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Application of coatings and their Influence on Carbide Inserts

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Abstract:- This paper discusses application and influence of coating on carbide insert to be used in the manufacturing industry as cutting tool. To achieve this in an efficient way, experiments on a variety of coatings are conducted on AISI 1018 steel, AISI M42 tool steel (58-63 HRC) and Titanium alloys (Ti64). The cutting tool will play an important role in metal removal process in producing the products. The quality of the product directly affects its competitive position, profitability and credibility in the market. One of the main pre-requisites for successful industrial production is the use of quality 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.

Design/methodology/approach: The conventional PVD and CVD methods have its limitations and that innovative processes are essential within the framework of an environmentally oriented quality management system. Meeting the requirements of ISO 9000 and ISO 14000 standards, the proposed model ensures the fulfilment of the basic requirements leading to the required quality of preparation processes and the quality of end products (hard coatings). In order to assess the impact of different coatings on the machining process, initial experiments simulate existing machining operations; this provides a standard for tool life and surface finish. The productivity enhancement of manufacturing processes is the acceleration of improved cutting tools with respect to the achievement of a superior tribological attainment and wear-resistance [4]. This resulted in developing hard coating for cutting tools; these hard coatings are thin films of one layer to hundreds of layers. These hard coatings have been proven to increase the tool life by as much as 10 folds through slowing down the wear phenomenon of the cutting tools. This increase in tool life allows for less frequent tool changes, therefore increasing the batch sizes that could be manufactured and in turn, not only reducing manufacturing cost, but also reducing the setup time as well as the setup cost.

Findings: 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 findings in the paper show that the Al2O3 coated tool perform better than uncoated in machining AISI 1018 steel, TiAlCrYN coated carbide insert in machining AISI M42 tool steel (58-63 HRC)and PVD –TiAlN&CVD –TiN-TiCN-Al2O3-TiN, in machining Titanium alloys (Ti64) The majority of carbide cutting tools in use today employ chemical vapour deposition (CVD) or physical vapour deposition (PVD) hard coatings. The high hardness, wear resistance and chemical stability of these coatings offer proven benefits in terms of tool life and machining performance [5-6]. The first technique of CVD deposits thin films on the cutting tools through various chemical reactions and coatings were traditionally deposited using the CVD technique. Another technique is PVD. This method deposits thin films on the cutting tools through physical techniques, mainly sputtering and evaporation.

Research limitations/implications: The implications of the paper tend to indicate that machining AISI 1018 steels without lubricant can be optimized using coated cutting tools. The limitations of the paper include machining at one specific cutting speed and the employment of a short-time tool wear method. The requirements from industry: 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. The performance of the cutting tools is evaluated by considering the progression of tool wear and the surface finish of the work piece. The specific objectives of this research study included:

1. Study the flank wear progression on each of the cutting tools used.

2. Study the change of surface finish throughout the tool life of each cutting tool.

3. Assess and analyze the results obtained for each tool, and evaluate their performance based on the effects of the coating materials used.

Practical implications: The quality of a company's product directly affects its competitive position, profitability and credibility in the market. Quality management system must undergo a process of continuous improvement, which extends from the deployment of preventive quality assurance methods to the application of closed loop quality circuits. The practical implications of the paper show that dry machining of steels can be achieved under certain circumstances. Further research is needed to explain how the wear mechanism changes with varying machining conditions.

Originality/value: The paper presents original information on the characteristics of dry machining of AISI 1018 steel under specific machining operations. The paper is of interest to manufacturing engineers and materials scientists.

Keywords: Machining; Steel AISI 1018, AISI M42 steel, Titanium alloys (Ti64) &Coatings.

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I. INTRODUCTION

The factors that lead to tool wear are mechanical, thermal, chemical, and abrasive [1-3]. 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. The wear zones are characterized by the type of wear that occurs on the tip of the tool and around the cutting edge. As a result of load factors exerted on the cutting tool edge, a few basic mechanisms dominate metal machining

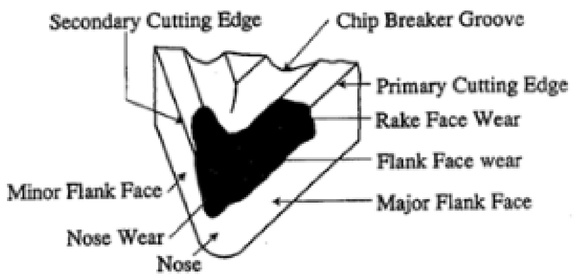

Fig.1. Wear zones on the cutting tool caused by chip formation [3]

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"[4,5]. 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 [6,7]. The aim of this paper is to establish the general model of an environmentally oriented quality management in the field of development and introducing of new hard coatings on cutting tools. The important aspect that is being vigorously researched is the hard coating for cutting tools.

These mechanisms include:

1. Abrasive wear – affected by the hardness of the tool and is controlled by the carbide content of the cutting tool material.

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.

II. EXPERIMENTAL PROCEDURES

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. An Emco Maier computer numerically controlled milling machine was used to mill bars of M42 tool steel that were one inch diameter bars with a measured surface roughness of 25 P m and a hardness of approximately 58-63 HRC. The type of machining regime used was a roughing cut using the parameters shown in Table 1.

Table 1. Cutting tool life experimental results for coated tools

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

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	30	156s
Ti0.44Al0.53Cr0.03N coated WC-Co	50	39s
	70	17s
	30	236.4s
Ti0.43Al0.52Cr0.03Y0.02 N coated WC-Co	50	64.5s
	70	28.1s

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. [10-11], and the simulation of stresses in titanium based coatings has been demonstrated by Dobrzanski et al. [12]. Dobrzanski also comments on the effectiveness of using multilayer nanocrystalline coatings on cutting tools [13].

III. 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 [14]. 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. Hard coating of single or multilayers of more stable and heat and wear resistive materials like TiC, TiCN, TiOCN, TiN, Al2O3 etc on the tough carbide inserts (substrate) (Fig. 2) by processes like Chemical Vapour Deposition (CVD), Physical Vapour Deposition (PVD) etc at controlled pressure and temperature enhanced MRR and overall machining economy remarkably enabling,

- Reduction of cutting forces and power consumption
- Increase in tool life (by 200 to 500%) for same VC or increase in VC (by 50 to 150%) for same tool life
- Improvement in product quality
- Effective and efficient machining of wide range of work materials
- Pollution control by less or no use of cutting fluid through reduction of abrasion, adhesion and diffusion wear
- Reduction of friction and BUE formation
- Heat resistance and reduction of thermal cracking and plastic deformation

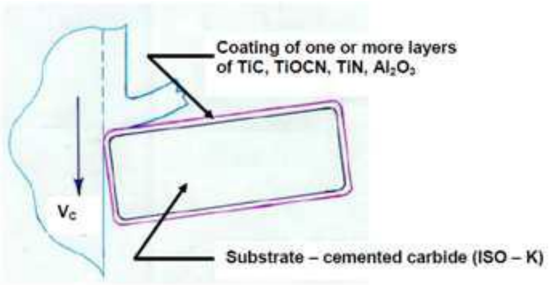

Fig. 2 Machining by Coated Carbide Insert

Coating of one or more layers of TiC, TiOCN, TiN, Al2O3

Substrate – cemented carbide (ISO – K)

The contributions of the coating continue even after rupture of the coating as indicated in Fig. 3

The cutting velocity range in machining mild steel could be enhanced from 120 ~ 150 m/min to 300 ~ 350 m/min by properly coating the suitable carbide inserts. About 50% of the carbide tools being used at present are coated carbides which are obviously to some extent costlier than the uncoated tools. Different varieties of coated tools are available. The appropriate one is selected depending upon the type of the cutting tool, work material and the desired productivity and product quality. The properties and performances of coated inserts and tools are getting further improved by;

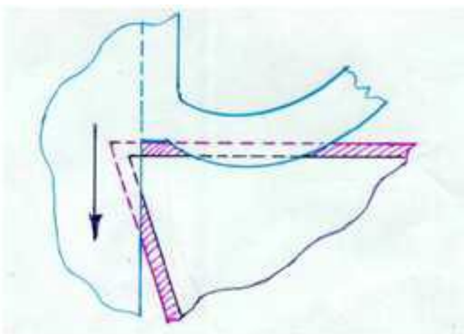

Fig. 3 Role of Coating even after its Wear and Rupture

Δ Refining the microstructure of the coating

Δ Multi layering (already up to 13 layers within 12 ~ 16 μm)

Δ Direct coating by TiN instead of TiC, if feasible

Δ Using better coating materials.

3.1 Substrate (tool) material:-Unlike high speed steels, whose operating conditions are primarily restricted by their annealing resistance, hot hardness and hot wear resistance, cemented carbides, cermets or cutting ceramics are essentially limited by their toughness behavior and their resistance to abrasion, diffusion and oxidation. One key area of interdisciplinary development work, which cannot be discussed in greater detail here, is improvement of the substrate materials.

3.2 Coating: - A second key area of interdisciplinary work, which is very complex, is the sophistication of the coatings. There are a great many external and internal process variables involved. Determining the relationship between both process variables is needed in order to achieve reproducibility and high quality in coated tooling.

3.3 Interface: -The study of interface problems in coating advanced tool material included the following parameters [15]:

- The surface morphology and microstructure of the substrate and the hard coating;
- The distribution of the elements at the interface;
- Possible reactions between elements from the substrate and the coating.

3.3 Machinability Tests: - Despite great advanced in the analysis of thin films, machinability tests are still needed to demonstrate the performance potential of hard coatings on cutting tools. The following experiments are intended to help isolate and interpret the interface characteristics between hard coating and substrate and theirs influence on the parameters in the machining process, and resulting forms and causes of tool wear. For the characterization of these parameters modern analytical techniques are used.

3.4 Quality management in development of hard coatings:-The quality of product directly affects its competitive position, profitability and credibility in the market. Thus, the major objective of quality management becomes that of achieving and maintaining the leadership in product quality and reliability. Product quality requirements should be defined for each product based on factors related to satisfying the needs and expectations of those whom the product serves. The concept of overall total quality control system should be encompassed all of the elements of quality assurance and quality control. Some problem-solving techniques on this area include the following [16]:

- Statistical process control,
- Root cause analysis,
- Quality control circles,
- Quality improvement techniques.

Quality assurance system must undergo a process of continuous improvement, which extends from the deployment of preventive quality assurance methods to the application of closed loop quality circuits. Quality assurance methods are thus frequently effective only when they are integrated into so-call “quality control circles”. Quality control circles are quality tools, which are used for achieving the above-mentioned aims and enable to transition from the quality of process to the quality of product throughout the active quality control. The principle behind systematic feedback into various levels of the “closed loop quality circuit” is that the use of historical data will prevent the same mistakes from being repeated, for example at the planning stage [17]. The basic elements by the establishment of the general model of quality management in the development and introducing of hard coatings on cutting tools are [18, 19]:

- Selection of the substrates and coatings,
- Preparation of hard coatings,
- Testing of hard coatings (in laboratory and workshop conditions),
- Industrial applications.

IV. 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 leads to the formation of mechanically weaker regions, which become prone to chipping. The incorporation of 3 mol% CrNin Til-xAlxN alloys did not change film hardness or microstructure [20]. The latter remained columnar with individual columns consisting of single grains over extended vertical distances. Adding an additional2 mol% YN increased the film hardness by HK0.025 §300 kg mm-2 while Y segregation during growth promoted continuous re-nucleation which resulted in a considerable grain refinement and a more equi-axed structure. Thermo-gravimetric analysis in oxidizing ambient atmospheres has showed [20] that the start of rapid oxidation was increased from 600oC for TiN to 950oC for Ti0.43Al0.52Cr0.03Y0.02N, compared to 870oC for Ti0.46Al0.54N and 920oC for Ti0.44Al0.53Cr0.03N. The initial oxidation reaction pathway was found to be similar for the three alloys with the formation of an Al-rich surface oxide and Ti-rich oxide under- layer. Annealing Ti0.44Al0.53Cr0.03N layers on steel substrates for 1 h at 950oC results in oxidation with cation out-diffusion, giving rise to void formation and under-dense columnar boundaries extending nearly to the film-substrate interface. Voids are also observed on the substrate side of the film-substrate interface due to rapid out-diffusion of Cr, which is rejected by Ti-rich sub- layers in the oxidized film and accumulates at adjacent boundaries. In contrast, the addition of only 2 mol% YN to form Ti0.43Al0.52Cr0.03Y0.02N reduces the oxide thickness from >3 m to 0.4 m while significantly inhibiting out-diffusion of substrate species. STEM-EDX profiles, obtained after annealing, show that Y segregates to nitride grain boundaries.

V. CONCLUSION

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. 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 has to be done in this area.

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