Stress-Strain Relationship in Microstructural Region Using Triangular Pyramidal Indenter

Masahito Mochizuki and Ryota Higuchi
Department of Manufacturing Science, Osaka University
Suita, Osaka, Japan

ABSTRACT

The evaluation method for microstructural stress-strain relationship of materials using the triangular pyramidal indenter is proposed in order to investigate the mechanical properties of steels and weld zone. The existing evaluation method using the ball indenter is correspondingly applied to the evaluation method using the triangular pyramidal indenter because the strain distribution under the indenter or the indentation curve on the unloading process between ball and pyramidal indentation has a similarity. The corresponding ball indenter whose projection area is equal to that of the triangular pyramidal indenter is used to replace the triangular pyramidal indentation to the ball indention, and the representative stress and strain that express the complicated deformation under the indenter are determined. The stress-strain relationships of single-phase steels in microstructural grain are estimated by the proposed method, and averagely correspond with those measured by the macro-tensile test. The difference of the stress-strain relationship due to the difference of the crystal orientation of each grain is possible to be negligible in this method. It is expected to clearly estimate the difference of the stress-strain relationship of each phase in such as dual phase steels by the proposed method.

KEY WORDS: Indentation test; Triangular pyramidal indenter; Ball indenter; Indentation curve; Stress-strain relationship; Microscopic heterogeneity.

INTRODUCTION

Inhomogeneities in steels and welded joints can profoundly influence their macroscopic strength properties, due to the different yield points and tensile strengths of the various phases that make up the microstructure. The grains in a metal such as dual-phase steels exhibit different deformation behaviors between the grains when a load is applied to the metal and the grains have different strength characteristics. This causes stress concentrations due to mismatches between displacements near grain boundaries, and in turn affects the macroscopic strength properties of a material. Thus, it is essential to gain a better understanding of the material properties on a microstructural level, of which the interiors of the grains making up polycrystalline materials are an example. This will be important not only for investigating microscopic phenomena in such materials, but also for evaluating their macroscopic characteristics. Tests for determining the macroscopic properties of a material, such as tensile strength tests, are of little value for assessing microstructural properties; for these, the indentation test is a well-established method. Indentation tests are typically used to measure the hardness of a material. Hardness has a consistent correlation with the yield point and tensile strength. This makes it a useful parameter for measuring on microscopic scales, for which tensile tests are not feasible. In addition, as measurement techniques have improved, it has been found that continuous load and penetration data obtained during the test provide indentation load-depth curves. These can be used to determine other parameters in addition to hardness, including longitudinal elastic modulus, Young’s modulus, and yield point (Kouketsu et al., 2003; Milman et al., 1993; Sakai, 1999).

It has also been proposed that the indentation load-depth curve can be used to estimate a material’s stress-strain relationship (Ahn and Kwon, 2001; Choi et al., 2003; Jang et al., 2003; Field and Swain, 1995). This method employs the indentation load-depth curve obtained in a test with a spherical indenter. However, the shape of the indenter in combination with factors such as the material and the volume of the region being tested can affect the accuracy of the data. The apex of a pyramidal indenter is sharp, enabling it to be applied to a relatively small region. It is thus more effective than a spherical indenter for measuring local material properties. In particular, when analyzing microscopic stresses at the grain level (Mochizuki et al., 2007; Higuchi et al., 2007), for example, examining the microstructure of steel and its inhomogeneities, it is desired to establish the most accurate model possible by measuring not only the properties of individual grains, but also the properties within the grains. By doing this, the resulting model will be more faithful to the actual material. A pyramidal indenter is expected to provide more detailed measurements inside grains and near grain boundaries than a spherical indenter. The dimensional precision of the indenter determines the accuracy of the measurement to a large degree when the measurement region is very small. The much greater ease of fabricating a pyramidal indenter than a spherical indenter holds promise for producing highly accurate indenters, and thus of obtaining highly reliable data.

The above considerations indicate that once a method for measuring the stress-strain relationship using pyramidal indenters has been established,