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On the mechanical behavior at sharp indentation of materials with compressive residual stresses

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ABSTRACT

The correlation between residual stresses and the global properties, i.e. hardness and size of the contact area, given by a sharp indentation test have been studied quite frequently in recent years. The investigations presented have been based on experimental, theoretical and numerical methods and as a result, the basic features of the problem are now well understood. Furthermore, in this context quantitative relations, for the determination of residual stresses using sharp indentation, have been presented. Such relations have proven to be reliable in case of predominantly tensile residual stresses while the accuracy of predictions is much worse at compressive stress states. It is therefore the aim of the present study to investigate this matter in some detail and to present possible mechanisms for the difference in indentation behavior between tension and compression. Accordingly, the results are essentially qualitative but necessary and detailed investigations needed for a quantitative understanding are suggested. The present analysis is based on theoretical and numerical methods and in the latter case, the finite element method (FEM) is relied upon. Classical Mises elastoplastic material behavior is assumed throughout the investigation.

1. Introduction

For the purpose of determining residual stresses and strains in a material, various experimental measuring techniques have been developed, such as indentation crack techniques [1], fracture-surface analysis, neutron and X-ray tilt techniques [2], beam bending, hole drilling [3], and layer removal [4]. Many of these methods are complicated and expensive or only applicable for some special purpose, for which they are developed. Therefore, the development of an alternative method for measuring residual stresses/plastic strains at the nano-, micro- or macro-level is of great interest. In the present study, a method based on sharp indentation testing is proposed. This is, indeed, of substantial practical importance as the effects of residual stress and strain fields in materials can be considerable with respect to, for example, fatigue, fracture, corrosion, wear, and friction.

Until recently, the influence of residual stresses and residual strains on the results given by a sharp indentation test, in comparison with the corresponding results for a material without residual stresses or residual strains present, i.e. a virgin material, has been studied only occasionally, and then mainly experimentally. This is in contrast to sharp indentation or hardness testing of virgin materials which is a well known experimental method used for determination of the constitutive properties of conventional materials such as metals and alloys, cf. e.g. Tabor [5], Johnson [6], Larsson [7] and Doerner and Nix [8]. In recent years the method has gained renewed interest due to the development of new experimental devices like the nanoindenter (Pethica et al. [9]), enabling an experimentalist to determine the material properties from extremely small samples of the material. Indentation testing is for example a very convenient tool for determining the material properties of thin films in ready-to-use engineering devices. However, returning to the case when residual fields are present, it should be mentioned that already in 1932 Kokubo [10] studied several materials subjected to applied tensile and compressive uniaxial stress. The Vickers hardness was measured and some very small influence from sign and size of the applied stress was found. However, the observed effect of stress on the hardness value was so small that no decisive conclusions could be drawn from these investigations.

As already indicated above, more recently, several investigations dealing with this issue have been presented, cf. e.g. [11]. The basic features of the problem were not fully understood, however, until Tsui et al. [12] and Bolshakov et al. [13] investigated, by using nanoindentation as well as numerical methods, the influence of applied stress on hardness, contact area and apparent elastic modulus at indentation of aluminum alloy 8009, an almost elastic–ideally plastic material. Qualitative results of interest were presented as it was shown that the hardness was not significantly affected by applied

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