STRESS-STRAIN CURVES AND DERIVED MECHANICAL PARAMETERS OF P91 STEEL FROM SPHERICAL NANOINDENTATION AT A RANGE OF TEMPERATURES

Ana Ruiz Moreno, European Commission, Joint Research Centre, Directorate G: Nuclear Safety and Security, Westerduinweg 3, The Netherlands
Ana.RUIZ-MORENO@ec.europa.eu
Peter Hähner, European Commission, Joint Research Centre
Francesco Fumagalli, European Commission, Joint Research Centre
Vendulka Haiblikova, Anton Paar TriTec. Rue de la Gare 4, Switzerland
Marcello Conte, Anton Paar TriTec
Nicholas Randall, Anton Paar TriTec

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Nanoindentation allows extracting local mechanical properties out of small regions of interest, such as welds, coatings or ion-irradiated layers. Probing the surface with spherical tips combined with several data analysis procedures allows deriving the complete elastic-plastic behaviour of the material under test, from the initial elastic response during loading, to the onset of plasticity and the post-yield behaviour. This works aims at comparing different measurement and analysis protocols to spherical nanoindentation tests performed at different temperatures on a ferritic/martensitic P91 grade steel, in order to derive meaningful indentation stress−strain curves (ISSC) and estimate parameters such as indentation modulus, yield strength, work hardening exponent and ultimate tensile strength. Indentations using spherical indenters have been carried out from room temperature to 600°C in vacuum in a set-up where thermal drift has been minimised by an active surface referencing system and an accurate temperature stabilisation in the contact area. To evaluate indentation tensile properties from nanoindentation results, the determination of the contact area, the definition of representative stress and strain, and the fitting to constitutive equations are the important steps, the most adequate choice of which is still matter of discussion and may depend on the instrument, material analysed and testing procedure. In the present work it is shown that the methodology used to determine the radius of the contact is critical to achieve consistent results. The geometrical definition of the contact radius provides a consistent shape of the ISSC; however it requires a good calibration of the true indenter radius as a function of depth. On the other hand, the Hertz model for the contact radius is very sensitive to the measurement of stiffness and presumes that the elastic modulus of the material is known or derived form the initial loading. The application of the different combinations of contact radius and strain definitions to nanoindentation data obtained by multi-cycle and continuous stiffness measurements revealed that Tabor's approach combined with geometrically determined radius best represented the ISSC relationship for the P91 characterized. This method was then extended to predict the high temperature tensile properties of the steel. The results of the nanoindentation characterization will be presented and discussed thereby comparing the performance of different measurement and analysis protocols.

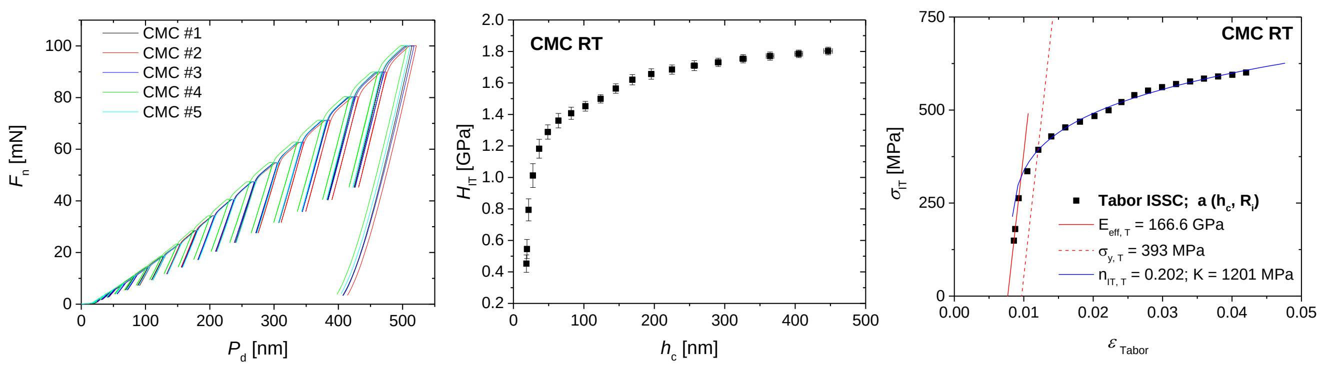

Figure 1 – (a) Load displacement curves obtained by multi-cycle indentation of P91 and (b) Hardness profile obtained by averaging the Oliver & Pharr analysis of each cycle in the five measurements shown in (a). (c) shows the values of E_{eff}, indentation yield stress, $\sigma_{y,IT}$, and indentation work-hardening exponent, n_{IT}, extracted from ISSC calculated using Tabor's formulation for strain and geometrical contact radius determination.