

# FINITE ELEMENT SIMULATION OF ULTRAMICROHARDNESS TESTS

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**SUMMARY:** A numerical study of the ultramicrohardness test is presented. Mesh refinements were tested in order to evaluate the influence of the finite element mesh on the simulation results. The influence of the friction coefficient value between indenter and sample was also evaluated. For that purpose specific finite element simulation software was used, and different materials were simulated using Vickers indenters with two different offsets. Post process analysis was full performed with GID.

**KEYWORDS:** Numerical simulation, Hardness.

## INTRODUCTION

The development of depth sensing indentation equipment has allowed easy and reliable determination of two of the most popular mechanical properties of materials: the hardness and the Young's modulus. However, some difficulties emerge in the experimental procedure to calculate the accurate values of the refereed properties. This is related, for example, with the geometrical imperfections of the tip of the diamond pyramidal indenter (such as the offset of the Vickers indenter), the definition of the contact area at the maximum load and the compliance evaluation. The numerical simulation of ultramicrohardness tests can be a helpful tool to better understand the influence of these parameters on the determination procedures for the calculation of the mechanical properties. In this way, different types of finite element mesh refinements were tested in order to evaluate the influence of the FE mesh on the hardness values. The influence of the friction coefficient value between indenter and sample was also evaluated.

To perform this study, specific simulation software, HAFILM, was developed. The simulations were performed with two different materials (AISI M2 steel and Nickel), using Vickers indenters with two different offsets. The software GID was used on the indentation results analyses.

## DESCRIPTION OF THE FE CODE HAFILM

The mechanical model that is the base of the FE code HAFILM, considers the ultramicrohardness test as a process of large deformations and rotations. The plastic behaviour of the material is described by the anisotropic Hill's criterion with isotropic and kinematic hardening. Elastic behaviour is considered isotropic. It is assumed that contact with friction

exist between the sample and a rigid indenter. To model the contact problem a classical Coulomb law is used. The association of the static equilibrium with the contact with friction makes use of an augmented multiplier. This led to a mixed formulation, where the kinematics (material displacements) and static (contact forces) variables are the final unknowns of the problem. For its resolution the HAFILM code uses a fully implicit algorithm of Newton-Raphson type. All non-linearities, induced by the elastoplastic behaviour of the material and by the contact with friction, are treated in a single iterative loop [1].

## INDENTER AND SAMPLE DESCRIPTION

For the description of the sample, three-linear eight-node isoparametric hexahedron are used (see e.g. [2]), associated with a selective reduced integration technique [3]. In brief, the dilatational contribution to the stiffness matrix is considered constant over the element, and equal to its value at the central point of the element, whereas a full integration rule is used for the deviatoric part. The main characteristics of the three different meshes used in this work are presented in table 1. This table shows the number of elements and their size on the indentation region that compose the finite element meshes. Because of the symmetry along the X and Z-axis only a fourth of the sample is used in the simulation (fig. 1).

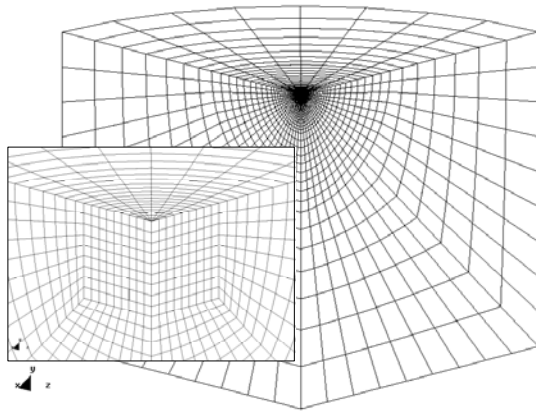


Figure 1: Finite element mesh

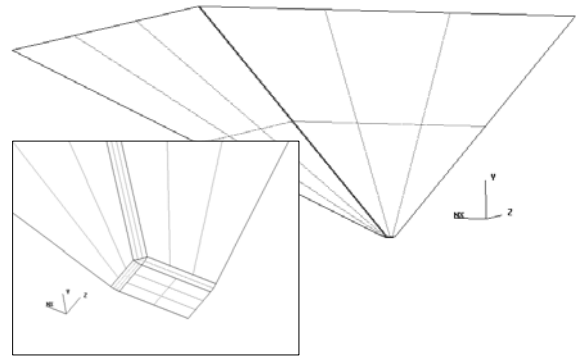


Figure 2: Numerical Vickers indenter

Table 1: Finite Element meshes.

Mesh	Mesh 1	Mesh 2	Mesh 3
Element Size ( $\mu\text{m}$ )	0.38	0.05	0.045
Number of elements	4680	5832	8008

The indenter geometry used in the numerical simulations is described by Bézier Surfaces, allowing a fine description of the tip. In this study two Vickers indenters with different offsets ( $0.0162 \mu\text{m}$  – Vickers 1;  $0.0485 \mu\text{m}$  – Vickers 2) were used. A top view of the indenter tip presents a rectangular shape where one side is larger than the other (see fig. 2). The mechanical properties of the used materials are presented in table 2. In this table  $\sigma_y$  is the yield strength,  $\nu$  is the Poisson ratio and K and n are the material constants of the Swift law describing the isotropic hardening.

Table 2: Mechanical properties of the used materials.

Material	$\sigma_y$ (GPa)	E (GPa)	$\nu$	K (GPa)	n
AISI M2 Steel	4.0	200	0.29	4.00	0.01
Nickel	0.2	220	0.31	1.05	0.08

## RESULTS

### Influence of the mesh size

Six numerical simulations using the three different meshes and two indenters (Vickers 1 and 2) were performed. The material used was the AISI M2 steel with one friction coefficient equal to 0.16. Figure 3 shows the hardness results obtained with the three meshes. The best hardness values were obtained with mesh 3. However mesh 2 also presents results with good accuracy. Evaluating the CPU time spent in simulations, it's possible to conclude that mesh 2 conducts to the best compromise present between hardness results accuracy and CPU time (CPU mesh 2 = 0.4 CPU mesh 3).

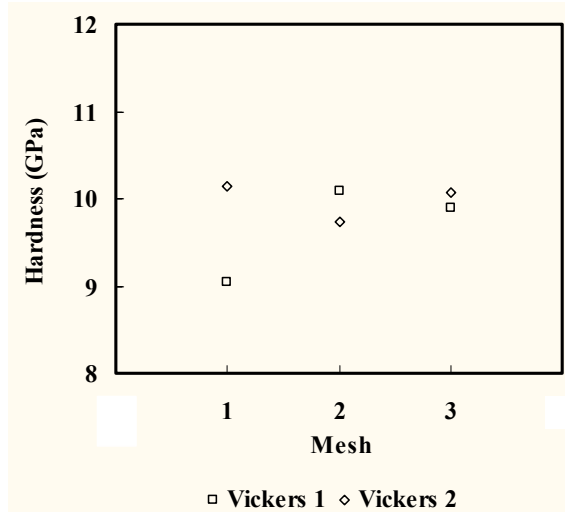


Figure 3 – Hardness distribution for the three studied meshes.

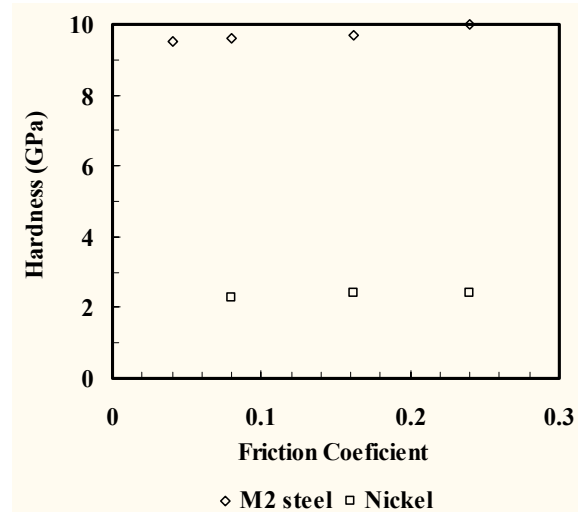


Figure 4 – Hardness distribution obtained with different friction coefficients.

### Influence of friction coefficient

Mesh 2 were used with indentador Vickers 2 in this analysis. The materials were the AISI M2 steel and nickel. The use of these two materials was related to the fact that they have significant different hardness values. In this analysis the following friction coefficients were tested: 0.04, 0.08, 0.16 and 0.24 [4, 5].

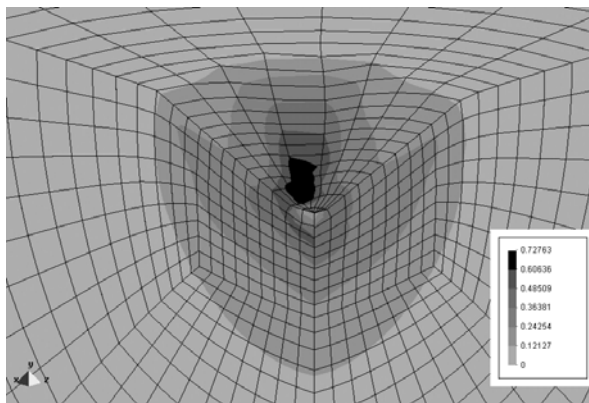


Figure 5 – Equivalent strain distribution on the steel sample for a friction coefficient equal to 0.08.

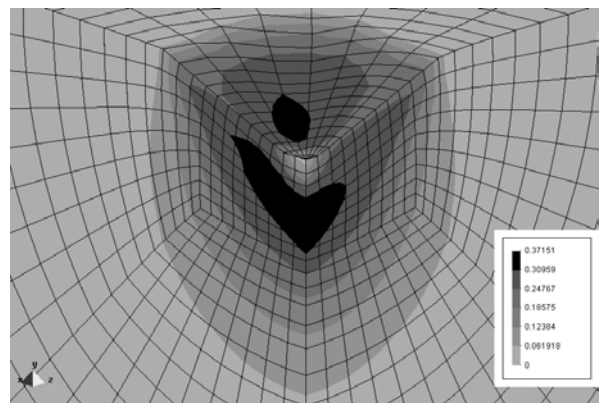


Figure 6 – Equivalent strain distribution on the steel sample for a friction coefficient equal to 0.24.

The hardness value obtained with the different friction coefficients is presented in figure 4. The small variation of the hardness values observed in figure 4 seems to indicate an apparent

independence on the value of the friction coefficient used. However, the analysis of the distribution of equivalent plastic strain at maximum load for the different cases of friction coefficients shows that for low values of the friction coefficient, the plastic deformation sharply increases (for comparison see figures 5 to 8). Low values of the friction coefficient produce a stress concentration on the offset region. Increasing the friction coefficient the stress distribution spreads over the contact region and the equivalent plastic strain is not so concentrated in the offset zone.

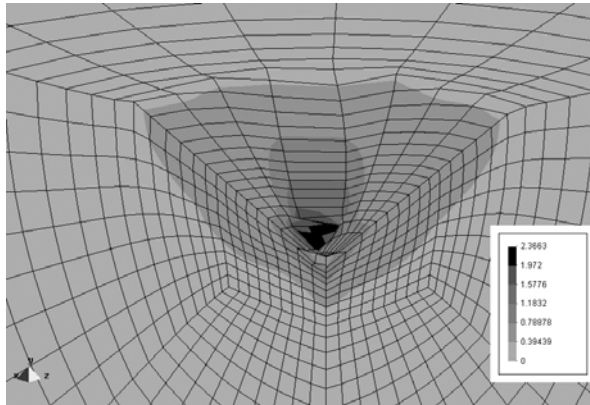


Figure 7 – Equivalent strain distribution on the nickel sample for a friction coefficient equal to 0.08.

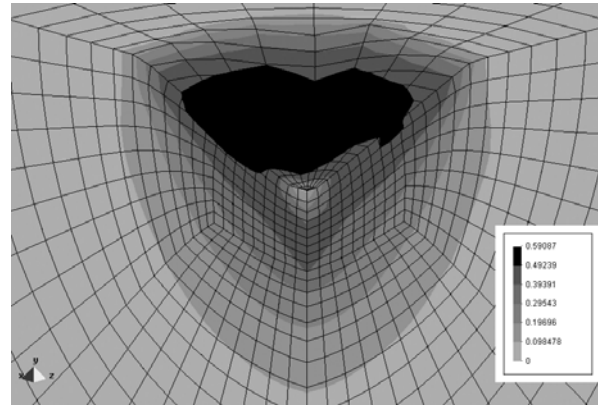


Figure 8 – Equivalent strain distribution on the nickel sample for a friction coefficient equal to 0.24.

## CONCLUSIONS

Results of finite element simulations of ultramicrohardness tests are presented. These results highlight the ability of finite element code HAFILM to simulate this type of tests.

The influence on the results of parameters such as the finite element refinement mesh and the friction coefficient between the indenter and the sample are presented. The study presented enables us to conclude that the hardness values are not significantly dependant of the friction coefficient considered. Accuracy is strangely dependent of the FE mesh. Sensitivity studies should always be performed. However, this parameter has a strong influence on the stress and strain distributions over the sample, which can be critical important for the calculations of other mechanical properties.

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