Characterisation of mechanical properties of Nickel samples near its surface using numerical modelling of the nanoindentation test.

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Introduction

In the last few years, material sciences have known a great technical progress, mainly in the microtechnic domain. The aim of this science is to design and to manufacture millimetric or even micrometric mechanical systems.
Traditionally, the characterisation of a material is made using a tensile test. In some cases, those tests are not suitable, especially in the case of bi-materials formed by thin films, which may not exceed few microns. It is materially difficult to manufacture a test specimen to make a tensile experiment. Therefore it is necessary to apply a method determining local mechanical properties so that we can understand and predict the behaviour evolution of these structures.

Objectif

This research consist firstly in studying nickel samples using instrumented nanoindentation technique, which allows Young's modulus and hardness of thin films to be evaluated. Secondly, it consist in doing a numerical modelling of the nanoindentation test in order to identify the elasto-plastic parameters of the behaviour law (1) of the material using a inverse method.

$$\sigma = R_0 + Q\,(1 - \exp(-b\,\varepsilon_p)) \qquad (1)$$

FEM modelling

Numerical modelling of the nanoindentation process is done using the axisymmetric two dimensional finite element method (2D). The indenter and specimen are treated as revolution bodies. The indenter was modelled as an elastic cone with a semivertical angle φ = 70.3° that gives the same contact area to depth ratio as a perfect Berkovich pyramid. This numerical modelling was established using three finite element codes (CAST3M, ZEBULON and LSDYNA) and then compared to the result in the literature (Fig.1).

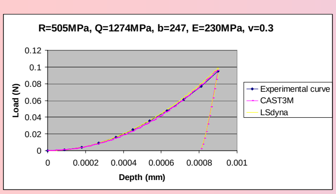


Fig.1 :Load-displacement curve with identified parameters.

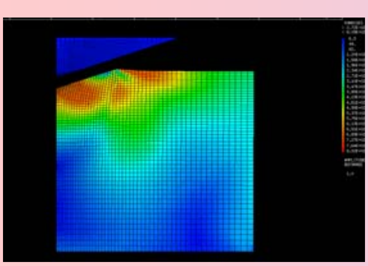


Fig.2 : Mesh with Von Mises strains of the whole sample with the indenter modelled as a movable surface.

Experimental procedure

Experiments were made on hardened and annealed Nickel samples having a grain diameter between 0.2 up to 150µm. The mark left by the indenter after the unloading was measured by an optical profilometer (Fig.3). This procedure allowed to determine the average value of the roll height and thus to calculate the real contact area *A* and the Young modulus *E*.

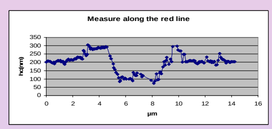
$$A = f(h_c) = 24.5\,h_c^2 + 170\,h_c + 94.89\,h_c^{1/2}$$

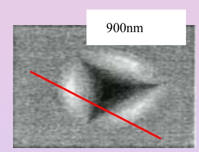
$$E_r = \frac{\sqrt{\pi}}{2\sqrt{A}}\frac{dP}{dh} \quad \text{et} \quad \frac{1}{E_r} = \frac{1-\nu^2}{E} - \frac{1-\nu_i^2}{E_i}$$

$$E_i = 1200 \ GPa \qquad \nu_i = 0.07$$

Indenter characteristic :

P is the load and h_c is the contact height





Algorithm for optimisation procedure

An identification procedure was needed to characterise the elasto-plastic properties of Nickel samples. This method aims to minimise an error between the experimental and the numerical curve using the Levenberg-Marquardt theory. The identification of the parameters was made for all experimental data and the results obtained allowed to draw a linear relationship between the hardened parameters $R_0 + Q$ of the constitutive law and the hardness H of the material (Fig.4).

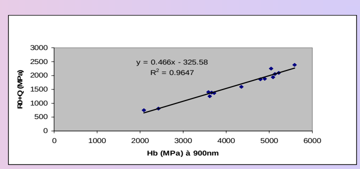


Fig.4 : Linear relationship between the hardened parameters of the constitutive law $R_0 + Q$ and the hardness H of the material.

Conclusion

In this study, the characterisation of the mechanical properties of the Nickel samples was realised using nanoindentation method and its numerical modelling was confirmed. An optimisation procedure for the inverse identification of the mechanical properties was applied to experiment data. In the near future, modelling and characterisation of materials having gradient properties will be realized to understand the irradiated material.