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Machining Hard Materials Using Coated Cutting Tools

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Abstract

This paper discusses improvements associated with the life of cutting tools used to machine M42 tool steel,Titanium alloy (Ti-64)and modified AISI P20 tool steel.Titanium is one of the important metals is used in various fields of engineering and medical sciences.In order to assess the impact of different tool coatings on the machining process, initial experiments simulate existing machining operations; this provides a standard for tool life and surface finish. The findings in the paper show that TiAlCrYN coated WC-Co cutting tools perform better than uncoated cutting tools to machine M42 tool steel. The implications of the paper tend to indicate that machining M42 tool steels without lubricant can be optimized using coated cutting tools. Polycrystalline diamond (PCD) can be successfully used to machining of titanium alloy (Ti-64) and modified AISI P20 tool steel using TiN coated inserts. The limitations of the paper include machining at one specific cutting speed and the employment of a short-time tool wear method. The practical implications of the paper show that dry machining of hardened tool steels can be achieved under certain circumstances.One of the main pre-requisites for successful industrial production is the use of quality coated cutting tools with defined mechanical and technological properties. Therefore, for the development and introduction of new coated cutting tool (new combination of cutting material and hard coatings), it is necessary to carry out a number of studies with the purpose to optimize the coatings composition and processing procedures, and also to test new tools in working conditions. The requirements from industry areto produce faster, better, safety and more ecologically, force us to develop new effective tools and innovative technologies. This provides a technological challenge to the scientists and engineers and increases the importance of knowing several scientific disciplines.

In general, a finish machining of a titanium component will be necessary, because of the requirement of exact dimensional accuracy, surface quality and material homogeneity. Machining of titanium alloy poses considerable problem due to its poor machinability. The poor machinability of titanium has led many large companies (for example Rolls-Royce and General Electric) to invest largeamount of money in developing techniques to minimize machining costs. Similarly, tool makers are looking for new tool materials which can extend tool life in the presence of such a challenge.

Keywords: Machining; Tool steel; Titanium alloy,Nanostructured coatings and Polycrystalline diamond (PCD).

Introductions

The use of coated cutting tools to machine various materials now represents state-of-the-art technology. Developments in coating equipment and processes now enable us to produce a wide range of different hard nitridic and oxidic films and to deposit them on various tool substrates as monolayer, multilayer, or composite coatings. Irrespective of whether cutting tool materials are being coated, the primary concern is to control and optimize properties such as coating adhesion, coating structure, coating thickness, etc., which determine the performance of the complex composite represented by a "coated cutting tool"[1,2].The present studies are of importance from two viewpoints. On the one hand, it is considered that the substrate material is important for the production of highly effective cutting tool, on the other, the performance maximum of hard coating on the different substrate is depended to precisely of the interface characteristic. The interface is analyzed with regard to surface state, mechanical treatment and surface roughness [3, 4].

The factors that lead to tool wear are mechanical, thermal, chemical, and abrasive [1,6]. Owing to chip formation a significant amount of heat is generated. Owing to the cyclic nature of the cutting operation these thermal loads pulsate leading to thermal fatigue of the cutting tool. The typical wear zones on the cutting tool edge are shown in Figure 1.

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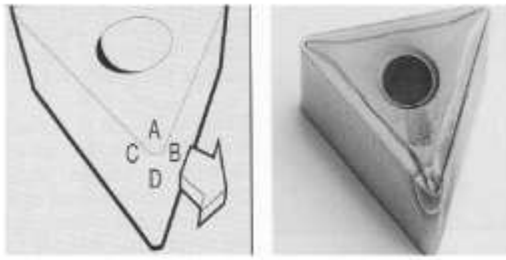

Fig.1. Wear zones on the cutting tool caused by chip formation [6]

These mechanisms include:

1. Abrasive wear – affected by the hardness of the tool and is controlled by the carbide content of the cutting toolmaterial.
2. Diffusion wear – affected by chemical loading on the tool and is controlled by the metallurgical composition of the tool and coating material.
3. Oxidation wear – causes gaps to occur in coated films and results in a loss of the coating at elevated temperatures.
4. Adhesion wear – occurs at low machining temperatures on the chip face of the tool and leads to the formation of a built-up-edge, and the continual breakdown of the built-up edge and the tool edge itself.
5. Fatigue wear (static or dynamic) – this is a thermo- mechanical effect and leads to the breakdown of the edges of the cutting tool.

Experiments were performed to assess the life of newly developed titanium based coated cutting tools. The assessment of machinability used in these experiments is related to the development of Taylor's tool life equations for uncoated and coated cutting tools. Taylor's tool life equation is stated as: VT-1/k = C (1) Where V is the cutting speed in meters per minute (m/min), T is the tool life in minutes (mins.), k is an exponent dependent upon the machining conditions and the tool and workpiece compositions, and C is a constant. For each tool life equation, a sample of the metal is turned at a specific cutting speed and the time it takes to wear 0.3mm of the flank face of the insert away from the cutting tool is measured and used in the calculation. For the machining of M42 tool steel, a computer numerically controlled lathe was used to vary the cutting speeds The uncoated cutting tool inserts were composed of 94wt. % tungsten carbide bonded with a 6wt.% cobalt binder. The coated cutting tools were supplied with a superlattice coating composed of up to 1000 deposited layers to form a coating thickness of 3-4μm. The maximum feed rate was used in these experiments was set at 0.2 mm per revolution of the machine tool spindle. The tools were initially sharp and were not previously used in any other applications. The coatings were developed for dry machining operations and research on the thin film coatings are described in references [7,8]. The initial cutting speed used for the experiments was set at 28 m/min. The tool life was measured by inspecting the cutting tool until 0.3mm of the flank had worn away, which is in accordance with ISO 8688-3685 standard. Further increments of cutting speed were made until a maximum cutting speed of 70m/min had been achieved. The improvement in cutting ability of coated tools using nanostructured PVD and CVD coatings has recently been reported by Dobrzanski et al. [9,10], and the simulation of stresses in titanium based coatings has been demonstrated by Dobrzanski et al. [11]. Dobrzanski also comments on the effectiveness of using multilayer nanocrystalline coatings on cutting tools [12]. The life of the uncoated and coated cutting tools was compared after measuring the progression of flank wear of the cutting tool inserts after machining at different cutting speeds under the conditions. The results of the tool life experiments are presented in Table 1.

Cutting Tool	Spindle speed (m/min)	Cutting tool life (minutes/seconds)
	30	91.2s
TiN coated WC-Co	50	16.54s
	70	6s
	30	144s
Ti0.46Al0.54N coated WC- Co	50	28s
	70	11.2s
	30	156s
Ti0.44Al0.53Cr0.03N coated WC-Co	50	39s
	70	17s
	30	236.4s
Ti0.43Al0.52Cr0.03Y0.02N coated WC-Co	50	64.5s
	70	28.1s

Table 1. Cutting tool life experimental results for coated tools

Coating materials

It was stated that in terms of the tool life coated inserts performed better than uncoated inserts. Coating increases the lubricity and reduces the affinity to the work piece material. This allows the coated inserts to perform much better than the uncoated inserts, especially at higher cutting speeds. The coating provides a better thermal barrier so the temperature is reduced. The speed attained after coating was double compared to that of the uncoated insert. The improvements achieved as a result of coating were extending tool life, attaining higher

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cutting speeds, and reducing production costs. Application of coated cutting tools in the modern machining practices today is very common and extensive. A suitable coating on a cutting tool improves the machinability of a material and enhances the tool life as well. Such beneficial effects of coating are achieved through remarkable improvement of wear resistance and anti-friction properties. In addition, the coating material is intended to offer chemical inertness to the work material at cutting temperature, especially for the sticky work materials. Otherwise, formation of built up edge on the rake surface is unavoidable, which leads to fluctuation of cutting force, deterioration in surface finish, drastic reduction in tool life etc. Index able coated carbide inserts are widely used in modern manufacturing industry. These inserts have one or more thin layers of wear resistance CVD or PVD coating such as TiC, TiN, Al2O3, ZrN, CrC or diamond, which can improve machinability significantly. Today, "coated carbide grades for roughing and cermets for finishing" is a well-established trend.In the up milling operations, the cutter encounters minimum chip thickness as it enters the work piecetool wear and short tool life. In the up milling operations, the cutter encounters minimum chip thickness as it enters the workpiece.

The majority of inserts presently used in various metal cutting operations are cemented carbide tools coated with a material consisting of nitrides (TiN, CrN, etc.), carbides (TiC, CrC, W2C, WC/C, etc.), oxides (e.g. alumina) or combinations of these [13,14]. Coating cemented carbide with TiC, TiN and Al_2O_3 dramatically reduces the rate of flank wear [15].

Coating with three layers of TiC-Al_2O_3-TiN as seen from the substrate are widely used for machining of many types of steels [13]. This type of coating improves the wear resistance of the tool by combining the properties of the three materials. The ranking of the solubility products and limits of TiC, TiN and Al_2O_3 in iron, compared to the carbide substrate, is in the order TiC>TiN> Al_2O_3 [15]. Therefore there is less driving force for significant dissolution-diffusion wear of Al_2O_3 to take place. Thus, having a coating layer of Al_2O_3 over an under layer of TiC help decrease the dissolution/diffusion wear at the TiC coating layer. This enhances the performance of the cutting tool, by including the TiC layer with a low wear rate and protecting it with a layer of Al_2O_3 to decrease the effect of diffusion/dissolution wear. The softer TiN outer layer helps in reducing the propagation of cracks into the inner coating layers, in addition to decreasing the welding of the chips to the cutting tool. Another reason for having the TiN as an outer layer, as opposed to inner layer, is that at higher temperatures of oxidation, the growth of TiO2 (rutile) under layer may affect the performance of the protective alumina over layer of the oxide [16].

Development of hard coating

Since the beginning of the nineteen-eighties, PVD coating has been used for large scale industrial coating of geometrically complex tools such as twist drills, reamers, taps, end mills, form tools, etc. Hard coating led to a major advance in the performance of these tools. Modern design of coated cutting tools place such high demands on the materials specified that they can very often only be met by tailoring composite materials for these specific applications. In particular, the requirements for substrate (bulk) properties, on the one hand, and tool surface properties, on the other hand, differ so much that the surfaces have to be specially treated and modified to meet the particular demands [17]. The availability of new coating systems and sophisticated coating processes enables us to understand previously unexplained phenomena relating to the performance of coated cutting materials. It is increasingly apparent that thermo-physical properties of the coatings have a substantial effect on their performance and operating parameters. The quality of coated cutting tools often depends on three main parameters, which are shown in Fig. 2[18].

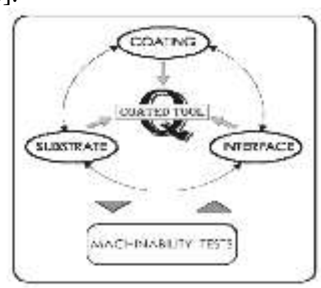

Fig. 2 The interaction of main parameters on the quality of coated cutting tools

Discussion

Coated cutting tools tend to retain a greater proportion of the bulk tool material. A possible reason for this could be due to the presence of the coating; at the tool-chip interface the coating suppresses high temperature generation, this leads to reductions in dissolution wear. As a result of machining, large portions of the tool are retained because there are mechanically robust regions. This is not the case for uncoated tools as noted in a previous study because high temperatures are generated that encourages dissolution wear. This research may be extended to study the effects of multi-layer coatings on cutting tool performance.

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Multi layers are composed of alternating layers of two different materials that can vary in number from few up to tens of thousands. Multi layers are believed to offer very high strength, hardness, heat resistance, and many new properties that could greatly enhance the performance of the cutting tools.

Also this coating technique can be further extended by application of Nano technology. Nanocomposite coating offer enormous potential for new applications in industrial areas.. The insert with a coating of Zerconia Toughened Alumina (ZTA). is done by RF (Radio Frequency)-sputtering process and the productivity andsurface roughness of ZTA coated is being tested and compared with uncoated tungsten carbide insert under the same cutting conditions. ZTA coated turning tool insert exhibits higher hardness, superior wear resistance and higher fracture toughness when compared with the uncoated and TiN coated insert.

Conclusion

During the machining of hardened M42 tool steel, TiAlCrYN coatings are effective at reducing tool wear due to chipping and tend to improve tool life. This was observed during rough machining operations and has not yet been observed in finish machining operations.

1. PCD can be successfully used to machining of titanium alloy (Ti-64)
2. .Of the four tool materials used, PCD yielded better material removal rate.
3. Of the four tools used temperature distribution is minimum in PCD tool resulted in better life. \
4. Influencing parameters in machining of titanium alloy (Ti-64) has been predicted with the help of RSM and Fuzzy Logic with an accuracy level of 95%.
5. The developed model could be effectively used for predicting of the output responses for a given set of input
6. Temperature on the cutting tool increased with increase in cutting speed.

One of the pre-requisites for successful production is the use of quality cutting tools with defined mechanical and technological properties. Therefore, for the development and introduction of new kind of cutting tool (cutting material or coating), it is necessary to carry out a number of studies with the purpose to optimize the substrate and coating composition, coating processing procedures, and the resulting work piece material machinability. In this paper author try to show the importance of improvement of cutting tool performance by PVD or CVD coatings. An attempt is made to apply the general model of quality management system based on "closed loop quality circuits" in development and introducing of coated cutting tools in the practice, and determine the strategy of the machinability in finish machining, where the dimensional accuracy, surface roughness and tool life are the major aspects of interest. Stimulated by the many innovative surface technologies reaching commercial maturity last decade, the discipline of surface engineering has been seen to flourish. As a new area of engineering, its future development should be amenable to planning, through the adoption of a logical interdisciplinary approach. Such an approach will provide the manufacturing industry with many new opportunities in the design of effective cutting tools and production processes. It can be concluded that cutting tool surface and surface coatings characterization, as well as quality assurance, are very important parts of effective cutting tools development. A great variety of powerful testing methods exists both to characterize surface coatings and to ensure that the quality is adequate. Non-destructive coatings methods that can be used for 100 % testing are, however still in the development stage, and further work hasto be done in this area.Today, "coated carbide grades for roughing and cermets for finishing" is a well-established trend.

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