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Effects of Hard Phase Size on Microhardness Measurement and Implication on Line Pipe and Weld Property Specifications

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ABSTRACT

Microhardness test has been used as an alternative test for measuring material's tensile properties. The test is especially useful when there are significant property gradient within a small dimension, or only a limited quantity of material is available, or the material is located at an inconvenient location. Attempts have often been made to establish the correlation between microhardness values and tensile properties, either yield strength or tensile strength. However, conflicting results have been found regarding the existence of such relations for steels partially due to the large scatters of the microhardness test data. One contributing factor could be the large variance of the test conditions. For example, the indentation load varies from 0.1 kilo-gram-force (kgf) to 1.0 kgf and the number of repeated tests range from a few to as many as 40.

Previous work by a number of researchers found the measured microhardness depends on the indentation load. For polycrystalline materials, the indentation load must be large enough to induce plastic strains in several grains before the measured hardness stabilized. Most structural steels have multiple phases, for example, soft ferrite, hard bainite or pearlite etc. The effect of the multiple phases on producing a load-independent microhardness value is not well understood. In this paper, three-dimensional (3D) finite element analyses (FEA) are conducted to simulate the microindentation process of a two-phase linepine steel. The effect of the size of the 2nd phase and the indentation touch-down location on the hardness is analyzed. The work is aimed at understanding the variation of microhardness values and establishing guidelines for obtaining consistent hardness measurement.

KEY WORDS: microhardness, Vickers hardness,

INTRODUCTION

Microhardness test is one of the most widely used tools for material property measurements. The test is usually done in conjunction with other measures of tensile properties, such as conventional tensile tests. However, in some cases, conventional tensile tests are impossible or impractical. For example, the material in the heat affected zone (HAZ) of weldments can have very high gradient of microstructures and properties within a small dimension. It is therefore impossible to extract conventional homogenous tensile specimens. Some new specimens have been proposed to measure the stress-strain properties, such as the notched tensile bar (Zhang et al., 2002; Bowker et al., 2006) and micro-tension specimen (LaVan and Sharpe, 1999; Mohr, 2006). However, the notched tensile bar test needs detailed calibration as the measured values are affected by the properties of neighboring regions due to geometric constraints. The micro-tension test on the other hand, requires very intricate specimen preparation. Furthermore the impact of specimen preparation on material properties is still unknown. Another example is the irradiated materials in nuclear reactors. The large-dose radiation as well as the elevated temperature during service can greatly alter the microstructures and mechanical properties of the materials in the reactor core internals and pressure vessels (Lucas, 1993; Busby, 2005). The radiation can lead to increased yield and ultimate strength, but reduced uniform elongation. Direct tensile tests of irradiated specimens are difficult due to high residual radioactivity and/or limited quantity of available materials.

Yield Strength and Microhardness Correlations

An alternate way to obtain the yield strength is to measure other material properties and convert them to yield strength using appropriate relationships. The microhardness is a good alternative material property. Among various microhardness tests, Vickers microindentation test is one of the most widely used tests. The Vickers indenter has a square-based pyramid shape and the angle between opposite faces is 136° (ASM Handbook 2000).

Tabor (1956) showed that the Vickers hardness is essentially a measure of the plastic yield of the material and the Vickers hardness can be estimated as

$$H_v = 0.3\sigma_0, \tag{1}$$

where H_v (kgf/mm^2) is the Vickers hardness. For non-strain-hardening materials, σ_0 (MPa) is the yield strength, and for strain-hardening materials, it is approximately the stress at 8% plastic strain on the stress-strain curve.

Recently, using detailed FEA, Larsson (2001) showed that for power-law strain-hardening materials, the Vickers hardness can be related to the yield strength as

$$H_v = 0.28(0.15)^{1/n}\sigma_y, \tag{2}$$

where n is the strain hardening exponent (where n=∞ corresponds to