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ADVANCED MATERIALS AND TECHNOLOGIES

# New Deformability Characteristics of Zirconia-Based Plasma-Sprayed Thermal Barrier Coatings at Low Loads

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**Abstract**—A new approach to determining the residual stresses and the energy characteristics of the deformability of zirconia-based thermal barrier coatings is described. This approach consists in the formation of a deformation hysteresis in the elastic range of deformation during four-point static bending and in estimating the energy density of relaxation of the elastic strain in the coatings.

*Keywords:* thermal barrier coating, four-point bending, deformation hysteresis, residual stresses, elastic energy density

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## INTRODUCTION

Ceramic coatings based on partly stabilized zirconia of the composition $ZrO_2$–(6–8)$Y_2O_3$ are widely used in the production of gas turbine engines (GTEs) to protect combustion chamber parts, and turbine and nozzle blades. The thickness of such coatings is 0.2–1 mm. These thermal barrier coatings (TBCs) usually consist of the following two layers: a refractory Ni–Co–Cr–Al–Y sublayer protects the surface of a part against high-temperature oxidation and salt corrosion, and the outer thermal barrier ceramic layer weakens the heat flow on the part due to its low thermal conductivity and porosity.

Plasma spraying is an effective method for the deposition of ceramic TBCs onto the large parts of the combustion chamber in GTE, since it can be used to produce high-quality coatings at a high output. However, plasma-sprayed TBCs are characterized by an insufficiently high resistance to thermal cyclic loads. Internal stresses appear in a coating during its formation, and their level depends on the nonuniformity of the deposited particle sizes, the layer and sublattice thicknesses, their ratio, and the differences between the thermal expansion coefficients and Young's moduli of the materials of both coating layers and the base [1, 2]. These factors cause a significant scatter of the mechanical properties of the coating, which decreases its reliability and service life.

From the standpoint of reliability and service life of coatings, their strength and deformability are the most important properties related to technological heredity. To create thick TBCs to increase the thermal protection of parts is a challenging problem, and the related increase in the level of residual stresses should be taken into account. The absence of full contact interaction between the coating layers along with a high level of residual stresses, which appear in the coating in spraying, determines the behavior of these coatings during loading and deformation. Therefore, to find the relation between the composition, the coating formation conditions, the coating thickness, and the mechanical properties of the coating is a challenging problem.

The four-point bending technique of studying the strength and deformation properties of coatings differs qualitatively from the three-point bending method [3]. This technique makes it possible to determine the mechanical properties of the coating–large base metal system, which more correctly reflects the real properties of the system. The mechanical properties of a coating thus determined can be used to choose the coating material, the optimum thickness of bilayer coating, the spraying parameters, and the quality of heat treatment after deposition [4–6]. The criteria of choice are usually such characteristics as the stress of cracking, the coating separation stress, and Young's modulus of a ceramic thermal barrier layer and the stiffness of the composite coating–base system. At the same time, this technique can be successfully used to study the behavior of coatings under low loads, without reaching their failure. This approach can give new