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Three-dimensional numerical simulation of Vickers indentation tests

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Abstract

The development of depth sensing indentation equipment has allowed easy and reliable determination of two of the most popular measured mechanical properties of materials: the hardness and the Young's modulus. However, some difficulties emerge in the experimental procedure to calculate accurate values of these properties. This is related to, for example, the tip geometrical imperfections of the diamond pyramidal indenter and the definition of the contact area at the maximum load. Being so, numerical simulation of ultramicrohardness tests can be a helpful tool for better understanding of the influence of these parameters on procedures for determining the hardness and the Young's modulus. For this purpose, specific finite element simulation software, HAFILM, was developed to simulate the ultramicrohardness tests. Different mesh refinements were tested because of the dependence between the values of the mechanical properties and the size of the finite element mesh. Another parameter studied in this work is the value of the friction coefficient between the indenter and the sample in the numerical simulation. In order to obtain numerical results close to reality, a common geometry and size of the imperfection of the tip of Vickers indenter was taken into account for the numerical description of the indenter.

Keywords: Numerical simulation; Vickers indentation

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1. Introduction

The ultramicrohardness test is commonly used to measure the materials mechanical properties. The most obvious of these properties is the hardness, which can be defined by the equation:

$$H = \frac{P}{A}, \tag{1}$$

where P is the maximum applied load and A is the contact area of the indentation immediately before unloading.

The experimental determination of the contact area, A, can be a hard task, when using ultramicrohardness test. In fact, the high performance attained by the current depth sensing indentation equipment in load and displacement resolutions allows for the use of ultra-low loads. However, the use of indirect methods is needed as well as the consideration of specific aspects for the contact area evaluation (see, e.g., Trindade et al., 1994; Antunes et al., 2002a; Oliver and Pharr, 1992), which are not common in the case of the classic microhardness tests, for which the size of the indentation is measured by optical means. The main aspects to be considered are related to the geometrical imperfections of the tip of the diamond pyramidal punch and the formation of pile-up or the presence of sink-in, which influence the shape and size of the indentation.

The ability of the ultramicrohardness equipment to register the load versus the depth indentation, during the test, enables us to evaluate not only the hardness, but also other properties, such as the Young's modulus. Based on the Sneddon relationship (Sneddon, 1965) between the indentation parameters and Young's modulus, Doerner and Nix (1986) have proposed an equation that relates the Young's modulus with the compliance of the unloading curve immediately before unloading, C, and the contact area, A, such as:

$$E_{\mathrm{R}} = \frac{\sqrt{\pi}}{2}\frac{1}{\sqrt{A}}\frac{1}{C}, \tag{2}$$

In this equation, E_{R}, is the reduced Young's modulus, which is a function of the Young's modulus and the Poisson's ratio, v, of the specimen (s) and the indenter (i), through:

$$\frac{1}{E_{\mathrm{R}}} = \frac{1-\upsilon_{\mathrm{s}}^2}{E_{\mathrm{s}}} + \frac{1-\upsilon_{\mathrm{i}}^2}{E_{\mathrm{i}}}. \tag{3}$$

Such as for the hardness calculation, the evaluation of the Young's modulus needs the correct determination of the contact area. Moreover, the correct determination of the compliance is needed for the evaluation of the Young's modulus.

The use of the numerical simulation to study the deformation process involved in the indentation test seems to be a useful tool for understanding the mechanical phenomena that takes place into the material under indentation. In the last few years, many works have used the numerical simulation to describe the indentation process. However, most of them use bi-dimensional analyses with spherical and conical indenters, and sometimes a load distribution is used instead of the indenter (see, e.g., Murakami and Yuang, 1992; Laursen and Simo, 1992; Sun et al., 1995; Cai and Bangert, 1995; Kral et al., 1993; Bolshakov et al., 1996; Taljat et al., 1998; Bhattacharya and Nix, 1988, 1991). Some works (see, e.g., Zeng et al., 1995; Wang and Bangert, 1993; Antunes et al., 2002b), show results from three-dimensional numerical simulations of the hardness tests with Vickers indenter, but in general do not take into account the friction, between the indenter and the indented material, and the existence of the offset in the tip of the indenter.

In the present study specific simulation software, HAFILM was developed to simulate ultramicrohardness tests. This home code enables us to simulate hardness tests with any type of indenter shape including the offset imperfection of the indenter tip and takes into account the friction between the indenter and the sample. A preliminary analysis on the influence of the finite element mesh refinements and on the friction coefficient on the hardness and Young's modulus numerical calculations is performed. In the following, a