Evaluation of mechanical reliability using IIT from macro to nano scale

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1. Introduction

Changes in mechanical properties and stress tate due to degradation, processing and welding of materials, ranging from bulk scale in structures to nano scale in electronic devices, can cause deformation and destruction of materials, so that can affects lifetime and reliability of materials.

There are international standard tests like uniaxial tensile test, fracture test etc. However, these methods require a specific material size and shape and also cannot be applied in the field, because they are destructive and time-consuming to preparing the test sample as well

Instrumented indentation testing (IIT) is a nondestructive and simple testing method. A continuous indentation load-depth curve, as shown in Fig. 1, can be obtained by performing the indentation test. Many researchers have studied the indentation load-depth curve to evaluate mechanical properties such as tensile and fracture properties and the state of materials such as residual stress and interfacial adhesion. IIT can be utilized to characterize material properties in multi-scale and in field. As using portable equipment, on site testing is available with simple and fast procedures.

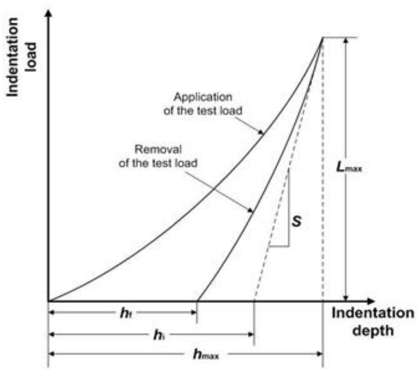

Fig. 1 Indentation load-depth curves

2. Evaluation of tensile properties

It is known that the relation between flow stress and mean pressure is expressed as [1]:

$$\sigma = \frac{1}{\varphi}\frac{L_{max}}{\pi a^2} \qquad (1)$$

φ is a plastic constraint factor and L_{max}, a is maximum load and contact radius. The plastic constraint factor is regarded as depending on material properties such as strain hardening exponent or material-independent constant.

In this paper, we used expanding cavity model suggested by Johnson for determining plastic constraint factor to analyze stress field beneath spherical indenter [2]. And core hardening factor k is proposed to express mean pressure analytically [3]. Using this analytic method, we finally determined plastic constraint factor and defined representative stress-strain equation. Fig. 2 showed schematic diagram of expanding cavity model expressing stress field beneath spherical indenter.

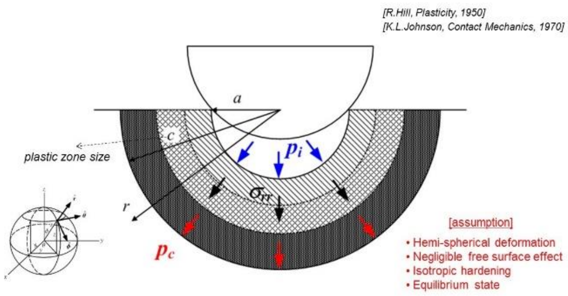

Fig.2 Expanding cavity model

With representative stress-strain points, we can describe flow curve using Hollomon equation.

$$\sigma = K\varepsilon^n \qquad (2)$$

K is strength coefficient and n is strain hardening exponent. Elastic modulus is obtained by IIT using Sneddon's equation and yield strength was evaluated by using Meyer equation and experimental relation with material constant A. Instability in tension was used to evaluate tensile strength with strain hardening exponent n.

3. Evaluation of residual stress

There are methods for measuring residual stress such as mechanics-based(slitting, hole-drilling etc.) and physics-based(X-ray, neutron diffraction etc.) methods. However, these methods have some limitations such as difficulty to applying in a local area and difficulty to obtain reliable data in the field.

The principle of residual stress evaluation using instrumented indentation testing (IIT) is shown in

Fig. 3. The residual stress is evaluated using load differences between the stress-free and stressed states at the same depth and contact area as obtained by IIT. If compressive residual stress exists, it squeezes the material around the indenter and hence a more load is needed to reach to the same indentation depth than in the stress-free state. On the other hand, if tensile residual stress exists, the material is released by tension and a less load is needed to reach to the same indentation depth than in the stress-free state.

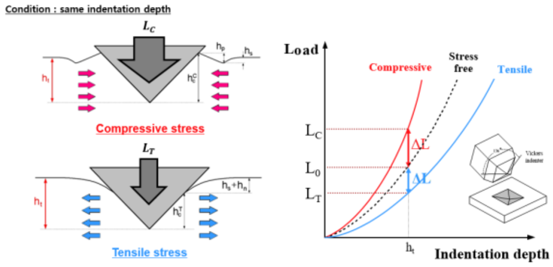

Fig. 3 Basic principle of evaluation of residual stress

Therefore, to evaluate the residual stress, two indentation load-depth curves are required, one in the stress-free state and the other in the stressed state. And the load difference between two curves can be determined at a given indentation depth.

In this study, we introduce the testing cases and field application that evaluate tensile properties and residual stresses(comparison with other methods) in multi-scale with various materials using indentation testing.

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