Quantity and quality assessment of multilayer coating adhesion strength

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Abstract. Development and improvement of modern machinery, increasing its performance efficiency are closely related to operation conditions of its main parts, units and devices becoming rougher. Various aggressive and force factors impact on machines and devices resulted in development of special protection and strengthening coatings including multilayer ones. Shifting from simple coatings to more complicated ones set the task to control their quality parameters.

1. Introduction

One of the most important characteristics of protection and strengthening coatings is their adhesion strength that defines protected part reliability [1].

Currently there are a lot of methods of assessments of coating adhesion strength that are divided into quantity methods and quality ones. Protection and strengthening coating adhesion strength quantity assessment provides more reliable control of the protected parts quality. Basic calculations are made with quantity assessment in techniques and technologies of mechanical engineering, quality assessment is meant to provide efficient functioning of the calculations. When designing and products quality are controlled the task is to provide required functional properties of the parts with coatings. Therefore, in order to accomplish this task, it is necessary to be able to express quality state of the object, i.e. to make quantity assessment of its quality.

Quantity methods are restricted with the limit value of adhesion strength or coating thickness, consequently they can't be used for example for ion-plasma coating properties assessments because they have low thickness and high cohesion strength.

At the same time the most prospective coatings for protecting important parts (including gas turbine machinery parts) are ion-plasma coatings. These coatings have high adhesion strength, that restricts the usage of cohesion strength assessment methods such as glue and pin methods [1, 3]. The glue method is restricted by the glue joint strength on the line "coating - tear off component", while the pin method doesn't allow to form solid coating because of the clearance between the sockolet and the pin. Therefore, to assess ion-plasma coating mostly adhesion strength quality methods are used, one of the most widespread methods is the method of bending the control sample with coating [4]. However, the last of the considered multilayer coating quality assessment methods doesn't allow to define real state of either coating adhesion strength or particular coating layers’ cohesion strength. Moreover, the more layers the coating has the more difficult coating adhesion state assessment is.
2. The research part
The above stated ideas resulted in a necessity to develop and study quantity and quality adhesion strength method of assessment of one- or multilayer ion-plasma protection and strengthening coatings.

The developed adhesion strength method of assessment of one- or multilayer coating is in putting layers of the tested coating onto the sample in the form of a metal plate, in bending the above mentioned plate with the tested coating and in assessing cohesion strength according to the coating destruction results. Above that, the microsection is prepared in the plane perpendicular to the incision line, then the following data should be defined on the microsection or its photographic image (figure 1).

\[Figure 1.\] Sample with coating bend detachment and angle deformation detection diagram (1 - bent plate-like sample with coating, 2 - coating, 3 - detachment area. OO' - bend angle bisector, O - cross point of the bisector with the line perpendicular to the coating surface, \(\alpha\) - sample bend angle, \(A_1\) - plate deformation area beginning point, \(A_2\) (\(A_2'\)) - end point of area of coating detachment from the foundation, \(\gamma\) - coating deformation angle, \(\gamma_1\) (\(\gamma_1'\)) – angle of coating detachment from the foundation).

\(O\) is the cross point of the sample bend angle bisector \(\alpha\). It goes through the sample bend centre \(O\). Together with the line perpendicular to the coating surface in point \(A_1\) and going through point \(A_2\) a line from point \(O\) through point \(A_2\) is put. It is necessary to define angle \(\gamma_1\) between \(OA_2\) line and bisector \(OO\); then it is necessary to put line from point \(O\) through point \(A_3\) and define angle \(\gamma_{\text{max}}\) (fig.2) between line \(OA_3\) and bisector \(OO\); then a line between point \(O\) through point \(A_4\) is put and angle \(\gamma_{\text{min}}\) between line \(OA_4\) and bisector \(OO\) is defined; where:

- \(\alpha\) – sample bend angle,
- \(A_1\) – plate deformation area beginning point,
- \(A_2\) – coating detachment from the foundation area end point,
- \(\gamma\) – deformation angle \((\gamma = \angle A_1OO')\);
- \(\gamma_1\) – coating detachment from the foundation angle \((\gamma_1 = \angle A_2OO')\);
- \(A_3\) – end point of the area of maximal detachment of a coating layer from the lower coating layer,
- \(\gamma_{\text{max}}\) – maximal coating layer detachment angle \((\gamma_{\text{max}} = \angle A_3OO')\),
- \(A_4\) – end point of the area of minimal detachment of a coating layer from the lower coating layer,
- \(\gamma_{\text{min}}\) – minimal coating layer detachment angle \((\gamma_{\text{min}} = \angle A_4OO')\).

Values of angles \(\gamma_1, \gamma_{\text{max}}, \gamma_{\text{min}}\) are evident about the strength of cohesion between the layers and between the coating and foundation, moreover the less value of \(\gamma_1, \gamma_{\text{max}}, \gamma_{\text{min}}\) is, the better coating adhesion strength is.

3. Research results
To assess adhesion strength between the coating and foundation as well as between the coating layers studies of two- and four-layer ion-plasma titan nitride coatings were conducted. Microphotographs of
the them are given in the pictures showing deformation and detachment angles defined (figure 2, figure 3).

**Figure 2.** Defining deformation and coating detachment angles in double-layer ion-plasma coating of the Ti-TiN system (1 - bent sample with coating, 2 - coating, the circle shows samples numbers; the angle values were defined for the sample designated 1 in the circle; \( \gamma \) - coating deformation angle; \( \gamma_1 \) - coating detachment from the foundation angle, \( \gamma_{\text{max}} \) - angle of maximal coating layers detachment from the foundation).

**Figure 3.** Two-sided definition of deformation and coating detachment angles in four-layer ion-plasma coating of the Ti-TiN system (1 - bent sample with coating, 2 - coating; \( \alpha \) – sample bend angle, \( \gamma \) - coating deformation angle, \( \gamma_1 (\gamma'_1) \) - angle of coating detachment from the foundation)

Also coating adhesion strength studies were conducted on plate-like samples as big as 10x100x2mm and made of stainless steel 12X18H10T. Ion-plasma multilayer coatings with interchanging titan and titan nitride layers were put. Titan layer thickness is 0.6 mcm, titan nitride layers’ thickness is 2.2 mcm with the first titan layer thickness of 0.8 mcm. Multilayer coating with eight layers and total thickness of 11.4 mcm was used. Studies were conducted with bend angle \( \alpha = 90 \) degrees. 8 samples were tested. Microsections on the side surfaces of the samples were prepared before bending on four samples, it was made after bending on the other four. To simplify the assessment of coating parameters in the bend deformed area of the samples
microsections in the mark area were photographed and required measurements were made on the photographs of the microsections. The microsections were prepared on the side part of the tested sample in the plane. Table 1 shows the results of the tests of the samples with multilayer coatings.

| Table 1. Results of the bend tests of the samples with multilayer coatings |
|---------------------------------------------------------------|
|                  | Multilayer coating adhesion strength parameters |       |
|                  | γ₁, degree | γₘₐₓ, degree | γₘᵢₙ, degree | K_{coat.detach} | K_{coat.detach-max} | K_{coat.detach-min} |
| 1                | 12         | 4            | 8            | 0.13           | 0.04               | 0.09               |
| 2                | 8          | 5            | 12           | 0.08           | 0.05               | 0.13               |
| 3                | 11         | 3            | 9            | 0.12           | 0.03               | 0.10               |
| 4                | 10         | 5            | 11           | 0.11           | 0.05               | 0.12               |
| 5*               | 9          | 6            | 10           | 0.10           | 0.07               | 0.11               |
| 6*               | 7          | 4            | 11           | 0.07           | 0.04               | 0.12               |
| 7*               | 13         | 4            | 9            | 0.14           | 0.04               | 0.10               |
| 8*               | 10         | 3            | 11           | 0.11           | 0.03               | 0.12               |

Notes:
Numbers of samples with sections produced after samples bending are marked with an asterisk (*).
Minimal adhesion samples are marked bold.

At the assessment of cohesion strength between the coating and foundation as well as between the layers of the coatings it should be counted that the less angles γ₁, γₘₐₓ, γₘᵢₙ values are and the less detachment coefficients values are, the more corresponding values of adhesion strength are.

4. Conclusion
There is an issue of the quantity assessment of adhesion strength of one- and multilayer ion-plasma coatings.

The method suggested is the method of quantity and quality assessment of one- and multilayer coatings adhesion strength that allows to assess adhesion strength between the coating and foundation as well as between the coating layers. The method can be used for assessing ion-plasma coating adhesion strength.

The studies of samples with ion-plasma one- and multilayer titan nitride coatings were conducted, that allowed to conduct a comparative analysis of the coatings provided with different options.

References
[1] Tushinskiy L I and PlohoV A V Studies of coatings physical and mechanical properties and their structure 1986 (Novosibirsk: Nauka) p 218
[2] Zimon A D Coatings and films adhesion 1977 (Moscow: Chemistry) p 345
[3] Hasui A, Morichaki O Welding deposition and splattering 1985 (Moscow: Engineering) p 240
Tabakov V P Forming wear resistant ion-plasma coatings for cutting tools 2008 (Moscow: Engineering) p 311