

Model izboljšanja rezalne zmožnosti orodja iz kermeta s prevleko TiN (PVD)

Model of Improvement of Cermet Tool Performance by TiN (PVD) Coating

MIRKO SOKOVIĆ

Značilnost zadnjega desetletja je uvajanje rezalnih orodij, prekritih s prevlekami PVD, ki imajo trenutno pomemben delež na tržišču rezalnih orodij. Proti obrabi odporne prevleke PVD (TiN, TiCN in TiAlN) uporablajo dandanes v industriji običajno za izboljšanje učinkovitosti orodij iz standardnega hitroreznega jekla, sintranega hitroreznega jekla in karbidne trdine. Prvi s prevleko PVD prekriti kermet se je na trgu pojavi pred nekaj leti. K učinkovitosti trdih prevlek na rezalnih orodjih prispeva veliko število dejavnikov, ki so bili analizirani z vidika izboljšanja kakovosti proizvodnje. Vendar je učinkovitost prevlek PVD močno odvisna od adhezije na podlago (substrat) in od odpornosti proti obrabi. Novi način za oceno prekritih rezalnih orodij je predlagan s t.i.m. indeksom učinkovitosti prekritega orodja (CTE).

Pričajoči prispevek se ukvarja z razvojem modela za kompleksno optimizacijo učinkovitosti s prevleko TiN (PVD) prekritih orodij iz kermeta z namenom, da bi lahko izdelovali izdelke s pričakovano ali z zahtevano veliko kakovostjo.

Ključne besede: kermeti, prevleke TiN, sistemi tribološki, testi obdelovalnosti, indeks CTE

The last decade was characterised by the introduction of PVD-coated cutting tools, which now hold a large share of the cutting tool market. Wear resistant PVD (Physical Vapour Deposition) coatings (TiN, TiCN and TiAlN) are regularly used to improve HSS (High Speed Steel), ASP (Anti Segregation Process) and hardmetal tools in industrial practice today. A few years ago the first PVD-coated cermet appeared on the market. Since a large number of factors contribute to the efficiency of hard coatings on cutting tools, these factors were analysed mainly from the point of view of product quality improvement. However the efficiency of PVD coatings depends greatly on the adhesion to the substrate and on the wear resistance. A new mode for estimation of coated cutting tools is proposed: i.e. the coated tool efficiency (CTE) index.

The present paper deals with the development of the model of complex performance optimisation of PVD-coated cermet tools in order to produce the expected or required high quality products.

Keywords: cermets, TiN coatings, tribological systems, machinability tests, CTE index

0 UVOD

Uporaba prekritih rezalnih orodij za obdelavo različnih materialov pomeni dandanes vrhunec tehnologije. Razvoj opreme in procesov za prekrivanje omogoča izdelavo zelo širokega spektra različnih, trdih, nitridnih in oksidnih plasti, ki jih lahko nanesemo na različne podlage kot enoslojne ali večslojne prevleke. Neodvisno od tega, ali je prekrita karbidna trdina, kermet ali HSS, sta poglavitna skrb nadzor in optimizacija lastnosti, kakor so adhezija prevleke, struktura prevleke, debelina prevleke itn., ki določajo zmožnost kompleksnega kompozita, predstavljenega s pojmom prekrito rezalno orodje [1].

Sedanje študije so pomembne z dveh vidikov. Na eni strani upoštevamo, da je osnovni material (substrat) pomemben za izdelavo zelo učinkovitega orodja iz kermeta na podlagi TiC (razvitega na inštitutu Jožef Stefan, Oddelek za keramiko) [2], po drugi strani pa je učinkovitost trde prevleke iz TiN na kermetu kot osnovnem materialu pomembno odvisna od

0 INTRODUCTION

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 nitride and oxide films and to deposit them on various substrates as monolayer or multilayer coatings. Irrespective of whether carbide, cermet or HSS are being coated, the primary concern is to control and optimise 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].

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 tool of TiC-based cermet (developed at the Jožef Stefan Institute, Ceramics Division) [2], on the other, the performance maximum of TiN hard coating on the cermet substrate is dependent

medsebojnega stika med prevleko in podlago (kermetom). Ta je bil analiziran glede na stanje površine, mehansko obdelavo in hrapavost površine. Za dokaz, da trda prevleka iz TiN (JOSTiN^R) pomeni izjemno difuzijsko zaporo med železom Armco in iz kermeta, je bila uporabljena tehnika difuzijskega člena (dvojice). Difuzijski členi in obrabljeni rezalni orodja so bili analizirani po metodah VEM (vrstična elektronska mikroskopija, ESRŽ (energijska spektroskopija rentgenskih žarkov) in SAE (spektroskopija Augerjevih elektronov) z namenom, da bi razpoznali osrednje mehanizme obrabe [3].

Kljub velikemu napredku pri analizi tankih plasti so testi obdelovalnosti še vedno potrebeni za prikaz potencialnih zmožnosti trdih prevlek na rezalnih orodjih. Naslednji preizkusi so bili namenjeni kot pomoč pri določitvi in razlagi karakteristik medsebojne povezave med prevleko in podlago ter njihovimi vplivi na parametre v obdelovalnem procesu ter na končne oblike in vzroke obrabe orodja.

1 ORODJA IZ KERMETA, PREKRITA S PREVLEKO PVD

Od začetka osemdesetih let se prevleka PVD uporablja v širokem obsegu industrijskega prekrivanja geometrijsko zapletenih orodij, kakor so: vijačni svedri, povrtala, navojni vrezniki, steblasta frezala, profilna orodja itn. Prekrivanje, prvotno s TiN, vodi k velikemu napredku, ki povečuje zmožnost teh orodij. V nasprotju s hitroreznimi jekli, pri katerih so pogoji za uporabo določeni predvsem z njihovo odpornostjo proti popuščanju, trdoto in odpornostjo proti obrabi pri povišanih temperaturah, so karbidne trdine ali kermeti v glavnem omejeni z njihovo žilavostjo ter odpornostjo proti abraziji, difuziji in oksidaciji.

Glavne prednosti kermetov na podlagi TiC pred standardnimi karbidnimi trdinami na podlagi WC so njihova dobra odpornost proti obrabi pri velikih rezalnih hitrostih, izredna trdnost in ostrina rezalnega robu ter dobra kakovost površine obdelanih izdelkov. V veliko primerih je lahko obdelovanec obdelovan brez uporabe hladilnih sredstev. Mehanske lastnosti prvotno razvitih stopenj so pomembno izboljšane in so dandanes primerljive z lastnostmi karbidnih trdin na podlagi WC [4]. Poleg teh atraktivnih lastnosti je obilje Ti in Ni v primerjavi z W in C nedvomno pomembna prednost, ki podpira zasnovno intenzivnih raziskovalnih aktivnosti na področju kermetov na podlagi TiC [5].

Prekrite karbidne trdine in kermeti so dosegli veliko kakovost, saj je skoraj 80 odstotkov vseh izmenljivih robov, uporabljenih pri struženju, sedaj že prekritih. Uporaba prekritih karbidnih trdin ali kermetov je bolj ali manj razširjena pri prekinjevanem rezanju, okoli 20-30%. Vzroke za to je treba iskati pri vstopnih in izstopnih razmerah (udarcih) in s tem pridruženimi mehanskimi in topotlnimi šoki, ki nalagajo zahtevna merila glede žilavosti in odpornosti proti obrabi rezalnega materiala.

precisely on the interface characteristics. The interface is analysed with regard to surface state, mechanical treatment and surface roughness. The diffusion couple technique was used to show that a TiN hard coating (JOSTiN^R) represents an excellent diffusion barrier between Armco iron and the cermet substrate. The diffusion couples and the worn cutting tools were analysed by SEM (Scanning Electron Microscopy), EDS (Energy Dispersive Spectroscopy) and AES (Auger Electron Spectroscopy) in order to identify the dominant wear mechanisms [3].

Despite great advances 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 their influence on the parameters in the machining process, and resulting forms and causes of tool wear.

1 PVD COATED CERMET TOOLS

Since the beginning of the 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. Coating, initially with TiN, led to a major advance in the performance of these tools. Unlike high speed steels whose operating conditions are primarily restricted by their annealing resistance, hot hardness and hot wear resistance carbides or cermets are essentially limited by their toughness behaviour and their resistance to abrasion, diffusion and oxidation.

The main advantages of TiC-based cermets over conventional WC-hardmetals are their good wear resistance at high cutting speed, superior edge strength and sharpness, and good surface quality of machined products. In many cases the workpiece can be machined without the use of cooling lubricants. The mechanical properties of early developed grades have been significantly improved and are nowadays competitive with the properties of WC-based hardmetals [4]. Beside these attractive properties, the abundance of Ti and Ni as compared to W and Co is undoubtedly an important attribute which supports the concept of intensive research activity in the field of TiC-based cermets [5].

Coated carbides and cermets have achieved a high quality standard, as evidenced by the fact that some 80 % of all indexable tips used in turning are now coated. Use of coated carbides or cermets is much less widespread in interrupted cut applications, at roughly 25-30 %. The causes are to be sought in the entry and exit impacts and the associated mechanical and thermal shocks, which impose much more exacting demands on the toughness behaviour of the cutting material than on its wear resistance.

1.1 Analiza tribološkega sistema pri odrezovanju

Razumevanje triboloških problemov, narave in lastnosti rezalnega materiala, hladilnega sredstva ter njihove uporabe so izjemnega pomena za napoved obstojnosti orodja za zanesljivo proizvodnjo v danih razmerah. Če so vsi parametri tribološkega sistema medsebojno optimalno kombinirani, lahko z veliko verjetnostjo pričakujemo, da bodo izbrani tehnološki parametri pri sedanjem strojni opremi dali optimalen izdelek. Teorija odpornosti orodja je zelo zapletena, ker je treba odvladati številne znanstvene vede.

Slika 1 prikazuje posplošen sistemski način analize tribološkega sistema med rezanjem, npr. struženjem, čelnim frezanjem itn. [6]. Tribološki sistem, ki se razvije, ko uporabimo prekrita orodja, lahko prikažemo na preprost način z modelom (poudarjenim na sl. 1), ki je temelj za analizo sistema: substrat (orodje iz kermeta) - prevleka TiN - obdelovanec. Substrat (3), ki je lahko orodje različne vrste, je prekrit s trdo prevleko TiN (2) in je v stiku z obdelovancem (1). Vsi rezultati sistematične raziskave kažejo, da je za učinkovitost celotnega sistema odločilnega pomena t.i.m. adhezijski spoj (5) med prevleko TiN in substratom (orodjem iz kermeta). Kakovost spoja neposredno definira učinkovitost prevleke TiN v tribološkem stiku (4) z obdelovancem.

Definicija parametrov, opis procesov in možnosti optimizacije obeh stičnih spojev (4 in 5) so predmet obsežnih raziskav. Poleg običajno opazovane obrabe, sprememb mehanskih lastnosti in problemov pri obdelavi, srečujemo kot pomembne parametre tudi adhezijo, fiziko in kemijo površin, epitaksijo in rast plasti ter elektronsko metalografijo. Zato je vsako prekrito orodje tudi interdisciplinarni znanstveni problem.

1.2 Indeks učinkovitosti prekritega orodja

V vseh primerih testiranja obrabe orodja je mogoče opaziti povečanje obstojnosti orodja iz kermeta prekritega s prevleko TiN (PVD), neodvisno od vrste obdelave, tako pri struženju kakor pri frezanju. Da bi lahko izrazili ta učinek številčno, oziroma označili to povečanje obstojnosti prekritega orodja, je bil vpeljan t.i.m. indeks učinkovitosti prekritega orodja (indeks CTE). Definiran je kot razmerje med obstojnim časom prekritega orodja in obstojnim časom enakega neprekritega:

$$\text{CTE} = \frac{\text{(obstojnost - tool life)}}{\text{(obstojnost - tool life)}} \frac{\text{orodje s prevleko PVD}}{\text{orodje brez prevleke PVD}}$$

PVD-coated tool

uncoated tool

1.1 Analysis of the tribo-system in cutting processes

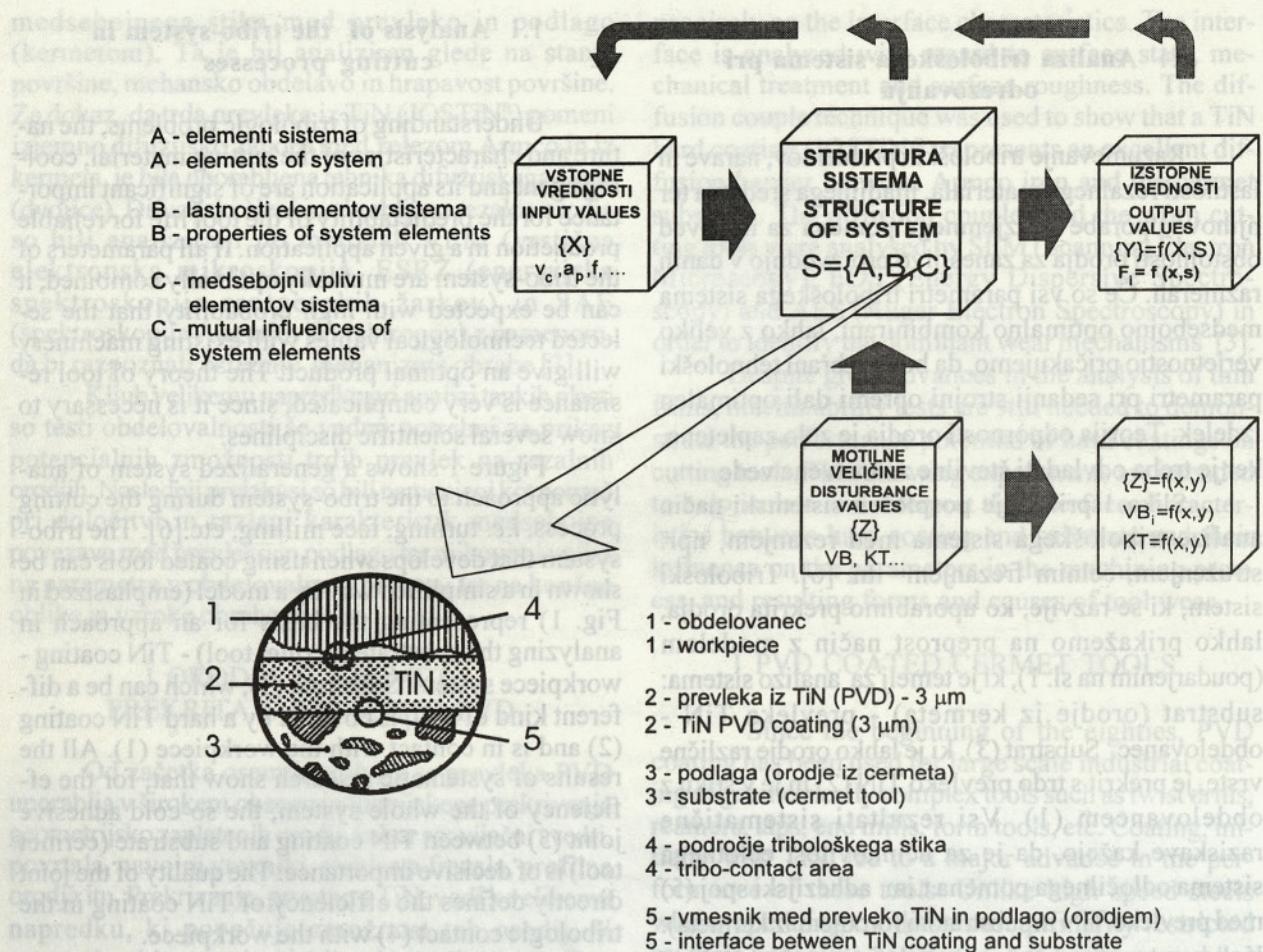
Understanding of tribologic problems, the nature and characteristics of the cutting material, cooling agent and its application are of significant importance for the predictability of the tool life for reliable production in a given application. If all parameters of the tribo-system are mutually optimally combined, it can be expected with high probability that the selected technological values with existing machinery will give an optimal product. The theory of tool resistance is very complicated, since it is necessary to know several scientific disciplines.

Figure 1 shows a generalized system of analytic approach to the tribo-system during the cutting process, i.e. turning, face milling, etc. [6]. The tribo-system that develops when using coated tools can be shown in a simplified way by a model (emphasized in Fig. 1) representing the basis for an approach in analyzing the substrate (cermet tool) - TiN coating - workpiece system. Substrate (3), which can be a different kind of tool, is covered by a hard TiN coating (2) and is in contact with the workpiece (1). All the results of systematic research show that, for the efficiency of the whole system, the so-called adhesive joint (5) between TiN coating and substrate (cermet tool) is of decisive importance. The quality of the joint directly defines the efficiency of TiN coating in the tribologic contact (4) with the workpiece.

The definition of the parameters, description of the processes and optimization possibilities of both contact spots (4 and 5) have been the subject of extensive research. Besides the regularly observed wear, change of mechanical properties and machining problems, we now also encounter as important parameters: adhesion, surface physics and chemistry, film growth and epitaxy and electron metallography. Therefore, every coated tool is also an interdisciplinary scientific problem.

1.2 Coated tool efficiency index

In all cases of testing tool wear, it is possible to note a marked increase in tool life of the cermet tool coated with a TiN (PVD) coating, irrespective of the kind of machining procedure, either turning or milling. To be able to evaluate this effect numerically, a name was introduced to denote this increase in the tool life of coated tools, i.e. coated tool efficiency index (CTE - index). This was defined as the ratio between the coated tool life time and the life time of an equal tool without coating:



Sl. 1. Sistemski način analize tribološkega sistema pri odrezovanju

Fig. 1. System approach to analysis of tribo-system in cutting process

Pri fini obdelavi je merilo za obrabo podano z izrazom $VB = 0,2$ mm. Tako je indeks učinkovitosti prekritega orodja označen kot: $CTE_{0,2}$. Podobno, v primeru običajne obdelave, za katero je merilo obrabe definirano z $VB = 0,4$ mm, je indeks učinkovitosti označen s $CTE_{0,4}$.

Glede na te definicije, smo definirali indeks učinkovitosti prekritega orodja za različne primere [7]:

- $CTE_{0,2} = 1,48$ pri finem struženju zlitin
- $CTE_{0,2} = 1,67$ pri finem struženju jekla
- $CTE_{0,4} = 3,00$ pri struženju legiranega jekla
- $CTE_{0,4} = 1,32$ pri čelnem frezanju jekla

Analiza serije primerov je pokazala, da se vrednost indeksa povečuje s težje obdelovanim materialom ali v težjih razmerah obdelave (še posebno večjem podajanju). Kakorkoli že, to izjemno povečanje indeksa CTE naj nas ne bi zapeljalo: pojavilo se bo takrat, ko bo obdelava z neprekritim orodjem popolnoma neučinkovita ali v določenih primerih celo

In fine machining, the criterion of wear is given by $VB = 0.2$ mm. Thus the coated tool efficiency index would be denoted as: $CTE_{0,2}$. Similarly, in the case of normal machining for which the wear criterion is defined by $VB = 0.4$ mm, the efficiency index would be denoted: $CTE_{0,4}$.

In accordance with this definition, we defined the coated tool efficiency indexes for the different cases as follows [7]:

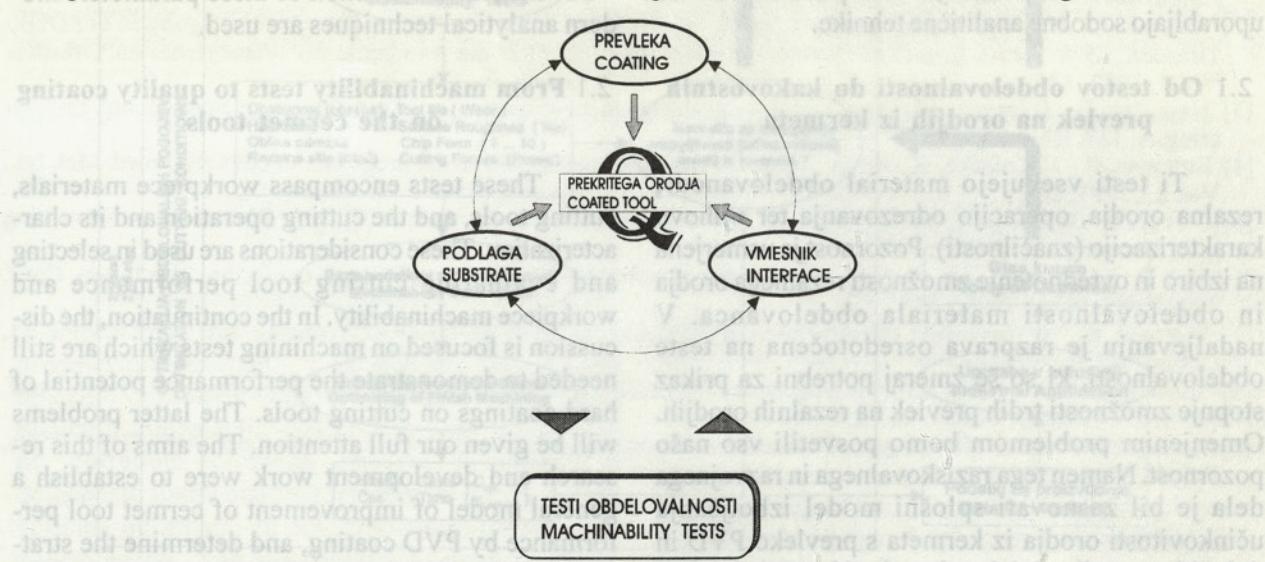
- by fine turning alloy (280 HB),
- by fine turning steel Ck 45,
- by turning alloy steel C 60N,
- by face milling steel Ck 45.

The analysis of a series of examples has shown that the value of the index increases with materials difficult to machine or in more difficult working conditions (especially higher feed rate). However, this enormous increase in the CTE-index should not mislead us: it will occur when the machining with an uncoated tool is most inefficient or in certain cases

nemogoča. Prednosti prevlek bi lahko izkoristili z uporabo višjih parametrov rezanja za doseg včje količine odrezanega materiala na enoto časa. Prekrita orodja se pogosto uporabljo tudi pri rezalnih parametrih, ki so enaki ali malo višji od tistih pri uporabi ekvivalentnih neprekritih. Povečana učinkovitost je potem preoblikovana skozi večjo količino odrezanega materiala na obstojnost orodja in ne na enoto časa v primerjavi z neprekritimi orodji.

2 OPTIMIZACIJA PREVLEKE TiN (PVD) NA PODLAGI IZ KERMETA

Zmožnosti novih sistemov prekrivanja in zapleteni postopki prekrivanja omogočajo, da razumemo prejšnje nepojasnjene pojave, povezane z učinkovitostjo prekritih rezalnih materialov. Vedno bolj je jasno, da imajo termofizikalne lastnosti prevlek močan vpliv na njihove uporabne lastnosti in obdelovalne parametre. Kakovost prekritih rezalnih orodij je pogosto odvisna od treh glavnih parametrov, ki so prikazani na sliki 2.



Vmesnik. Študija problemov vmesnega stika pri sodobnem prekriterju rezalnemu materialu (kermet na podlagi TiC) vsebuje naslednje parametre [3]:

- površinsko morfologijo in mikrostrukturo podlage in prevleke TiN (PVD);
- porazdelitev elementov v vmesniku;
- mogoče reakcije med elementi iz podlage in prevleke;
- prevleka TiN (PVD) kot difuzijska zapora med kermetom na podlagi TiC, skupaj z železom Armco;
- možne interakcije med Ti in atomi železa v vmesniku.

Testi obdelovalnosti. Kljub velikemu napredku pri analizah tankih plasti so testi obdelovalnosti še vedno potrebni za jasnejši prikaz potencialnih zmogljivosti (učinkovitosti) trdih prevlek na rezalnih orodjih. Naslednji preizkusi imajo namen izluščiti in poudariti pomen značilnosti vmesnika med trdo prevleko in podlago, njegov vpliv na parametre obdelovalnega procesa ter rezultirajoče oblike in vzroke za obrabo orodja.

Za karakterizacijo teh parametrov se uporabljajo sodobne analitične tehnike.

2.1 Od testov obdelovalnosti do kakovostnih prevlek na orodjih iz kermeta

Ti testi vsebujejo material obdelovancev, rezalna orodja, operacijo odrezovanja ter njihovo karakterizacijo (značilnosti). Pozornost je usmerjena na izbiro in ovrednotenje zmožnosti rezalnega orodja in obdelovalnosti materiala obdelovanca. V nadaljevanju je razprava osredotočena na teste obdelovalnosti, ki so še zmeraj potrebni za prikaz stopnje zmožnosti trdih prevlek na rezalnih orodjih. Omenjenim problemom bomo posvetili vso našo pozornost. Namen tega raziskovalnega in razvojnega dela je bil zasnovati splošni model izboljšanja učinkovitosti orodja iz kermeta s prevleko PVD in določiti strategijo obdelovalnosti pri končni obdelavi (znotraj področja tehnologije približane oblike). Slika 3 prikazuje osrednji del tega modela.

Prvi korak menedžmenta kakovosti v tem primeru je bil narejen z izbiro metode (PVD ali CVD) in optimizacijo parametrov procesa nastajanja trde prevleke. Drugi korak je odločitev za teste obdelovalnosti, ki po eni strani potrjujejo pravilnost odločitev v prvem koraku in po drugi strani zagotavlja pravilne podatke o potrebnem času in stroških obdelave, upoštevajoč izbrane parametre obdelave in zahtevano kakovost izdelka [8].

Potencialne zmožnosti prekritih in neprekritih orodij lahko torej dosledno primerjamo na naslednje načine:

- neprekrita z različno prekritimi orodji (TiN; Ti(C,N); (Ti, Al)N; CrN itn.) - določanje vrednosti indeksa CTE;

Interface. The study of interface problems in coating advanced tool material (TiC-based cermet) included the following parameters [3]:

- the surface morphology and microstructure of the substrate and the TiN (PVD) coating;
- the distribution of the elements at the interface;
- possible reactions between elements from the substrate and the coating;
- the TiN (PVD) coating as a diffusion barrier at the TiC-based cermet couple with Armco iron;
- the possible interaction between titanium and iron atoms at the interface.

Machinability Tests. Despite great advances 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 their influence on the parameters in the machining process, and resulting forms and causes of tool wear.

For the characterisation of these parameters modern analytical techniques are used.

2.1 From machinability tests to quality coating on the cermet tools

These tests encompass workpiece materials, cutting tools, and the cutting operation and its characterization. These considerations are used in selecting and evaluating cutting tool performance and workpiece machinability. In the continuation, the discussion is focused on machining tests which are still needed to demonstrate the performance potential of hard coatings on cutting tools. The latter problems will be given our full attention. The aims of this research and development work were to establish a general model of improvement of cermet tool performance by PVD coating, and determine the strategy of the machinability in finish machining (within the field of the Near-Net-Shape technology). Figure 3 shows the central part of this model.

The first step of quality management in this case was carried out by selection of the method (PVD or CVD) and optimization of the parameters for hard coating processing. The second step, the decision to choose the machinability tests offers the correctness of the first step on the one hand and, on the other, provides the correct dates about the time and costs of machining, considering the selected parameters of machining and required product quality [8].

The performance potentials of coated and uncoated tools can consequently be compared in the following ways:

- uncoated versus differently coated tools (TiN; Ti(C,N); (Ti,Al)N; CrN etc.) - determining the value of the CTE-index;

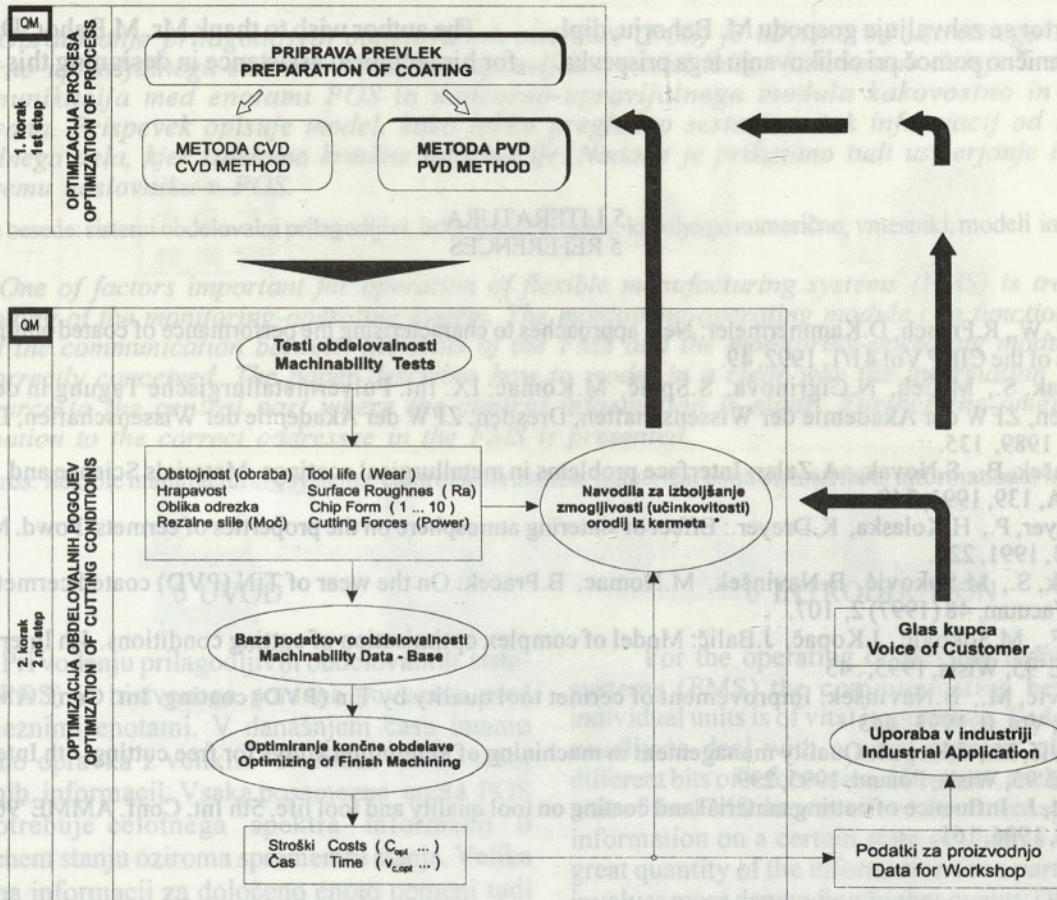
- različno prekrita orodja v enakih postopkih obdelave;
- različno prekrita orodja v različnih postopkih obdelave (struženje, frezanje itn.) [9].

Nekaj rezultatov takšnih testnih primerjav je objavljenih v drugih prispevkih [1], [5] in [7].

- differently coated tools in the same machining processes;
- differently coated tools in various machining processes (turning, milling, etc.) [9].

Some results of such comparative testing are given in other publications [1], [5] and [7].

MENEDŽMENT KAKOVOSTI TRDIH PREVLEK NA REZALNIH ORODJIJAH QUALITY MANAGEMENT OF HARD COATING ON CUTTING TOOLS



Sl. 3. Od testov obdelovalnosti do kakovostnih prevlek na orodjih

Fig. 3. From machinability tests to quality coating on the tool

3 SKLEPNE UGOTOVITVE

Eden od prvih pogojev za uspešno proizvodnjo je uporaba kakovostnih rezalnih orodij z definiranimi mehanskimi in tehnološkimi lastnostmi. Potemtakem je za razvoj in uvajanje novih vrst rezalnega orodja (rezalnega materiala ali prevleke) treba opraviti številne študije, da bi optimirali sestavo materiala (podlage), poteke postopkov in iz tega izhajajoč obdelovalnost materiala obdelovanca.

3 CONCLUDING REMARKS

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 kinds of cutting tools (cutting material or coating), it is necessary to carry out a number of studies with the purpose of optimizing the material (substrate) composition, processing procedures, and the resulting machinability of the workpiece material.

V tem prispevku smo skušali prikazati pomembnost izboljšanja zmožnosti orodja iz kermeta s prevleko TiN (PVD). Podan je splošen model zagotavljanja kakovosti prekritih orodij iz kermeta in določanja strategije obdelovalnosti pri končni obdelavi, kjer so dimenzijska natančnost, hrapavost površine in obstojnost orodja najpomembnejši parametri našega zanimanja.

Zahvala

Avtor se zahvaljuje gospodu M. Bahorju, dipl. inž. za tehnično pomoč pri oblikovanju tega prispevka.

In this paper we have been trying to show the importance of the improvement of cermet tool performance by TiN (PVD) coating. An attempt is made to apply the general model of quality assurance of cermet coated tools, 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.

Acknowledgments

The author wish to thank Mr. M. Bahor, Dipl. Ing. for his technical assistance in designing this paper.

5 LITERATURA 5 REFERENCES

- [1] König, W., R.Fritsch, D.Kammermeier: New approaches to characterising the performance of coated cutting tools. Annals of the CIRP Vol.41/1, 1992, 49.
- [2] Novak, S., M.Čeh, N.Cigrinova, S.Spaic, M.Komac: IX. Int. Pulvermetallurgische Tagung in der DDR, Dresden, ZFW der Akademie der Wissenschaften, Dresden. ZFW der Akademie der Wissenschaften, Dresden, Vol. 3, 1989, 135.
- [3] Navinšek, B., S.Novak, A.Zalar: Interface problems in metallurgical coatings. Materials Science and Engineering, A, 139, 1991, 249.
- [4] Ettmayer, P., H.Kolaska, K.Dreyer.: Effect of sintering atmosphere on the properties of cermets. Powd. Met. Int., Vol. 23, 1991, 224.
- [5] Novak, S., M.Soković, B.Navinšek, M.Komac, B.Praček: On the wear of TiN (PVD) coated cermet cutting tools. Vacuum, 48 (1997) 2, 107.
- [6] Čuš, F., M.Soković, J.Kopač, J.Balič: Model of complex optimisation of cutting conditions. 4th Intern. Conf. AMME '95, Wisla, 1995, . 45
- [7] Soković, M., B.Navinšek: Improvement of cermet tool quality by Tin (PVD) coating. Int. Conf. AMPT '93, Dublin, Vol. II, 1993, 443
- [8] Soković, M., J.Kopač: Quality management in machining of aluminium alloys for free cutting. 4th Inter. Conf. AMME '95, Wisla, Poland, 1995, 299.
- [9] Kopač, J.: Influence of cutting material and coating on tool quality and tool life. 5th Int. Conf. AMME '96, Wisla, Poland, 1996, 161.

Avtorjev naslov: mag. Mirko Soković, dipl. inž.,

Univerza v Ljubljani
Fakulteta za strojništvo
Aškerčeva 6
1000 Ljubljana

Prejetjo: 28.2.1997
Received: 28.2.1997

Author's Address: Mag. Mirko Soković, Dipl. Ing.

University of Ljubljana
Faculty of Mechanical Engineering
Aškerčeva 6
1000 Ljubljana, Slovenia

Sprejetjo:
Accepted: 30.4.1997