MULTI-SCALE APPROACH OF THE INSTRUMENTED INDENTATION TECHNIQUE ON THE FRACTURE TOUGHNESS ESTIMA TION

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ABSTRACT

Instrumented Indentation Technique (IIT) is widely used to determine the mechanical properties of materials. The elastic modulus is usually determined by applying the methodology proposed by Oliver and Pharr **[1]** who supposed that its value is independent of the indentation depth. However, some authors **[2, 3]** have observed a decrease of the elastic modulus when the indenter displacement increases which allowed them to introduce a continuous damage theory used afterwards to estimate the fracture toughness of ductile materials. The assumption made by the authors is that a damage in the region very close to the bottom of the indent results in the formation of microvoids which leads to the variation of the elastic modulus as a function of the indenter displacement. Starting from this observation, Lee *et al.* **[2]** proposed an energy model based on the Griffith's theory and the continuous damage mechanics (CDM) which states that the elastic modulus variation is related to the fraction void volume through a variable damage, introduced by Kachanov **[4]**, related to the surface density of the microdefects. On the other hand, the works carried out over ductile materials by Li *et al*. **[3]** have been performed only with nanoindentation data preventing a discussion on the scale-effect.

The aim of this work is to determine the fracture toughness of SAE 1020 and SAE P20 steels by instrumented indentation using a multi-scale approach, *i.e*. nano, micro and macro range of loads. In addition, the indentation data are corrected taking into account different aspects: *i*) the influence of the compliance, *ii*) the influence of the deformation mode around the indent, piling-up or sinking-in, and *iii*) the influence of the tip defect on the contact area calculation. To take into account the deformation around the indent, the methodology of Oliver and Pharr **[1]** is applied when sinking-in is observed whereas the methodology of Loubet *et al*. **[5-7]** is applied for piling-up. The difference being noticeable in the way of the contact indentation depth is calculated. To take into account the tip defect for which its influence depends on the scale of measurement, the contact area is corrected using the complex function proposed by Oliver and Pharr **[1]** at a nanoscale and, at the microscale, by adding the truncation length as proposed by Troyon *et al*. **[8]**. Finally, we observed that the plot of the total compliance versus the inverse of the square root of the contact area over the total range of indentation loads could not be represented by a unique straight line, thus confirming the postulate of continuous damage theory. The fracture toughness obtained applying the methodology proposed were 246 $MPa.m^{1/2}$ for the SAE 1020 steel and 262 $MPa.m^{1/2}$ for the SAE P20 steel which are in a good agreement with the results obtained by Lee *et al*. **[2]** even if a difference is observed with the results of Xue *et al*. **[5]**.

Key words : *Fracture toughness, Multi-scale indentation, continuous damage theory.*

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