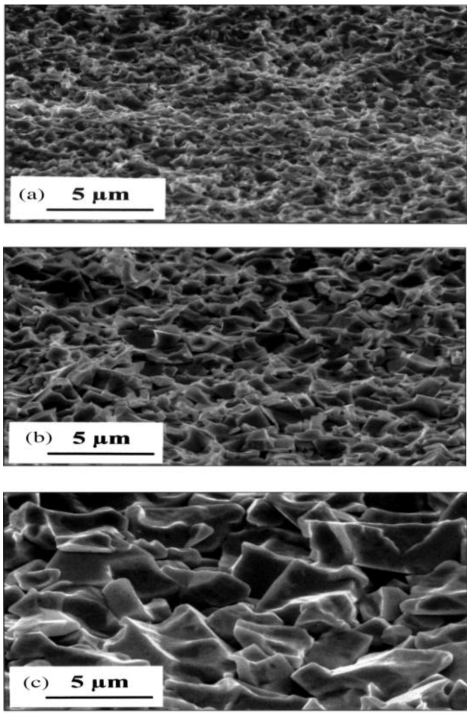


Fig. 1. Surface morphology of 1 mm- (panel a), 3 mm- (panel b) and 6 mm-grained (panel c) WC-Co substrates submitted to two-step chemical etching with Murakami's reagent and $H_2O_2qH_2SO_4$.

2.2 Consolidation of Nano WC/Co Composites

Consolidation of nanomaterials is a significant and challenging requirement for the engineering application of nanomaterials. The consolidation methods must preserve the nanometer grain sizes of the starting ma terials in order to preserve their expected advantages in physical properties through scale up to engineering application. There has been limited effort to consolidate nanoparticles to specimen volumes useful for physical property measurements [66]. Several techniques have been used during research on the consolidation of nano WC/Co composites.

Plasma Spray

Using thermal spray processing to deposit a coating of nano powders offers a high rate deposition method that can provide the effective pressure and temperature required to sinter high density nanostructured materials. However, most "as is" nano scale powders cannot be deposited, as they will closely follow the stream lines of the carrier gas. Thus, when the thermal spray gas jet is impinging on a substrate surface, very small particles will be slowed down and diverted by the flow in the stagnation region. Another practical difficulty is feeding the small particles into the gas stream. Particles smaller than 10 mm are extremely difficult to feed into the gas flow and can result in plugged particle feed lines because of particle agglomeration.

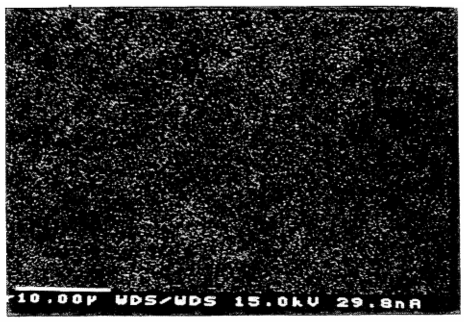


Figure 2. Cobalt dot map of MMI WC/Co @2000 X.

III. PERFORMANCE ANALYSIS

3.1 Predicted Chip Formation and Validation of the Finite Element Model.

It can be seen that the maximum temperatures of all states during cutting are in the region where there is friction between the tool and the chip. The maximum temperatures within the chip reach around 879 o C after 0.004 sec. These results agree well with the literature (Holmberg and Matthews, 1994; Saglam Unsacar and Yaldiz, 2005). The results show that the steady state is reached within the simulation time, as the tool/chip contact length is constant after 5 seconds. Figure 3 shows the predicted cutting force with the experimental cutting force. The total cutting forces were obtained from the sum of reaction forces acting on the coating surface. The simulation results showed that the cutting force increased until it reached the steady state where the cutting force no longer increases. The steady state cutting forces were used to compare with the experimental data obtained from Yen, Y-C, Jain, A, Altan, T (2004), for the cutting speed of 100 m/min. It can be seen from Figure 2b that the predicted cutting forces agree well with the experimental results (10 % lower). The high inelastic heat fraction used in this model leads to higher chip temperature, therefore the chip was softening and less cutting force was needed to deform it.

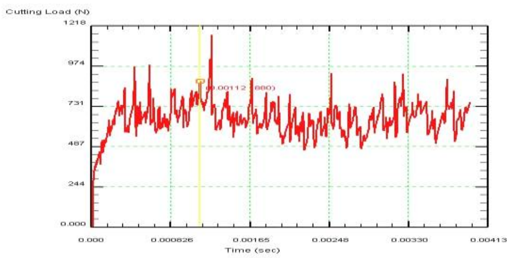


Figure 4: a) The predicted cutting force compare with the experimental cutting forces by Yen, Y-C, Jain, A, Altan, T (2004) of 850 N at the same conditions.

3.2 Diffusion Of Element From WC/Co Carbide To Ti–6Al–4V Alloy (Vice Versa)

The cross-section of the diffusion couple before and after heating in air atmosphere for 90 min at 800 ◦C is illustrated in Fig. 4. An about 20_m layer with loose structure can be observed at the Ti–6Al–4V alloy near the interface (Fig. 4(b)). The qualitative compositional profile shows the presence of W and Co in this layer.

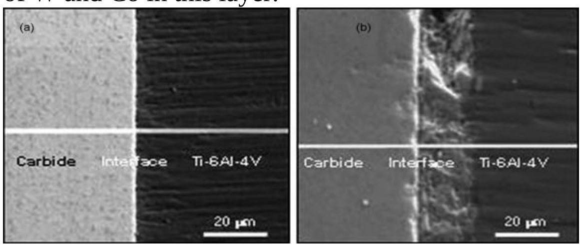


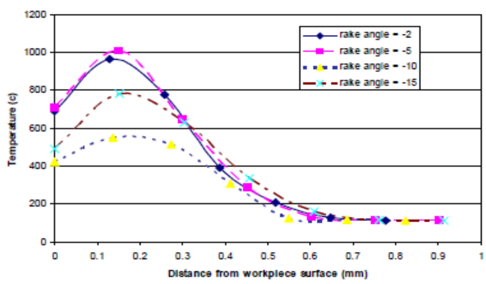
Fig. 3. SEM micrographs of the diffusion couple (a) before and (b) after heating in air atmosphere for 90 min at 800 ◦C.

3.3 Cutting Tests

In order to verify, that the stress state in the substrate's subsurface forwards cohesive tool damage, cutting tests with selected tools from all three suppliers have been performed. C45 has been cut by single tooth face plain milling. The cutting conditions were as follows: tool diameter d = 80 mm, cutting speed vc = 250 m/min, depth of cut ap = 2 mm, width of cut ae = 32 mm, feed per tooth fz = 0.3 mm. The stop criterion was VB = 200 µm.

IV. PERFORMANCE ANALYSIS

The maximum temperature increases with rake angle when the rake angle is smaller than 10o. It may be observed that there is the best rake angle for most of the cutting speeds where the temperature is the smallest. For the cutting speed of 100, 200 and 250 m/min the lowest temperature occurred at the rake angle of around 10o. This is because the normal pressure across the tool/chip interface is high with higher rake angle, such that the critical friction stress becomes constant according to the modified Coulomb law. The contact length is high at the low rake angle. Therefore, the local heat generation, which is proportional to the frictional shear stress, is also constant at the high rake angle.



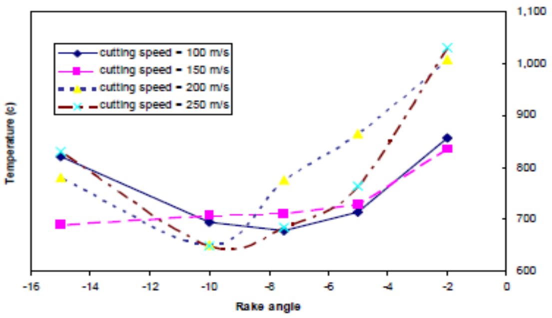


Figure 5: (a) The temperature along tool surface for different rake angle at the cutting speed of 200 m/min and (b) The effect of tool rake angle and cutting speed on predicted cutting temperature.

The wear depth at the nose of carbide cutting edge for rake angle -15 degree the during machining process. The wear depth between 0.00536 mm to 0.00766 mm. The same phenomenon accured for other the rake angle setting. The maximum wear depth for rake angle of 0 degree and –15 degree reached 0.00466 mm and 0.00361 mm respectively.

The effect of coolant on the residual stresses generated is shown in Fig.6. Dry cutting results in tensile residual stresses at both the cutting speeds tested, whereas the use of coolant results in compressive stresses up to 15 mm from the periphery and then becomes tensile residual stresses. The use of coolant lowers friction and increases the heat removal from the surface, thus resulting in the dominance of mechanical effects.

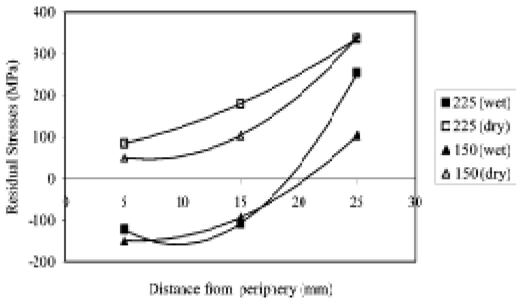


Fig. 6. Effect of coolant on the residual stresses for CBN (C1 type) cutting tool at two different cutting speeds (150 and 225 m/min; 0.15 mm/rev; 0.5 mm) at 5, 15 and 25 mm from the periphery.

Residual stresses and surface roughness generated by CBN and mixed alumina ceramic cutting tools in the facing operation of Inconel 718 has been investigated and the influence of cutting speed, depth of cut, insert geometry and coolant on the residual stresses and surface roughness have been quantified for CBN cutting tools. The following are the conclusions that could be derived from this investigation.

V. CONCLUSION

Nano-grained WC/Co composites have the potential to become the new materials for tools and dies, and wear parts. Benefits of nano-grained WC/Co approach include shorter sintering time, high purity, and precise control of composition. These materials

have superior properties and more homogeneous microstructure than those of conventional WC/Co composites do. The development and improvement of cemented carbide cutting tools have supported the exponential increases in metal cutting productivity (measured by cutting speeds) in this century. Materials of the future will have to satisfy the requirements imposed by high-speed machining, such as high-temperature strength, chemical stability, and oxidation resistance. Currently, research is aimed at developing grades having improved wear, corrosion, and oxidation resistance. The highest stress and strain on work piece occurred in the primary shear zone due to the highest deformation in this region, followed by the secondary shear zone. The maximum generated temperature was also found on shearing zone.

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