ABSTRACT

Mechanical properties must be evaluated at high temperatures to predict high-temperature deformation or fracture behavior, since high-temperature properties differ greatly from those at room temperature. High-temperature hardness testing, a representative high-temperature test, is generally used because it is a simple test whose results relate to tensile properties. Recently an advanced method to evaluate hardness without optical observation has been developed: the instrumented indentation test (IIT), which simultaneously applies a load and measures displacement. Here we suggest a new method to determine the contact area between indenter and material and thus evaluate Vickers hardness at high temperatures without optical observation. To determine the exact contact area, we introduce a contact area calibration function that takes into account the pileup effect around the indentation mark. Comparison of the results of this new method with those of conventional high-temperature hardness tests confirms its usefulness.

KEY WORDS: high temperature; instrumented indentation test; Vickers hardness; contact area; plastic deformation

INTRODUCTION

Many materials currently in use for industrial applications experience service not only at room temperature but also at high temperatures. In high-temperature environments, the mechanical characteristics of metallic materials, such as yield strength, tensile strength, work-hardening exponent, hardness, and elastic modulus differ greatly from those at room temperature. For this reason, high-temperature mechanical properties must be evaluated when developing new structures. The usual methods for evaluating material properties at high temperature are tensile and hardness testing. However, these test methods require specific specimen dimensions and cannot be applied to structures in use. In particular, conventional high-temperature hardness tests are expensive and subject to observer error in microscope readings. To overcome these limitations, we have developed a new method for evaluating high-temperature mechanical properties by instrumented indentation testing (IIT). IIT gives accurate measurements of the continuous variation of indentation load as a function of indentation depth (fig. 1). Since instrumented indentation testing has great potential for extensive in-field use due to its simple and nondestructive specimen preparation and test procedure, the instrumented indentation test has been investigated in order to assess mechanical properties by analyzing the indentation load–depth curve.

The great merit of high-temperature instrumented indentation testing is that the contact area can be determined merely by interpreting the load-depth curve, i.e. without optical observation. However, it is very difficult to determine the exact contact area because of complex elastic-plastic deformation behavior around the indentation mark. Here, in order to determine the exact contact area, we use a contact area calibration function that is expressed in terms only of indentation parameters and reflects the elastic and plastic deformation of metallic materials. Using this function allows evaluation of high-temperature Vickers hardness without optical observation.

THEORETICAL BACKGROUND

Contact model of instrumented indentation test

Elastic deflection and plastic deformation (pile-up/sink-in) around the indentation mark are generated when the specimen is loaded by a geometric indenter. For this reason, it is difficult to estimate the indenter’s exact contact depth from the maximum depth measured by the machine. To take into account the complex phenomena around the indentation mark, we express contact depth $h$, as