Correlation of Nanoindentation and Conventional Mechanical Property Measurements -
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EXTENDED ABSTRACT

A series of model ferritic alloys and two commercial steels [1,2] were used to develop a correlation between conventional mechanical property measurements and nano-indentation hardness measurements. The NanoIndenter-II® [3] was used with loads as low as 0.05 g_f and the results were compared with conventional Vickers microhardness measurements using 200 and 500 g_f loads. When the nanohardness data were corrected to account for the difference between projected and actual indenter contact area, good correlation between the Vickers and nanohardness measurements was obtained for hardness values between 0.7 and 3 GPa. The relationship between Vickers and nanohardness measurements is shown in Figure 1.

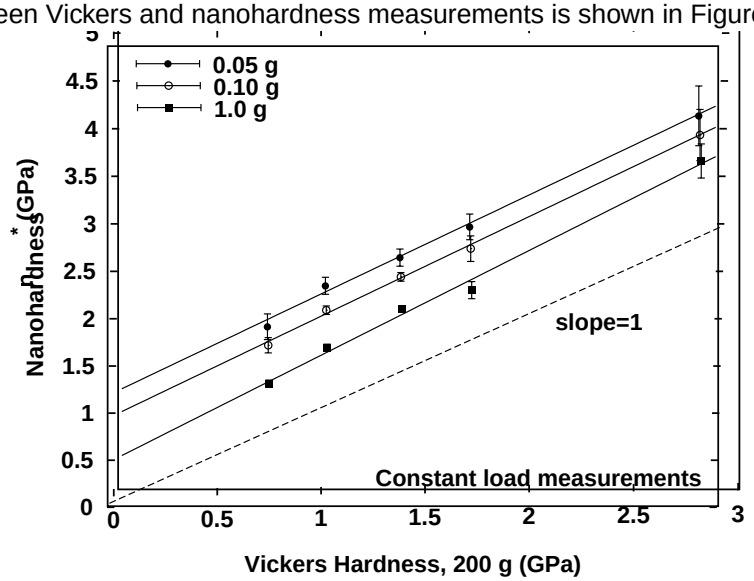

Figure 1. Comparison of 200-g_f Vickers hardness and constant-load nanohardness measurements

The nanohardness values show the well-known apparent increase in hardness with decreasing indent depth [4], which is responsible for the different zero-intercepts in Figure 1. The physical origin of the zero-offset in Figure 3 is not known, but the hardness changes are consistent for all the alloys. Thus, only the intercept, and not the slope of the ΔH_N vs. ΔH_V line changes and changes in hardness are well correlated. Overall, the slope of each line is within a few percent of the bottom dashed line which was drawn with a slope of 1.0. based on the average slope of the lines in Figure 1 and additional data, the following correlation is found between the two hardness measurements: $\Delta H_V/\Delta H_N$=0.937 GPa/GPa.

Tensile property measurements were made on these same alloys using 0.020 in.-thick sheet tensile samples. A linear correlation was found between the change in Vickers hardness and tensile yield strength in these ferritic and ferritic/martensitic steels with yield strengths in the range of 150 to 750 MPa. This correlation is shown in Figure 2. Using the available data, a correlation between nanohardness and tensile yield strength can be obtained in two ways. The first is derived from the linear relationships shown between Vickers hardness and yield strength in Figure 2 (slope=0.2836 MPa/MPa), and between nanohardness and Vickers hardness in Figure 1 (Eqn. (1)). The product of these slopes yields $\Delta H_N/\Delta\sigma_y$=266 GPa/MPa. Alternately, the tensile data can be plotted against the nanohardness data and the average slope obtained directly. In this case, the correlation obtained is (as it must be) nearly same:

$$\Delta\sigma_y\ [MPa] = 274\Delta H_N\ [GPa] \qquad (1)$$

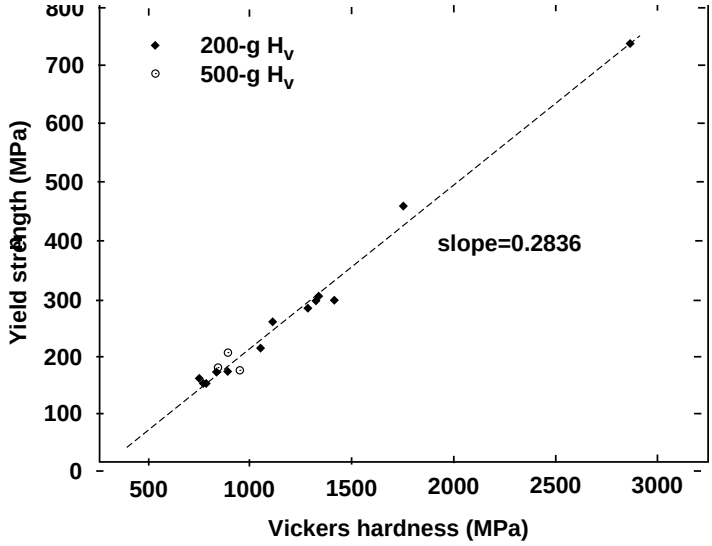

Figure 2. Comparison of yield strength and Vickers hardness for all materials in study.

The successful correlation of nanohardness measurements with bulk mechanical properties is significant not only because of the validation of the nanoindentation technique, but also because of its implications for ion irradiation studies. This validation supports the application of ion irradiations to simulate the effects of neutron irradiation, allowing studies to be carried out without the complications associated with testing radioactive specimens. For example, reliable estimates of mechanical property changes can be obtained for the high dose conditions reached at the end of fission reactor lifetimes. Similarly, the technique can be used to more rapidly screen alloys for irradiation performance and to investigate variables such as alloy composition or thermal-mechanical treatment. With the cross-section technique [1,2], is possible to use the nanoindenter to obtain data for a range of doses on a single specimen. In conjunction with TEM observation, changes in mechanical properties can be correlated with microstructural changes, and parameters such as the strength of microstructural obstacles preventing dislocation motion can be measured.

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REFERENCES

[1] P. M. Rice and R. E. Stoller, Journal of Nuclear Materials **244** 219 (1997).
[2] P. M. Rice and R. E. Stoller, *Hardening Behavior of Ferritic Alloys at High Doses and After Thermal Aging*, NUREG/CR-6643 (ORNL/TM-1999/297), Oak Ridge National Laboratory, Oak Ridge, TN, April 2000.
[3] W.C. Oliver, and G.M. Pharr, Journal of Materials Research, **7** (6), 1564 (1992).
[4] J. B. Pethica, R. Hutchings, and W. C. Oliver, Philosophical Magazine A **48**, 593 (1983).

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