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Mechanical Properties of the Coating/Substrate Composite System: Nanostructured Copper Films on a LiF Substrate

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Abstract—The study of a series of composite structures (CSs) such as CS-1, CS-2, and CS-3 being "soft film/soft substrate" systems revealed much new information on the mechanical properties of these materials. The general and distinctive properties of CSs both within the series of CS-1, CS-2, and CS-3 and the properties of raw materials of Cu and LiF are considered. It is found that the deformation process passes through three main phases in a wide range of loads at the nanomicroindentation of Cu/LiF CSs: (1) when $\beta = h/t < 0.5$ (h is the indentation depth, t is the coating thickness) the plastic deformation is mainly concentrated in the film, and only a small elastic deformation can take place in the substrate; (2) at $\beta \approx 1.0$ the deformation occurs in the film and in the interface zone; (3) when $\beta > 1.0$ the plastic deformation extends into the substrate bulk, capturing all the typical levels of the system (film–interface zone–substrate) naturally becoming more complex as the load increases. It is shown that the "film/substrate" CSs are complex systems with their highly individual properties even possessing the same chemical composition with the same production method, differing by only one parameter (the film thickness t).

Keywords: mechanical properties, specificity of deformation, Cu/LiF, dynamic indentation

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INTRODUCTION

Coating/substrate composite structures (CSs) are nowadays the objects of thorough investigation with the purpose to obtain more complete understanding of these structures' behavior on exposure to an external local load, in particular, at micro- and nanoindentation [1–10]. However, in most works only the mechanical properties of the coating are studied, though the structural behavior of a CS as an integral is very important as CSs are actually new materials whose elastic and plastic properties differ from the characteristics of their components. Thus, in works [6, 11] it is shown that the hardness of the CS is more than the hardness of both the substrate and the coating. In the other works [5, 12] it is established that the CS hardness varies with the applied load rate. For this reason, when determining the hardness of thin films through indentation it is very important to take account of the contribution made by the substrate as the measured hardness is a complex quantity (so-termed "composite hardness") which depends on the relative depth of indentation and mechanical properties of both the film and the substrate [2, 7, 13].

There are different views on the critical load value below which in a coating/substrate CS the whole deformation under the indentation is concentrated only in the coating, and when it is achieved it is also distributed into the substrate bulk. Work [6] shows that in the case of a "soft coating/hard substrate" CS, in particular, for the Cu/Si pair, the contribution of the substrate starts to have a significant impact on the CS hardness when the depth of indentation is approximately equal to the film thickness. For a "hard coating/soft substrate" pair or at similar values of hardness and Young's modulus of the coating and the substrate, the contribution of the substrate is observed at much lesser depths of indentations. In works [7, 14] there is introduced the parameter β, the relative depth of indentation: $\beta = h/t$ (where h is the depth of indentation, t is the coating thickness), which helps the authors to estimate the contribution of the substrate to the value of the coating/substrate system hardness. For the systems with different compositions the authors showed that the influence of the substrate begins at $\beta \approx 0.35$. Other investigators [2, 15] think that the substrate influence even starts at a depth of $\beta \approx 0.1$, and the depth of indentation cannot be more than 10% of the coating thickness in order the coating hardness be correctly determined. It should be noted that the above mentioned investigations are usually based on