Analytical models for nanoindentation of thin coatings

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Determination of the mechanical and physical properties of materials of natural and artificial origin is a scientific and technical task of vital importance in all the fields of human practical activity.

One of the methods for determining the mechanical and physical properties of materials is nanoindentation. It began playing the role of the separate scientific and technical branch in the 1990s. The development of the industry is characterized by the improvement of the apparatus of the nanoindentation test unit, as well as the mechanical and mathematical support represented by a mechanical and mathematical model of the indentation process and by a mechanical and mathematical model of the material under study, taking into account its mechanical and physical properties

The mathematical model allows, in addition to determining the mechanical and physical parameters of the material sample, to establish the adequate dimensions of all elements of the nanoindentation test unit - the dimensions of the indenter, the indentation depth and force, the dimensions of the contact area, the depth of displacement of the material surface outside the contact area, as well as other contact characteristics necessary for the selection of an adequate equipment for observation and measurement of all parameters of the indentation process. Certain parameters of the indentation of a material sample make it possible to comprehensively determine a number of mechanical and physical properties of materials of both natural and artificial origin in a single indentation test due to an adequate mathematical model of the indentation process.

In the present work indentation of an elastic isotropic coated half-space by a rigid punch is considered. The coating is assumed to be homogeneous, layered or functionally-graded. The contact problem is reduced to the solution of a dual integral equation. A kernel transform of the integral equation is approximated by a ratio of two polynomials taking into account its asymptotic behavior. The solution of the integral equation with the approximated kernel transform was constructed analytically using the bilateral asymptotic method. Analytical expressions for the distribution of the contact stresses, indentation force, depth, stiffness and contact radius are obtained. Simplified expressions for these quantities are also proposed based on the simplest one-parametric approximation of the kernel transform. The analysis of the accuracy of the obtained solutions is made depending on the value of dimensionless coating thickness and ratio of the effective elastic moduli of the coating and the substrate. The difference between the contact characteristics for the coated and non-coated materials are analyzed in details. Correlation of the theoretical and experimental results is also discussed.

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