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TOOLS, POWDERS, PASTES

ON THE REDUCTION OF RESIDUAL STRESSES IN VACUUM-PLASMA-SPRAYED DISCRETE-STRUCTURED COATINGS

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The paper discusses residual stresses in vacuum-plasma-sprayed titanium nitride coatings. It is shown that replacing of continuous coatings with discrete-structured ones reduces residual stresses in them. A decrease in residual stresses depends on the size of a discrete segment: the smaller the segment, the greater this dependence. The approach proposed makes it possible to limit residual stresses in a coating while maintaining its continuity, and to reduce the probability of its contact fracture.

To ensure and improve cutting ability of metal-cutting tools, one has to solve a complex of various problems including assurance of required physico-mechanical and cutting properties of a tool while maintaining an adequate tool reliability during the operation. These targets can be achieved by using wear-resistant protective coatings. For this purpose, vacuum-plasma-sprayed coatings are widely employed. They possess high adhesive and cohesive strengths which permit taking full advantage of their inherent properties. The cohesive strength of these coatings is in many respects due to a high level of residual compression stresses that arise during the coating application [1]. However, during the tool operation under the conditions of considerable contact loads a combined action of compression contact stresses and residual compression stresses can impair the contact strength of the coating and cause it to break down [2]. Furthermore, an increase in the coating thickness can adversely affect the adhesive strength due to a large stress gradient across the coating [3]. Replacing of a coating of continuous structure with that of discrete-mosaic structure [4] can ensure the best use of all the benefits offered by a cutting tool coating while providing a high contact strength of the coating.

The objective of the present work has been to search for ways of improving contact strength of a coating through reducing residual stresses in wear-resistant vacuum-plasma-sprayed discrete-structured coatings.

To clarify the influence of the coating thickness, design and continuity on the level of residual stresses in vacuum-plasma-sprayed titanium nitride coatings applied to the surface of high-speed steel, we carried out experimental investigations with subsequent calculation of residual stresses. The (Ti, Al)N coatings of various thicknesses were applied to R6M5 steel specimens measuring $120 \times 5 \times 0.5$ mm by plasma-phase condensation under ion bombardment in a NNB-6.6-I1 ("Bulat-20") apparatus. The coating thickness depends on the deposition time. The discrete-structured coatings were produced by using special "masks" [5]. By varying the size of mask meshes we managed to prepare coatings with different dimensions of discrete segments as

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well as with different degrees of continuity ψ. The degree of continuity was defined as a ratio of the total surface area of discrete segments to the substrate surface area.

The residual stresses in coatings σ_c^{resid} were determined on the basis of the following consideration: in the case of coating application to a thin substrate fastened in a special jig, the residual stresses in the coating cause the substrate to hog once the coated specimen has been removed from the jig. We measured deflection of thus deformed specimen and calculated the residual stresses by the formulas based on the deflection curve equation [6]

$$\sigma_c^{resid} = \frac{32E_s H_s^3 f}{3a^2 h_c (1-\mu_s)(2H_s + h_c)}, \quad (1)$$

where $2H_s$ and h_c are respectively the substrate and coating thicknesses, E_s and μ_s are respectively the modulus of elongation and Poisson's ratio, f is the specimen deflection, a is the specimen length.

Figures 1 through 3 show the residual stresses calculated by (1) for various coating thicknesses h and discrete segment sizes D.

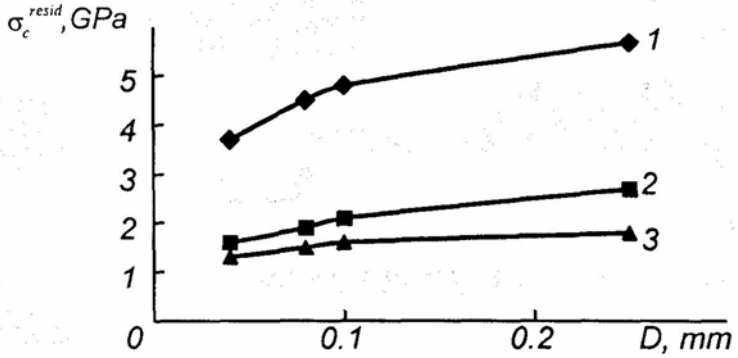

Fig. 1. Residual compression stresses vs. the discrete segment size for discrete-structured coatings of 2 (*1*), 6 (*2*) and 10 (*3*) μm in thickness.

Analysis of the findings has demonstrated that significant compression stresses arise in the vacuum-plasms-sprayed (Ti, Al)N coatings. The discrete-structured coatings have smaller residual stresses in comparison to the continuous coatings. These stresses tend to go down with decreasing sizes of discrete segments (see Fig. 1).

The residual stresses decrease for both the continuous- and discrete-structured coatings with increase in coating thickness (see Fig. 2). This is attributable to the fact that as the distance from the substrate–coating interface grows (i.e. with increasing thickness) the stresses in the coating decrease and so do the mean stresses throughout the coating layer. At the same time, the growth of the stress gradient is known to entail coating detachment from the substrate [3]. Therefore, despite a decrease in stresses with increasing coating thickness the problem of reducing stresses is still of critical importance.

In a discrete-structured coating the residual stresses are diminished with decreasing discrete segment dimensions, with the degree of continuity being constant, ψ = 57% (see Fig. 3). This suggests a stress relaxation in the surface layer of the discrete structure in addition to a decrease in specimen deflection through reduction of surface area where the residual stresses are active.

The present findings enable us to infer that a decrease of the discrete segment dimensions while keeping a preset degree of continuity restricts the residual compression stresses and reduces the probability of the coating breaking down under the contact loading. The diminishing of residual stresses owing to the discrete structure and the reduction of dimensions of discrete segments enable one to increase the coating thickness in comparison to continuous coatings. Thus,

the coating design ensuring high performance of a coating can be envisaged at the stage of tool design and coating application.

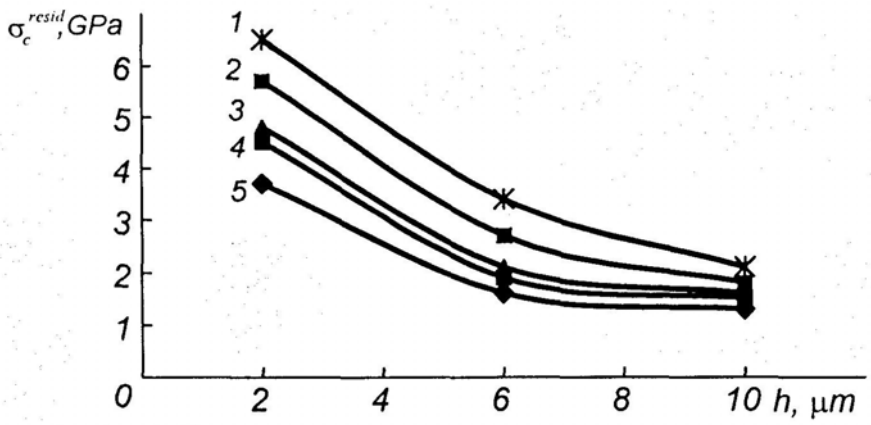

Fig. 2. Residual compression stresses vs. coating thickness for a continuous coating (*1*) and a discrete-structured coating with discrete segments measuring 0.25 × 0.25 (*2*), 0.1 × 0.1 (*3*), 0.08 × 0.08 (*4*), 0.04 × 0.04 (*5*) mm.

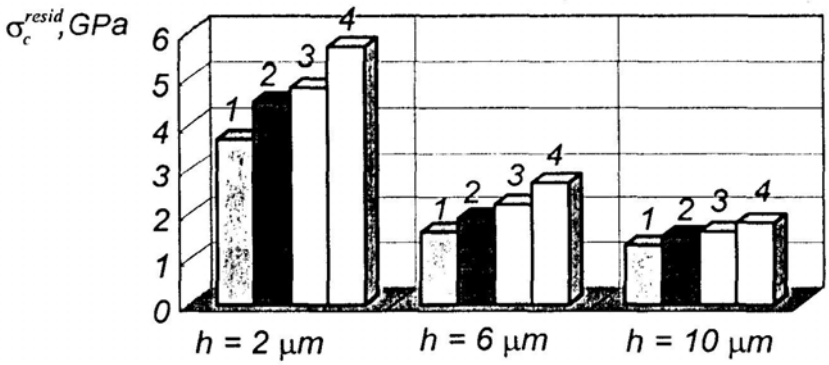

Fig. 3. Residual compression stresses in discrete-structured coatings with a degree of continuity of 57% with discrete segments measuring 0.04 × 0.04 (*1*), 0.08 × 0.08 (*2*), 0.1 × 0.1 (*3*), 0.25 × 0.25 (*4*) mm.

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