

Zagotavljanje kakovosti površin in površinskih prevlek

Quality Assurance of Surfaces and Surface Coatings

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Inženirstvo površin je dandanes priznano kot sodobna tehnologija, ki ima velik pomen pri uspešni in zelo učinkoviti uporabi (eksploataciji) materialov v tehniki. Medtem ko postaja uporaba površinskih prevlek zelo razširjena, postaja potreba po oceni kakovosti in zanesljivosti teh plasti vse pomembnejša, tako za dobavitelje prevlek - z vidika nadzora procesa, kakor tudi za uporabnike - z vidika ugotavljanja, ali so lastnosti prevleke ustrezne za nameravano uporabo. Da bi izdelovali takšne prevleke in pripravili površine sprejemljive, npr. v predelovalni industriji, je treba utemeljiti, ovrednotiti in vpeljati ustrezne postopke zagotavljanja kakovosti.

Ključne besede: zagotavljanje kakovosti, kakovost površin, prevleke površin, karakterizacija površin

Surface engineering, now recognised as an enabling technology of major importance in the successful, is the most effective, and efficient exploitation of materials in engineering practice. As the use of surface coatings becomes widespread, the need to assess the quality and reliability of these films becomes more important, both for coating suppliers as a means of process monitoring and for users as a means of identifying whether the properties of the coating are suitable for the intended application. In order to produce such coatings and surface treatments acceptable in, for example, the manufacturing industry, there is need to establish, evaluate, and implement appropriate quality assurance procedures.

Keywords: quality assurance, quality of surface, surface coatings, characterizing surfaces

0 UVOD

Sodobno oblikovanje delov za termo-elektrarne, letalsko ali vesoljsko industrijo ima tako velike zahteve glede predpisanih materialov, da jih lahko najpogosteje izpolnijo le kompozitni materiali, posebej prirejeni za tako uporabo. Zahteve po lastnostih masivnega materiala, na eni strani, ter lastnostih površine, na drugi strani, se razlikujejo tako močno, da je treba površine posebej pripraviti in prilagoditi, da bi izpolnile pričakovane zahteve. Ta postopek se imenuje *inženirstvo površin*. Da bi zadostili specifikacijam, morajo biti označene površine in uporabljeni metodi zagotavljanja kakovosti podobne postopkom, uporabljenim pri masivnem materialu [1] in [2].

Karakterizacija površine glede na kemično sestavo, mikrostrukturo ter lastnosti je odločilen korak pri raziskavi in razvoju postopkov obdelave površine, ker izid določi, ali bodo specifične zahteve pri oblikovanju izdelka dosežene ali pa ne (sl. 1) [3]. Ta je lahko opravljena s t.i.m. porušnimi ali neporušnimi postopki in je tudi pomembna značilnost zagotavljanja kakovosti, brž ko v proizvodnji steče določen postopek inženirstva površin. Toda karakterizacija površine nikakor ni samo pot k zagotavljanju kakovosti. Čeprav je pri predelavi masivnega materiala, na primer jekla, pomembno obvladovanje parametra procesa, ki rutinsko ugotovi

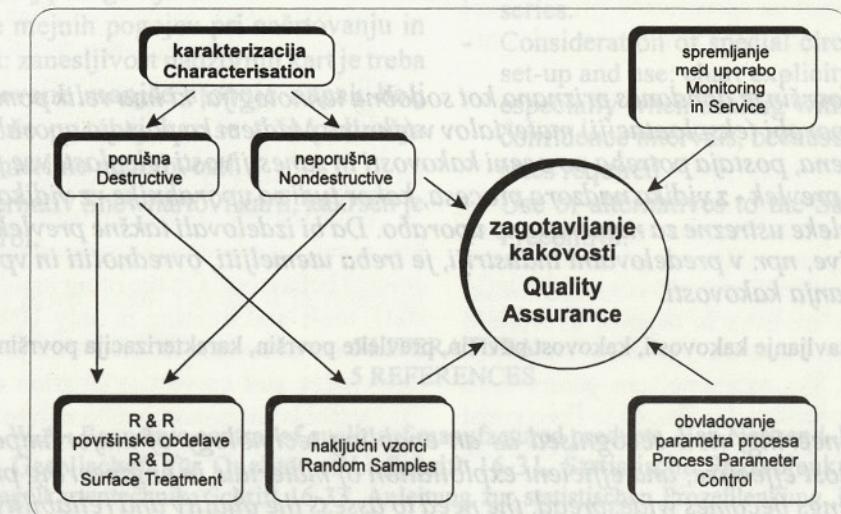
0 INTRODUCTION

Modern designs of components for the power-generating, aircraft, or space industry 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 bulk properties, on the one hand, and surface properties, on the other hand, differ so much that the surfaces have to be specially treated and modified to meet the particular demands. This treatment is termed *surface engineering* and, in order to meet the specifications, the surfaces have to be characterised and the methods of *quality assurance* have to be applied in a way similar to procedures used with the bulk material [1] and [2].

The *surface characterisation*, with respect to composition, microstructure, and properties, is the decisive step in research and development of surface treatments because the outcome determines whether or not specific design requirements can be achieved, Figure 1 [3]. It can be done in a destructive or nondestructive way, and it is also an important feature of quality assurance, once the particular surface engineering treatment has gone into production. But surface characterisation is by no means the only way of assuring quality. As in the production of bulk materials such as steel, the process parameter control, which is the control of routines found to yield

določeno lastnost želenega izdelka, je tudi spremljanje njegovega obnašanja pri uporabi namenjeno za celovito zagotavljanje funkcioniranja površine [4] in [5].

the desired product, is the foremost procedure; the monitoring of components' behavior in service also serves to assure the functioning of the surface [4] and [5]. m-processes or single respectively small



Sl. 1. Karakterizacija kot del postopka zagotavljanja kakovosti [3]
 Fig. 1. Characterisation as part of the quality assurance procedures [3]

Vsi ti različni postopki so namenjeni razvoju in oblikovanju metod priprave površin, prilagojenih za specifične obremenitve in funkcije.

1 KARAKTERIZACIJA POVRŠIN IN POVRŠINSKIH PREVLEK

Običajno lahko inženirstvo površin izvedemo na tri različne načine (sl. 2):

- s pripravo površine masivnega materiala brez spremembe njegove kemične sestave ali mikrostrukture, npr. s poliranjem, povečamo odpornost proti koroziji ali nosilnost drsnih ležajev;
 - z modifikacijo površine, npr. s hladno predelavo, difuzijskimi procesi itn., brez ustvarjanja izrazite vmesne plasti;
 - s prekrivanjem površine z različnimi materiali, ki vključuje nastanek vmesne plasti.

Očitno v prvem primeru zadošča za karakterizacijo funkcije in strukture nekaj atomskih plasti; v drugem primeru, je treba upoštevati celotno modificirano cono; v tretjem primeru pa se je treba ukvarjati tudi s problemom vmesnika.

Pravkar zadeva karakterizacijo in zagotavljanje kakovosti, vključuje tretji primer preostala dva, dasiravno moramo upoštevati modificirano sestavo površinske plasti, spremembe strukture in gradientni potek lastnosti. V takšnem pomenu je sistem, ki zajema masivni material, vmesnik, površinsko prevleko ali modificirano površinsko plast in površino, zelo zapleten in skupaj z izhodnimi sistemskimi lastnostmi, ki jih zahteva

All these different procedures serve to develop and process surfaces tailored for specified loading and functions.

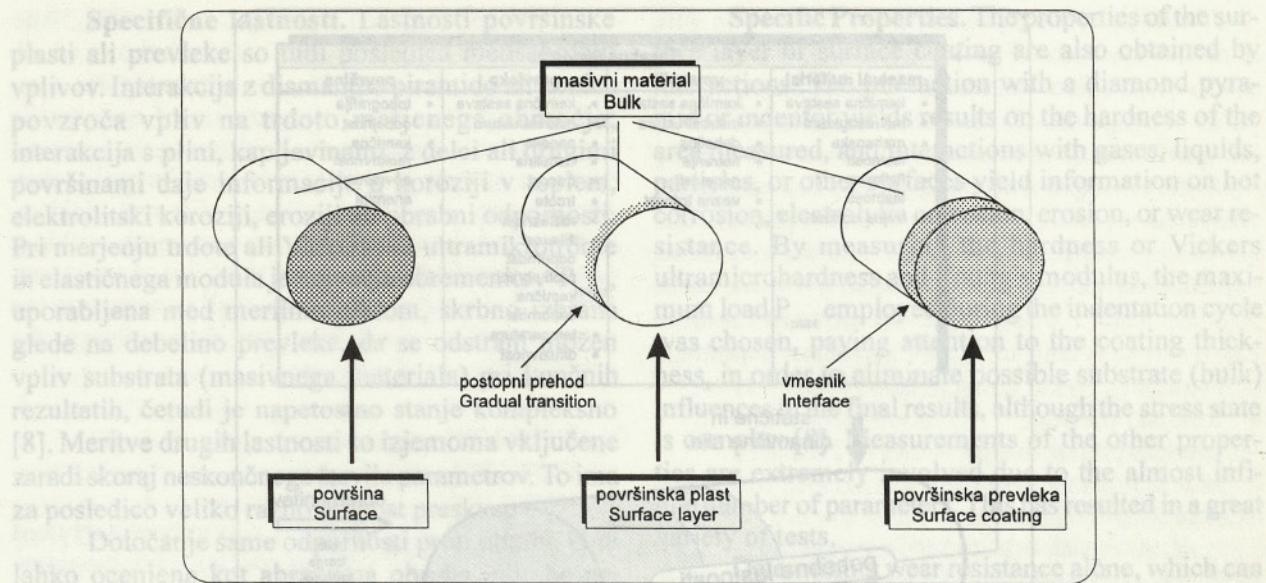
1 CHARACTERISATION OF SURFACES AND SURFACE COATINGS

Generally, surface engineering can be carried out in three different ways (Fig. 2):

- preparing the surface of bulk materials without changing its composition or microstructure, e.g., by polishing to increase the corrosion resistance or load capacity of slide bearings;
 - modification of the surface, e.g., by cold working, diffusion processes, etc., without creating a well-defined interface;
 - coating the surface with a different material, which incorporates an interface.

Obviously, in the first case, it is sufficient to characterise the function and structure of a few atomic layers; in the second case, the entire modified zone has to be taken into account, and in the third case, the problems of the interface also have to be dealt with.

As far as characterisation and quality assurance are concerned, the third case incorporates the two other cases as well, although with modified surface layers, compositional, structural, and property gradients also come into account. In these considerations the system involving bulk material, interface, surface coating or modified surface layer, and surface, is very complex and, together, yields the



Sl. 2. Različni načini inženirstva površin
Fig. 2. The different types of surface engineering

konstrukter, imajo v vsakem posameznem primeru pomembno vlogo. Kompleksnost takšnega sistema je prikazana na sliki 3.

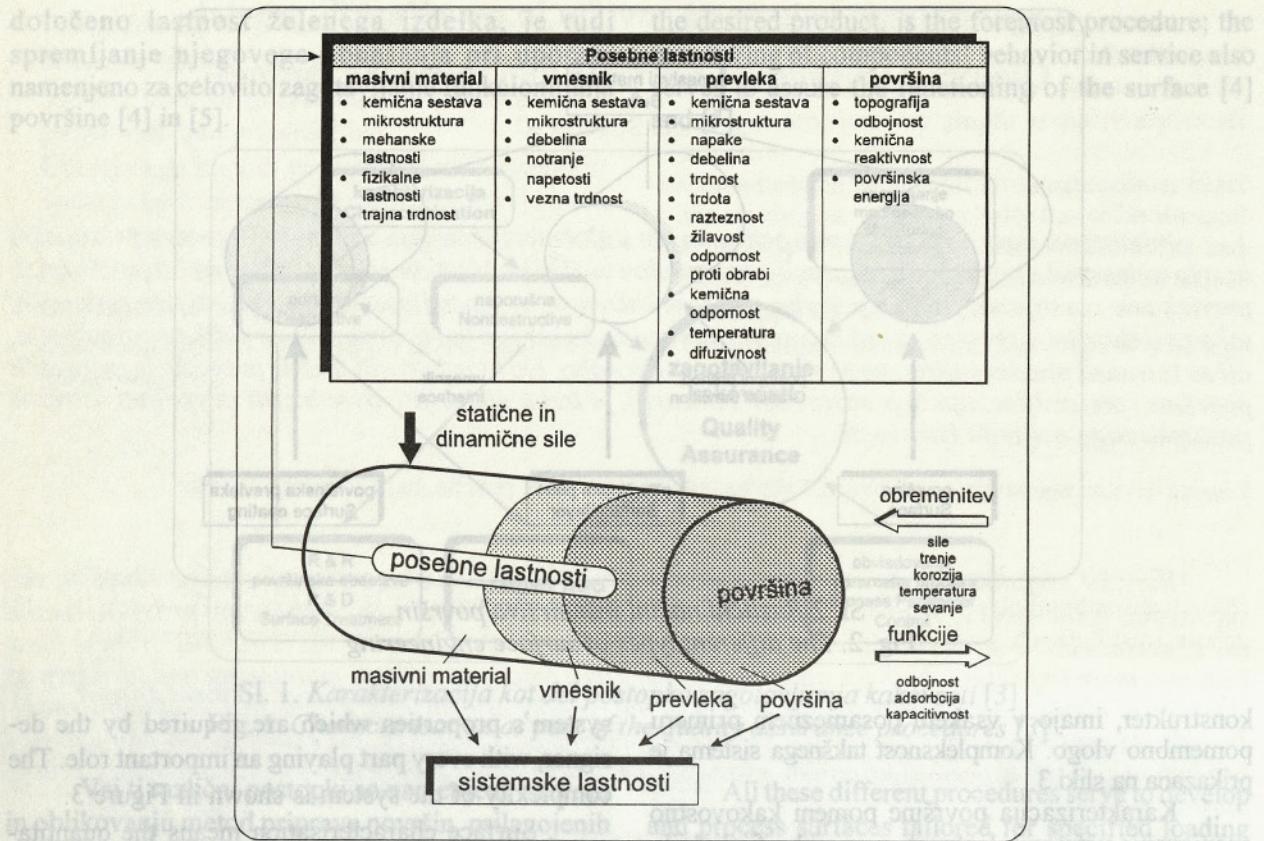
Karakterizacija površine pomeni kakovostno ocenjevanje ustreznih lastnosti z uporabo fizikalnih, kemičnih in tehnoloških učinkov. Tukaj je mogoče praktično razločiti med karakterizacijo glede na strukturo in kemično sestavo ter karakterizacijo glede na druge lastnosti.

Struktura in kemična sestava. Posameznik lahko uporabi veliko število interakcij za karakterizacijo površine ali metalografskega prereza. Tipala se lahko uporabijo za študij profila površine, plini in kapljevine pa za študij poroznosti in površinske energije. Znano je, da interakcije površine s fotonimi in elektronimi ne vodijo le k ustvarjanju slike prek svetlobne in elektronske mikroskopije, temveč tudi k informacijam o kemični sestavi, strukturi molekul ter stanju povezave; z metodo difrakcije rentgenskih žarkov lahko dobimo podatke o parametrih kristalne rešetke [2]. Globina plasti (velikostni red), do katerih sežejo posamezne analitične metode, so različne: spektroskopija Augerjevih elektronov (AES), foto spektroskopija rentgenskih žarkov (XPS), sekundarna spektroskopija ionov (SIMS) ter spektroskopija ionskega razprševanja (ISS). Razumljivo je, da so samo zadnje tri metode zmožne neposredne karakterizacije površine, energijska disperzija rentgenskih žarkov (EDX) pa dejanskega merjenja masivnega materiala - substrata. Pri odstranjevanju površine "plast za plastjo" z razprševanjem ali metodo krogelnega obrusa [6] se lahko te metode analize površine uporabijo za ponazoritev globinskega profila površinskih plasti, npr. prikaz oksida na prevleki ali pa adsorbiiranega ogljika [7].

system's properties which are required by the designer, with every part playing an important role. The complexity of the system is shown in Figure 3.

Surface characterisation means the quantitative assessment of the relevant properties by means of physical, chemical, and technological effects. Here it is practical to distinguish between characterisation with respect to structure and composition, and characterisation with respect to other properties.

Structure and Composition. One can use a great number of interactions to characterise a surface or a metallographic section. Feeler gauges can be used to study the surface contours, or gases and liquids to study porosity and surface energy. Notably, the interactions of a surface with photons and electrons not only lead to image via light and electron microscopy, but also yield information on chemical composition, molecular structure, and binding status; by way of X-ray diffraction, knowledge of lattice parameters can be obtained [2]. The information depths (scale) of different analytical methods are different: Auger Electron Spectroscopy (AES), X-Ray Photo Spectroscopy (XPS), Secondary Ion Mass Spectroscopy (SIMS), and Ion Scattering Spectroscopy (ISS). Obviously, only the latter three methods are capable of characterising the immediate surface, EDX actually measuring the bulk of the material. By removing the surface layer by layer via sputtering or ball-cratering [6], the surface analysis methods can be used to obtain depth profiles of surface layers, e.g., showing the oxide on top of the coating, as well as the adsorbed carbon [7].



Sl. 3. Lastnosti izdelka kot rezultat interakcij

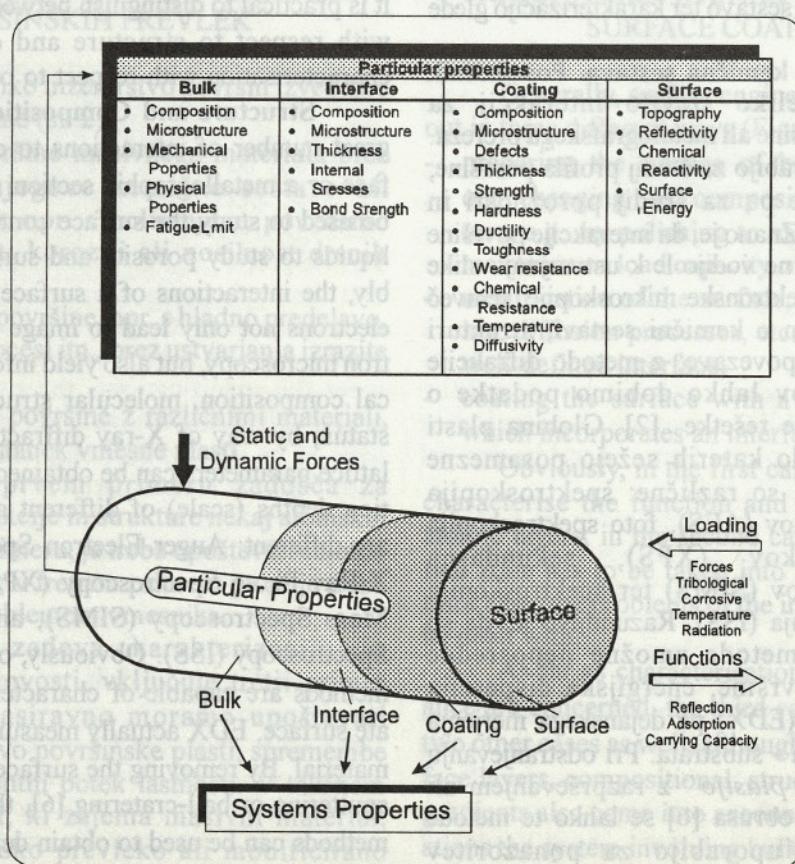


Fig. 3. Properties of a component as a result of interactions

Specifične lastnosti. Lastnosti površinske plasti ali prevleke so tudi posledica medsebojnih vplivov. Interakcija z diamantno piramido ali konico povzroča vpliv na trdoto merjenega območja; interakcija s plini, kapljevinami, z delci ali drugimi površinami daje informacije o koroziji v toplem, elektrolitski koroziji, eroziji ali obrabni odpornosti. Pri merjenju trdote ali Vickersove ultramikrotrdote in elastičnega modula je največja obremenitev P_{\max} , uporabljena med merilnim ciklom, skrbno izbrana glede na debelino prevleke, da se odstrani možen vpliv substrata (masivnega materiala) pri končnih rezultatih, četudi je napetostno stanje kompleksno [8]. Meritve drugih lastnosti so izjemoma vključene zaradi skoraj neskončnega števila parametrov. To ima za posledico veliko raznovrstnost preskusov.

Določanje same odpornosti proti obrabi, ki je lahko ocenjena kot abrazivna obraba, obraba pri drsenju ali kotaljenju, lahko vodi k razvoju številnih preskusov, ki vsi rabijo posebnemu namenu in sicer dejstvu, da je odpornost proti obrabi sistemsko lastnost.

Vezna trdnost. Medpovršinske lastnosti vplivajo na obnašanje prevlek pri obremenjevanju, zato je posebnega pomena študij trdnosti povezave med materialom prevleke in substrata (podlage). Zaradi majhne debeline prevlek, ki običajno variira med 500 µm pri napršenih prevlekah in manj ko 10 µm pri trdih prevlekah, je ta naloga zelo težavna. Preskusi, ki so na voljo, lahko uporabljajo normalne napetosti, strižne napetosti ali stališča mehanike loma.

- *Natezni preskusi* so manj primerni, ker mora biti vpenjalni del povezan s prevleko ali adhezijsko ali s trdim lotanjem. Pri tem postopku prevleka in vmesnik medsebojno vplivata drug na drugega in je zelo pogosto adhezijska zveza prešibka za testiranje dobro sprijetih prevlek.
- *Strižni preskusi* so manj uporabni zaradi zelo zahtevne in drage priprave vzorcev in se težko uporabljajo za prevleke z debelino, manjšo od 100 µm.
- V primeru *preskusov mehanike loma* je zelo velika nevarnost nastajanja razpok.

Če povzamemo: kvantitativna karakterizacija vezne trdnosti še vedno ni uspešno rešena.

Debelina prevleke. Merimo jo lahko na več načinov, odvisno od lastnosti prevleke ter podlage (substrata):

- optične metode,
- metode odstranjevanja (odnašanja) prevleke,
- elektromagnetne metode,
- metode razprševanja prevleke,
- metode vzbujanja prevleke.

Brez poglobljene analize je razvidno, da metoda za merjenje debeline kakršnekoli prevleke na katerikoli podlagi še vedno *ni nujno neporušna*.

Specific Properties. The properties of the surface layer or surface coating are also obtained by interactions. The interaction with a diamond pyramid or indentor yields results on the hardness of the area measured, and interactions with gases, liquids, particles, or other surfaces yield information on hot corrosion, electrolytic corrosion, erosion, or wear resistance. By measuring the hardness or Vickers ultramicrohardness and Young's modulus, the maximum load P_{\max} employed during the indentation cycle was chosen, paying attention to the coating thickness, in order to eliminate possible substrate (bulk) influences in the final results, although the stress state is complex [8]. Measurements of the other properties are extremely involved due to the almost infinite number of parameters. This has resulted in a great variety of tests.

Determining wear resistance alone, which can be classified under abrasive wear, sliding wear, and rolling wear, has led to the development of a great number of tests, which all serve a particular purpose, reflecting the fact that wear-resistant is a system property.

Bond Strength. The interfacial properties influence the behaviour of coatings under loading, and it is of particular interest to study the strength of the bond between coating material and substrate. Due to the thinness of coatings, which generally varies between 500 µm for sprayed coatings and less than 10 µm for hard coatings, this task is very difficult. The tests available either use normal stresses, shear stresses, or a fracture mechanical approach:

- *The tension tests* suffer because a counter bar has to be bonded to the coating either by adhesives or by brazing. By this procedure, the coating and the interface itself might be affected and, very often, the adhesive bond is too weak to test a well-adhering coating.
- *The shear tests* suffer from the very exacting and costly sample preparation, and cannot be applied to coatings less than 100 µm thick.
- In the case of *fracture mechanical testing*, the introduction of cracks is extremely involved.

The summarise, the quantitative characterisation of bond strength has not yet been solved successfully.

Coating Thickness. The coating thickness can be measured in many different ways, depending on the properties of coating and substrate:

- optical methods,
- removing methods,
- electromagnetic methods,
- scattering methods,
- excitation methods.

Without going into detail, it can be stated that there is a thickness measuring method for any coating on any substrate, yet it is *not necessarily non-destructive*.

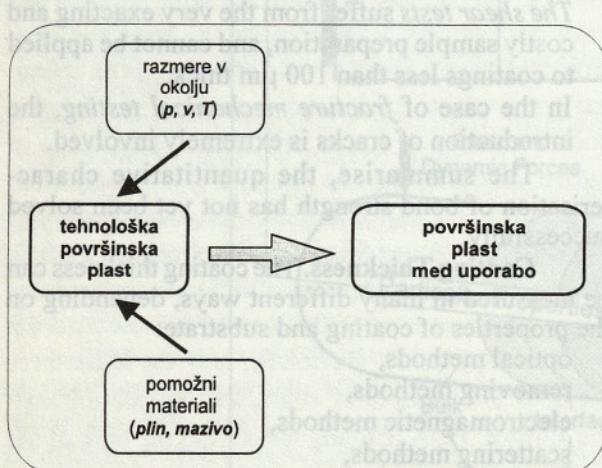
Nespecifična preskušanja. Doslej so bile obravnavane metode za karakterizacijo, s katerimi merimo specifične lastnosti kvantitativno. Vendar pa so na voljo številni nespecifični preskusi, ki so bili razviti med praktičnim delom s sistemi *prevleka/podlaga*. Običajno ti uporabljajo zelo zapleten način obremenitve, katerih rezultat so podatki o trdnosti povezave, kohezivni trdnosti znotraj prevleke, napakah povezovanja, razteznosti prevleke in so pogosto zelo v pomoč pri ocenjevanju celotne kakovosti prevleke ter njene povezave s podlagom (substratom). Nekaj izmed teh so:

- torzijski preskus,
- preskus prepogibanja,
- udarni preskus (trk),
- razenje površine.

Znameniti test razenja površine je zelo razširjen za ocenjevanje *kakovosti trdih prevlek*, ampak interpretacija rezultatov pri tem terja veliko izkušenj [2] in [9].

Preskušanje med uporabo. Večina površinsko obdelanih delov je med uporabo izpostavljenih zelo specifičnim in pogosto zapletenim načinom obremenitve, za kar sta zlasti primerna korozionsko agresivno okolje vode in plinov ter različne tribološke aplikacije (sl. 4) [2] in [10]. Da bi dobili podatke o dejanski zmogljivosti pri uporabi, je treba posamezne dele preskušati pri simuliranih razmerah, ki so zelo blizu tistim pri uporabi.

V primeru prekritega rezalnega orodja je skoraj nemogoče voditi neposredno raziskavo dogodkov, ki potekajo v prevleki in na površini orodja *med samim rezalnim procesom*. Kar je navadno narejeno, je identifikacija poprocesnih sprememb na površini prevleke (razpoke, obložek) ter pod površino v vmesni plasti (odstop prevleke, učinkovitost difuzijske prepreke) [11].



Sl. 4. Shema transformacije tehnološke površinske plasti v eksploracijsko plasti [2] in [10]

Nonspecific Testing. So far, the characterisation methods discussed are those, which measure specific properties in a quantitative way. However, there are a great number of nonspecific tests available that have evolved during the practical work on *coating/substrate* systems. Generally, they apply a very complex loading profile and yield results on bond strength, cohesive strength within a coating, bonding defects, and ductility of a coating; they will also often work very well in assessing the general quality of a coating and its bonding to the substrate. Some of them are:

- torsion test,
- folding test,
- impact test,
- scratch test.

Notably, the *scratch test* is very widely used to assess the *quality of hard coatings*, but the interpretation of results requires great experience [2] and [9].

Testing under Service Conditions. Most surface-engineered components are subjected to very special and often complex loading profiles in service, which is particularly the case in corrosive aqueous and gaseous environments and for tribological applications, Figure 4 [2] and [10]. In order to obtain data on the actual performance in service, the components have to be tested under closely simulated service conditions.

In the case of a coated cutting tool it is almost impossible to conduct direct research of events going on in the coating surface *during the cutting process itself*. What is usually done is identification of post-process changes on the coating surface (cracks, B.U.E. - Built-Up Edge) and under the surface in the interface (coating delamination, efficiency of diffusion barrier) [11].

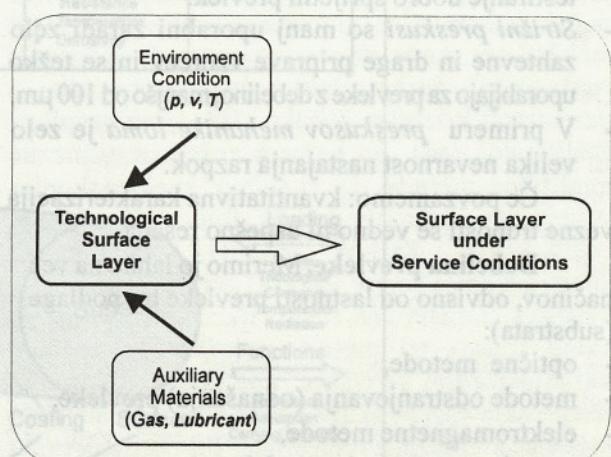


Fig. 4. Schematic display of transformation of the technological surface layer into a surface layer in service [2] and [10]

2 POSTOPKI ZAGOTAVLJANJA KAKOVOSTI

Brž ko se lotimo površinske obdelave v proizvodnji, morajo biti uporabljeni postopki zagotavljanja kakovosti za vzdrževanje določenega standarda, doseženega med razvojnim delom, ki je bil ustreznost pretehtan za posamezni izdelek. Ti postopki so enake narave kakor tisti, uporabljeni med obdelavo masivnih materialov in jih lahko razvrščamo takole:

- obvladovanje parametrov procesa,
- naključno vzorčenje,
- neporušni preskusi,
- spremljanje med uporabo.

Obvladovanje parametrov procesa. Najpomembnejši del postopkov se ukvarja z obvladovanjem vseh surovcev in procesov, uporabljenih med površinsko obdelavo. Ti parametri morajo biti natančno obvladovani in vzdrževani znotraj specificiranih mej, zato da dobimo enotno kakovost celotne serije izdelkov in ves čas poteka procesa. Znano je, če se pojavi problem kakovosti, mora biti prvi zdravilni korak preverjanje kakršnihkoli odmikov (nepravilnosti) parametrov procesa.

Naključno vzorčenje. Metode preskušanja, opisane za karakterizacijo površin in prevlek, so bile vse uporabljeni za ustrezeno zagotavljanje kakovosti, v odvisnosti od vrste in namena posameznega dela ter posamezne površinske obdelave.

- V primeru *majhnih delov*, se vzamejo eden ali več vzorcev iz vsake izdelane serije in preskusijo glede na ustrezne lastnosti.
- V primeru *večjih delov*, se pogosto ločeno pripravijo majhni vzorci v natančno enakih razmerah poteka procesa in jih potem izpostavijo izbranim preskusom.

V obeh primerih se lahko uporabijo porušne ali neporušne metode preskušanja.

Posebne neporušne metode preskušanja. Med njimi so posebej zanimive tiste, ki omogočajo preskušanje vsakega posameznega kosa (100-odstotno preskušanje). Navadno najbolj uporabljana metoda je vizualni pregled vzorcev obdelanih kosov in njihovo razvrščanje glede na določene standarde. Napake prevleke, npr. mehurčki, neprekrita področja ter spremembe v barvi, lahko tako odkrijemo zelo preprosto. Primer: barva prevlek iz TiN je močno odvisna od kemije; *blešeča zlata površina* kaže na stehiometrično sestavo prevleke iz TiN [2]. Večina metod za merjenje debeline prevlek se lahko uporabi za 100-odstotno pregledovanje; padec električne napetosti je dober kazalec gostote/poroznosti izolirne prevleke.

Spremljanje med uporabo. Zagotavljanje kakovosti ne pomeni samo zagotoviti kakovost izdelave pred dobavo, temveč tudi upošteva, da naj površine in prevleke ne bi odpovedovali pri uporabi, kar se pogosto kaže v obliki dragih ali usodnih stranskih učinkov.

2 QUALITY ASSURANCE PROCEDURES

Once a surface treatment has gone into production, quality assurance procedures have to be applied to maintain the standard achieved during development work, and need to be considered adequate for the component. These procedures are of the same nature as the ones used during the production of bulk materials and can be categorized as follows:

- process parameter control,
- random sampling,
- nondestructive testing,
- monitoring in service.

Process Parameter Control. This most important of procedures deals with control of all raw materials and processes used during the surface treatment. These parameters have to be strictly controlled and maintained within specific limits in order to obtain uniform quality over a product series and all periods of time. It is well known that, if a quality problem arises, the first remedial step has to be the checking of any deviations in the process parameters.

Random Sampling. The testing methods described to characterise surfaces and coatings are all used for quality assurance as well, depending on the type and purpose of the particular component and the particular surface treatment.

- In the *case of small components*, one or several samples are taken from every batch produced and tested with respect to the relevant properties.
- In the *case of larger components*, separate small samples are often prepared under exactly the same process conditions and then subjected to the tests selected.

In both cases, destructive and nondestructive testing methods can be used.

Special Nondestructive Testing Methods. Among them are those of particular interest that allow testing of every single piece (100 % testing). The most common one is that used in the sample visual inspection of the treated pieces and categorizing them according to certain standards. Coating defects, e.g., blisters, uncoated areas, and changes in colour can be detected quite easily in this way. As an example: the colour of TiN coatings depends greatly on the chemistry, and a *bright golden surface* indicates the stoichiometric composition of TiN [2]. Most coating thickness measuring methods can be used for 100 percent examination; the breakdown voltage is a good indicator of the density/porosity of an insulating coating.

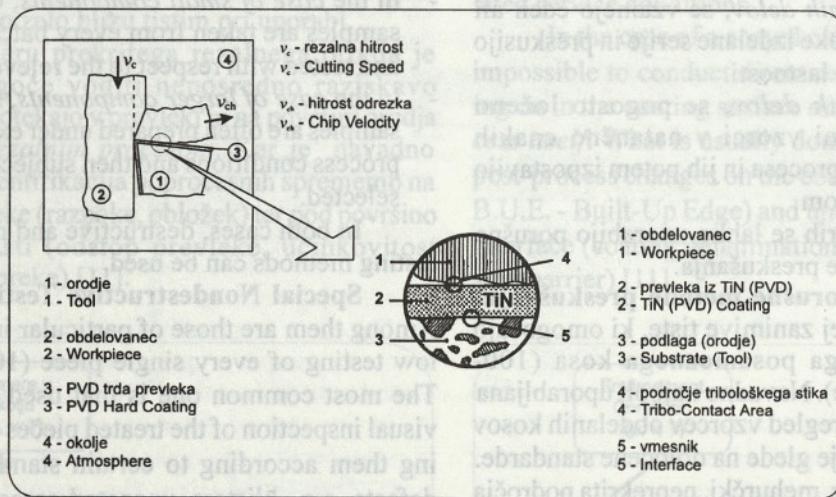
Monitoring in Service. Quality assurance not only means assuring the production quality before delivery, but also implies that surfaces and coatings should not fail when in use, which could often result in expensive or catastrophic side effects.

3 OBVLADOVANJE KAKOVOSTI TRDIH PREVLEK ZA REZALNA ORODJA

Razvoj opreme in procesov za prekrivanje omogoča izdelavo zelo širokega razpona različnih, trdih, nitridnih in oksidnih plasti, ki jih lahko nanesemo na različna rezalna orodja kot enoslojne ali večslojne prevleke. Neodvisno od tega, kateri rezalni materiali so prekriti, sta poglavitna skrb obvladovanje in optimizacija lastnosti, kakor so adhezija prevleke, struktura prevleke, debelina prevleke itn., ki določajo zmožnost kompozita, predstavljenega s pojmom *prekrito rezalno orodje*. Tribološki sistem, ki se razvije med rezalnim procesom, ko uporabimo prekrita orodja, lahko prikažemo preprosto z modelom (poudarjenim na sl. 5), ki je temelj za analizo sistema: *orodje - trda prevleka - obdelovanec* [12]. Definicija parametrov, opis procesov in možnosti optimizacije obeh dotikalnih 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 večanje plasti ter elektronsko metalografijo. Zato je vsako prekrito orodje tudi *interdisciplinarni znanstveni problem*.

3 QUALITY CONTROL OF HARD COATINGS FOR CUTTING TOOLS

Developments in coating equipment and processes now enable to produce a wide range of different hard nitride and oxide films and to deposit them on various cutting tools as monolayer or multilayer coatings. Irrespective of the type of cutting materials 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 composite represented by a coated cutting tool. The tribo-system that develops in the cutting process when using coated tools can be shown in a simplified way with a model (emphasized in Fig. 5) representing the basis for an approach in analyzing the *tool - hard coating - workpiece system* [12]. 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, changes of mechanical properties and machining problems, we now encounter as important parameters also adhesion, surface physics and chemistry, film growth and epitaxy and electron metallography. Therefore, every coated tool is also an *interdisciplinary scientific problem*.



Sl. 5. Struktura tribološkega sistema v procesu odrezovanja pri uporabi prekritih orodij
Fig. 5. Structure of tribological system in cutting process by use of coated tools

Obvladovanje kakovosti trdih prevlek na orodjih ali konicah orodij je težaven problem, ker so prevleke tanke, večinoma manj ko $5 \mu\text{m}$; prevleka ter adhezijske lastnosti morajo biti odlični, če niso poškodovani med uporabo. Na sliki 6 so naštete ustrezne lastnosti skupaj z metodami preskušanja, ki jih lahko uporabimo. Zanimivo, test razenja površine, s svojim nedefiniranim profilom obremenitve, se lahko uporabi za merjenje adhezivnih in kohezivnih lastnosti. Merjenje debeline prevleke je tudi problem

Quality control of hard coatings on tools or tool tips presents a difficult problem because the coatings are thin, mostly less than $5 \mu\text{m}$, and coating and adhesive properties have to be excellent if the coating is not to fail during use. In Figure 6, the relevant properties are listed together with the testing methods that can be applied. Interestingly, the scratch test, with its undefined loading profile, has to be used in order to measure the adhesive and cohesive properties. Measuring the coating thickness also

in je lahko izvedeno le na porušni način. Glede na postopke zagotavljanja kakovosti se le vizualni pregled in tipalo lahko uporabita za 100-odstotni pregled: druge metode preskušanja se lahko uporabijo le za naključno vzorčenje.

presents a problem and can only be done destructively. According to the quality assurance procedures only visual inspection and feeler gauge can be used for a 100 percent inspection: the other testing methods can only be applied to random samples.

Metode preizkušanja Testing Methods				Lastnost Property
metalografska Metallography (MET)	vrstična elektronska mikroskopija Scanning Electron Microscopy (SEM)	tipalo Feeler Gauge (FG)		struktura Structure
MET	SEM	tipalo Feeler Gauge (FG)		topografija Topography
MET	SEM	FG	krogelni obrus Ball Cratering	debelina Thickness
			test razenja Scratch Test	trdota Hardness
			test razenja Scratch Test	adhezija Adhesion kohezija Cohesion
valjček/kolut Pin/Disc			krogla/kolut Ball/Disc	torna obraba Friction Wear

Sl. 6. Možno zaporedje pri prekušanju trdih prevlek
Fig. 6. Possible testing sequence for hard coatings

4 SKLEP

Spodbujana s številnimi inovativnimi tehnologijami obdelave površine, ki so dosegle tržno zrelost od leta 1980 naprej, je vidno vzcvetela znanstvena panoga *inženirstvo površin*. Kot novo področje tehnike, njen prihodnji razvoj naj bi odgovorno načrtovali skozi logično prisvajanje interdisciplinarnih stališč [2] in [4]. Tako stališče si bo zagotovila predelovalna industrija s številnimi novimi priložnostmi v oblikovanju tehničnih izdelkov in izdelovalnih procesov [13].

Lahko povzamemo, da so karakterizacija površine in površinskih prevlek, tako kakor zagotavljanje kakovosti zelo pomembni deli inženirstva površin. Velika pestrost mogočih metod preskušanja obstaja za karakterizacijo obeh, površin in površinskih prevlek, ter prepričanje, da je kakovost ustrezna. Neporušne metode pri prevlekah, ki bi se lahko uporabljale za 100-odstotno preskušanje, so še zmeraj v fazi razvoja, zato mora biti nadaljnje delo opravljeno prav na tem področju.

Zgornja in spodnja toleranca inč. ki ju je določil konstruktor. Za krmilne površine je treba toleranco območje razdeliti na tri enake omočje. Srednji dve

4 CONCLUSION

Stimulated by the many innovative surface technologies reaching commercial maturity since 1980, 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 [2] and [4]. Such an approach will provide the manufacturing industry with many new opportunities in the design of engineering components and production processes [13].

It can be concluded that surface and surface coatings characterisation, as well as quality assurance, are very important parts of surface engineering. A great variety of powerful testing methods exists both to characterise surfaces and surface coatings and to ensure that the quality is adequate. Nondestructive coatings methods that can be used for 100 percent testing are, however still in the development stage, and further work has to be done in this area.

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