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ISSN 0543-5846
METABK 51(1) 21-24 (2012)
UDC – UDK 669.131.6/.7+669.14]:[620.169.1+620.178=111

THE EFFECT OF SPECIFIC RELATIONSHIP BETWEEN MATERIAL AND COATING ON TRIBOLOGICAL AND PROTECTIVE FEATURES OF THE PRODUCT

Received – Prispjelo: 2010-12-30
Accepted – Prihvaćeno: 2011-05-15
Original Scientific Paper – Izvorni znanstveni rad

Today, parts and tools are increasingly made of composite materials. Realization of specific connection between basic material and coating is very important. The quality of coating on products, in terms of wear and resistance to destruction, has a large impact on productivity and reliability of production processes, in particular their life. In this paper, based on experimental investigations, the effect of specific relationship between the base material and coating on tribological and protective features of the product is analyzed.

Key words: materials, tribology, coatings, scratch, adhesion

Utjecaj specifične veze između materijala i prevlake na tribološke i zaštitne karakteristike proizvoda. Danas se dijelovi i alati sve češće izrađuju iz kombiniranih materijala. Ostvarenje specifične veze između osnovnog materijala i prevlake je izuzetno značajno. Kvaliteta prevlake na proizvodima, sa aspekta habanja i otpornosti na razaranje, ima velik utjecaj na produktivnost i pouzdanost proizvodnih procesa, a osobito na njihov vijek trajanja. U radu je na temelju eksperimentalnih istraživanja analiziran utjecaj specifične veze između osnovnog materijala i prevlake na tribološke i zaštitne karakteristike proizvoda.

Ključne riječi: materijal, tribologija, prevlake, skreč, adhezija

INTRODUCTION

The most important prerequisite for improving the scientific and technological progress is the fundamental reconstruction and development of engineering complex. Technology of machining and forming technology are the basis technologies for material processing. Tools have always been the base of industrial production. For making almost all products made from various materials that we use in everyday life it is necessary to have the right tool [1, 2]. Widespread application of coated tools is caused by its high efficiency, thanks to the coating strength of tool increases significantly tools. Until now, there is no evidence of correlation between the tool strength tools and coating features, and questions of optimization of the properties of coating and tool base complex are still unsolved.

Persistence of tools and machine parts can be increased by different surface engineering processes such as the preparation of surface and changing composition of the surface layer using appropriate method, or by applying to the surface a thin layer of another material having the desired mechanical and physical-chemical characteristics. The best protection against tool wear is a few micrometers thick layer of hard coating on the base material.

The tendency of tool materials development and technologies of their surface reinforcement is conditioned by the need aimed at improving the physical and mechanical properties of tool materials, including the strength, heat stability, resistance, brittleness long been considered an important, while other properties are considered less important. Ignoring the importance of certain properties of tool material is one of the main reasons for lack of understanding of the main functions of durable coating on the tool.

It is necessary, for each tribological system, to decide on appropriate methods of protecting the surface of its elements based on the prevailing wear mechanism [3 - 5].

Development of theoretical concepts in the field of materials surface resistance greatly contributes to the quick improvement of surface coating technology.

SPECIFIC CONNECTIONS BETWEEN THE BASE MATERIAL AND COATING

Hard coatings were initially used only for the protection of cutting tools, and later for the protection of forming tools and other type of tools. In addition, hard coatings are increasingly being used for protection of machine parts [6].

Adhesion is defined as a situation in which two surfaces stick together due to chemical or mechanical connections (Figure 1). The opposite of cohesion, where the connection happens in one material, adhesion is a connection between the two materials. Adhesion is not a fundamental physical quantity, it is the set many features. Adhesion at the atomic level is well defined, but the connection to the macroscopic adhesion, which is

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technologically interesting, is still unclear. Condition for successful use of protective coating is the good adhesion. It is possible to provide by adequate pretreatment of tool surface, which includes sand blasting, chemical cleaning, et al. Adhesion is improved by applying a thin middle layer, which provides a chemical connection to the substrate. Adhesion can be improved by ion bombardment during the coating process (ion coverage), because high energy parts of the plasma allow the appearance of pseudo-diffusion zones.

If work is positive, the base and layer attract (adhesion) and if it is negative then they reject. Great adhesion, i.e. great work of adhesion can be achieved if the two materials with a large specific surface energy are in connection. Balanced growth of a thin layer with a large number of nucleation centers, indicating strong chemical connections between the base and layer, and that the adhesion of resulting system will be good. In contrast, it can expect weak connection and the possible formation of pores on the boundary if the growth is spot; therefore the adhesion will be weak. Scheme of tribological system and four different types of boundary between the base and coating are given in Figure 1.

The thickness of the coating significantly affects the efficiency of tool and it is very important data for the technologists. Based on series of investigations it can be concluded that there are optimal coating thicknesses for the specific conditions. The difference between the values of coefficients of linear expansion of the base material and deposited layer influences the appearance of residual stresses in increasing of thickness of the coating on the boundary of base-coating. Stresses grow and they tend to break adhesive connections between coating and the base. Long-term effects of internal stresses on the adhesive connections lead to its gradual destruction, with the adhesive resistance decreases. The optimum coating thickness depends on the technology of coating, which determines the quality of its adhesion, the presence of defects and stresses, as well as the conditions of tool exploitation.

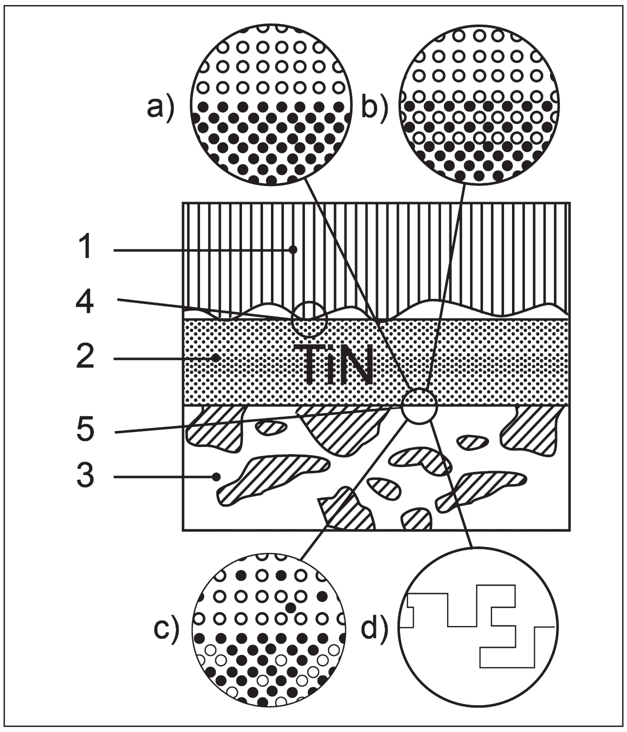

Figure 1 Scheme of tribological system: 1-workpiece, 2-hard coating, 3-base, 4-tribological contact (lubricant), 5-adhesive joint between the coating and base: a)keen boundary, b)connected boundary, c)diffusion boundary, d)mechanical boundary

EXPERIMENTAL TESTS OF SPECIFIC CONECTION BETWEEN THE BASE MATERIAL AND COATING

From the microscopic point of view the adhesion represents strength of chemical connections between atoms of base and coating. Directly measuring the strength of these connections is expensive and unsuitable for industrial use. Mechanical methods are of primary importance. Mechanical methods of adhesion measuring are oriented towards the easier practical use, not to the physical background. For measuring the adhesion of hard coatings the scratch test and the test with print are mostly applied.

In this study the measurement of adhesion hardness was performed. For adhesion of hard coatings, where exists a few micrometers thick layer of high hardness on medium-hard basis, scratch test can be applied.

Scratch test is performed with a diamond tip of a standard form (type Rockwell C, tip radius is 0,2 mm) on the surface of coating. Size of adhesion is determined by the minimum force that through the diamond needle can scratch into coating. There are two ways of measuring. The first method is the measurement at a constant load, where it must do more scratching; every following must have a greater load. Another way of measuring is done by increasing the load linearly from 0 N to the desired maximum load on the same scratching phase. Important terms of scratching are the following: load range (0-150 N), scratching speed (10 $m \cdot min^{-1}$), load speed (100 $N \cdot min^{-1}$).

During the process of scratching two parameters are observed. One is a scratching force or force in the tangential direction which is at low load equivalent to the force of friction. Coefficient of scratching force and the load is called the scratching coefficient. It is a dimensionless size, which is at low load equivalent to the coefficient of friction. The second parameter is the acoustic emissions, which is released during the formation of micro cracks. At the end of scratching, a scratch is observed with an optical microscope. The analysis is based on a decision of critical loads for the certain type of load. They are indicated by the abbreviation Lc_n, where n is the order number. Unfortunately the use of these marks is not unique. Standard (ENV 1071-3, 1994) provides only critical loads Lc_1 and Lc_2, and $Lc(AE)$. The good correlation is between the critical force $Lc(T_t)$ and Lc_5 as well as between $Lc(AE)$ and Lc_3. Selected critical forces in N are measures of adhesion. Acceptable adhesion is for the $Lc_5 > 60$ N. The first condition for a correct result is a sufficient number of measurements. On each sample it should be made at least three scratching and the measuring device should periodically calibrate to the reference sample. Conditions of measuring are determined by measuring standard (ENV 1071-3, 1994).

Quality of coating, from the tribological point of view, today is determined by the measuring instrument known as Scratch tester. Measuring instruments differ in the level at which the measurement is done. In industry and research institutions measurements are carried out at the micro level and in laboratories where they perform fundamental researches measurements are carried out at the nano level.

To determine the exact micro strength of persistent coatings it is necessary that its thickness is three times larger than the depth of print. Accurate micro hardness of coating, on the basis of TiN at the given loads, can be measured if the thickness of the coating is not less than 0,5 micrometers. Superior adhesion of the coating reduces the likelihood of forming a free area on the boundary under the coating, which leads to an increase of the value of micro strength. During the penetration of the measuring tool in the material or coating, it suffers not only in volume in which a crater forms, but on its edges too. Therefore, in determining the strength it is consider that weight must be several times larger than the depth of print. Only under these conditions specified values of strength adequately characterize the material resistance to penetration of the measuring tool. When adhesion of coating is good, plastic deformation of coating and base takes place. If the adhesion is poor, on the coating-base boundary under the load, layering takes place and plastic deformation is not spread to the base (Figure 2).

Base and its hardness influence on the ratio of penetration depth of measuring tool (h) and coating thickness (H). This ratio ranges from 1/3 to 1/6. Method for evaluating quality of adhesion of coating with tool basis is only suitable in the case of control flat surface forms. To control the quality of adhesion of coatings on complex profiled tool or element it is necessary to use the flat models. Coating is applied simultaneously to the tool and the model so the conditions are identical to conditions of the tool coating. Development of methods for reliable quality control of coating on tool is an important task that requires a operating solution. During the experiment the normal load, frictional force, friction coefficient μ and acoustic emission (AE) are measured.

Contemporary design of these devices has a sensor for monitoring the depth of notches during the test.

The duration of the test is determined by selection the changes of the normal force per unit time / $N \cdot \mathrm{min}^{-1}$ and their maximum size. The length of the notch is determined by choice of sliding speed v/ $m \cdot \mathrm{min}^{-1}$. Basic characteristics of scratch tester ST99 are given in [7].

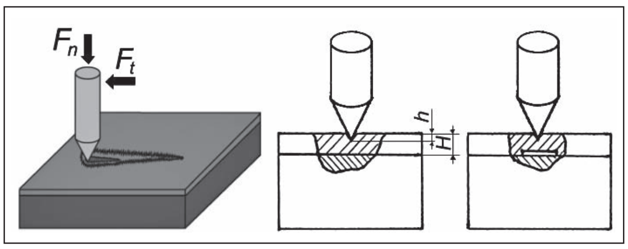

Figure 2 Measurement of adhesion using scratch test and scheme of propagation of distortions under measuring palpus in good and poor adhesion

Measuring the shape and depth of notch is done after the experiment on measuring device Sytem Talysurf Form No.6 Taylor Hobson, which is used for identification of the surface topography.

The base material to which the coating applied is 100Cr6. This material is mostly used for making forming tools (forging) and elements of ball bearings. Thickness of TiN coating on the samples is from 1,8 to 6 micrometers. TiN layers are used as hard, decorative coatings, coatings for corrosion protection, coatings for protection of wear and they may be used as coatings for diffuse barrier.

The grain size in the layers varies depending on the deposition conditions, a negative bias on the substrate leads to a decrease of grain in the layer.

Monitoring the changes of the friction force and the coefficient of friction for the change of normal load from 0 to 150 N during the realization of contact enabled the identification of critical size of normal force F_{nc} at which the coating is destroyed. Changes of the friction force and the coefficient of friction for the normal force changes were observed on the computer monitor by using appropriate software and printed on a printer DESK JET 840C. The records of the measurements of samples 100Cr6/TiN-1, 100Cr6/TiN-2 and 100Cr6/TiN-3 are given in the Figures 3, 4 and 5.

Experimental determination of heights of the surface roughness of 100Cr6/TiN-1 sample is shown in Figure 6.

In the Figure 7 diagrams of changes of the friction coefficient for 100Cr6/TiN-1, 100Cr6/TiN-2 and 100Cr6/TiN-3 samples are given.

Complete coating distortion for 100Cr6/TiN-1 is at normal load of 83 N, for 100Cr6/TiN-2 is at normal force of 87,5 N and for 100Cr6/TiN-3 at normal force of 50 N.

One can see that the coefficient of scratching is the smallest for 100Cr6/TiN-2 sample (Figure 4).

The adhesion of coating to the base is very dependent on the technology of previous preparation of the sample surface. This is one of the most important questions of persistent coating technology, which requires detailed analysis.

The experiments show that the optimal coating thickness is in the range of 3-5 micrometers. At lower thickness coating does not provide a sufficient degree of durability

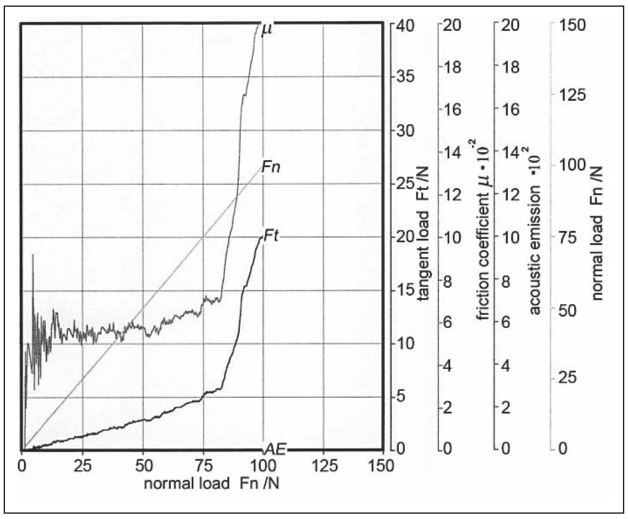

Figure 3 Scratch test 100Cr6/TiN-1

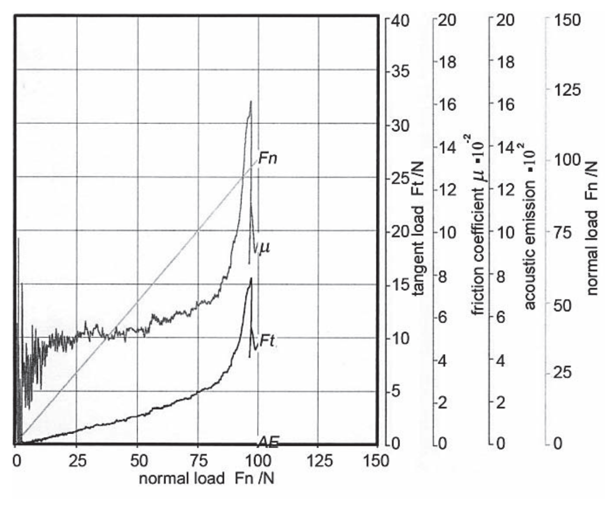

Figure 4 Scratch test 100Cr6/TiN-2

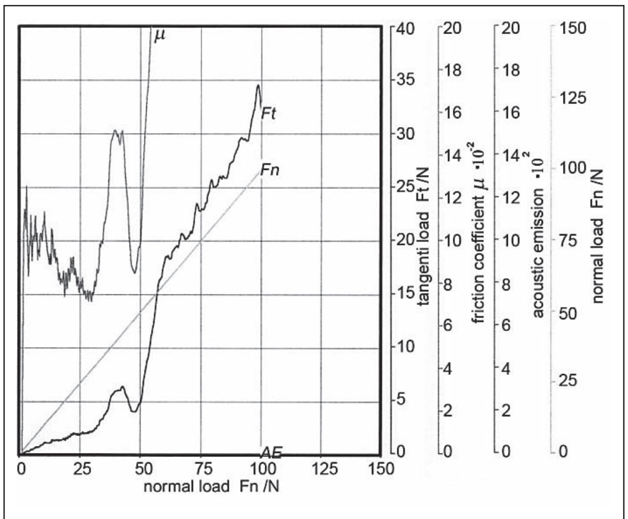

Figure 5 Scratch test 100Cr6/TiN-3

and at higher thickness the adhesion of the coating becomes worse and the likelihood of its failure is increased.

CONCLUSION

Surface strengthening is useful for the surface of machine elements and tools.

The quality of the coating from tribological aspects and in terms of resistance to destruction is necessary in the process of their application to the contact surfaces of solid elements, and in the process of their selection for specific contact conditions. TiN coatings have high strength and durability, which is 2-8 times higher than the durability of the base material. Durability depends on the base material and coating process which is indicated by the results shown in the test diagrams.

An important task placed in front of the science of materials at the modern level of development of persistent coating technology is to search for new and compositions that would guarantee highly efficient tools and optimal durability of elements of the tribological systems.

Acknowledgements – this work was supported by grant TR -14059 from Ministry of Science of Republic of Serbia

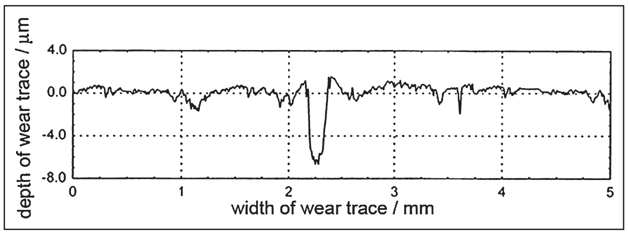

Figure 6 Roughness heights to the length of the profile 100Cr6/TiN-1

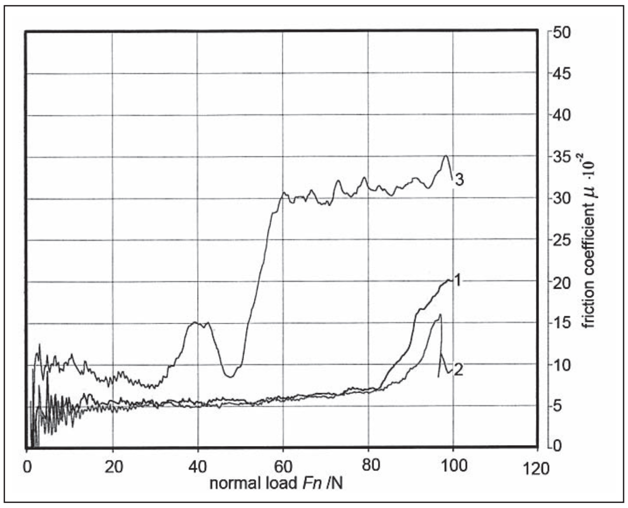

Figure 7 Scratching coefficient for 100Cr6/TiN-1, 100Cr6/TiN-2 and 100Cr6/TiN-3

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List of symbols and acronyms

AE	Acoustic emission
μ	Friction coefficient
h	Penetration depth of measuring tool
H	Coating thickness
F_{nc}	Critical normal load
F_n	Normal load
F_t	Tangent load
Lc_1	Critical load for chipping
Lc_2	Critical load for tearing
Lc_3	Critical load for flaking
Lc_5	Critical load for total delamination
$Lc(AE)$	Critical load for starting of acoustic emission
$Lc(F_t)$	Critical load for increasing of scratch force

Note: The responsible translator for English language Elisabeth Salmore, Faculty of Philosophy, Novi Sad, Serbia