Spherical Indentation 실험과 유한요소 해석기법을 이용한 탄소성 물성치 측정

The Measurement of Properties for Elastic-Plastic Material by Using Spherical Indentation and Finite Element Analysis

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Abstract

In this paper, forward and reverse analysis is introduced in order to estimate the elastic-plastic properties from a power-law hardening bulk specimen materials with one simple spherical indentation impression test.

In order to verify the reliability of the reverse analysis, we have simulated about a large range of materials that essentially cover all engineering materials, using ABAQUS(6.91) program. Then, we could obtained the fitting functions and plastic parameters from the numerical analysis results. Next, through the procedure of reverse analysis we can obtain the yield stress and power-law exponent.

Finally, obtain good agreement between the result from reverse analysis and initial input data from experiment.

Keywords : *Spherical indentation, Reverse analysis, Plastic deformation, FEM analysis*

1. Introduction

Instrumented spherical indentation is widely used to probe the elastic and plastic properties of engineering materials. Because, in contrast with conical indentation the spherical indentation is more simply to approach the target value which just using one simple impression test can get fairly accurate elastic-plastic properties of bulk specimen. During the experiment, a rigid indenter penetrates normally into a homogeneous solid (Fig.1(a)), and the indentation load P, displacement δ, are continuously recorded during loading and unloading(In this paper, we just consider the loading part, ignore the unloading part)(Fig. 1(b)). Denoting the specimen Young's modulus by E and yield stress by σ_y, without losing generality, the uniaxial stress-strain $(\sigma-\varepsilon)$ curve of a stress-free solid can be expressed in a power-law form Eq. (1):

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$\sigma = E\varepsilon$ for $\varepsilon \leq \sigma_y / E$ and $\sigma = R\varepsilon^n$ for $\varepsilon \geq \sigma_y / E$ (1)

Where n is the work-hardening exponent, for most ductile metals and alloys n is between 0.1 and 0.5. Where $R \equiv \sigma_y (E/\sigma_y)^n$ is the work-hardening rate. In addition, the Poisson's ratio regarded as a less affective factor, therefor, fix the value as $\nu = 0.3$ to all engineering materials during indentation analysis.

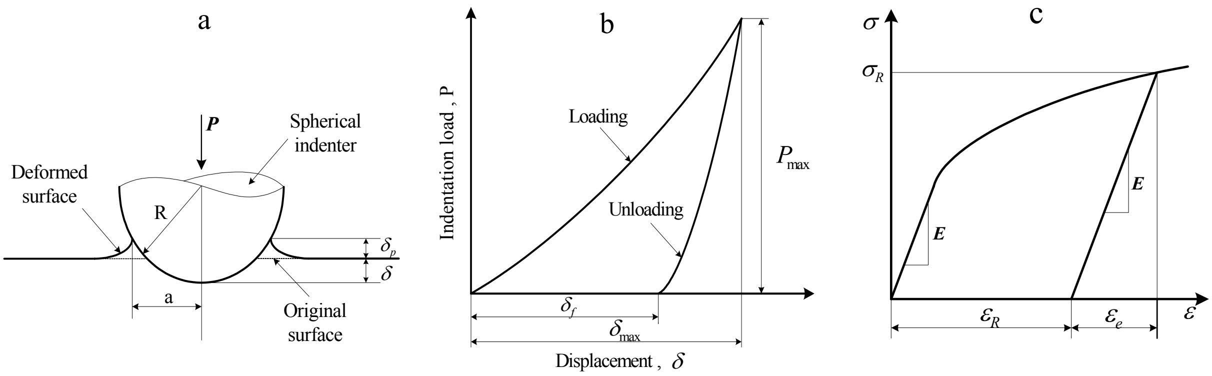

Fig. 1. (a) Spherical indentation with bulk specimen (b) Typical indentation load-depth curves (c) The uniaxial stress-strain curve

2. Dimensional analysis

Based on the new definition of representative strain[1] that define representative strain to be the plastic strain, for uniaxial loading(Fig. 1(c)):

$$\varepsilon = \varepsilon_e + \varepsilon_P \equiv \varepsilon_e + \varepsilon_R \tag{2}$$

The presentative strain ε_R is a function of δ/r. In order to, close to that of the Berkovich indenter and cube indenter, we choose two indentation depths $\delta_1/r = 0.13$ and $\delta_2/r = 0.3$ respectively[6]. These values are adequately deep to overcome the strain gradient effect[7]. Correspondingly, the representative stress is:

$$\sigma_R(\varepsilon_R) = \sigma_y [\frac{E}{\sigma_y}(\frac{\sigma_R(\varepsilon_R)}{E} + \varepsilon_R)]^n \tag{3}$$

Dimensional analysis leads to:

$$\frac{C_1}{\sigma_R^{(1)}(\varepsilon_R^{(1)})} \equiv \frac{P_1}{\delta^2 \sigma_R^{(1)}(\varepsilon_R^{(1)})} = \Pi_1(\frac{\overline{E}}{\sigma_R^{(1)}(\varepsilon_R^{(1)})}, n) \tag{4}$$

$$\frac{C_2}{\sigma_R^{(2)}(\varepsilon_R^{(2)})} \equiv \frac{P_2}{\delta^2 \sigma_R^{(2)}(\varepsilon_R^{(2)})} = \Pi_2(\frac{\overline{E}}{\sigma_R^{(2)}(\varepsilon_R^{(2)})}, n) \tag{5}$$

Where, P_1 and P_2 are the indentation loads, $\varepsilon_R^{(1)}$ and $\varepsilon_R^{(2)}$ are the representative strains corresponding with $\delta_1/r = 0.13$ and $\delta_2/r = 0.3$ respectively. Where, $\overline{E} = E/(1-\nu^2)$ is the plane strain modulus. The dimensionless functional forms will be determined by fitting the numerical results. In this paper, we assume the value of E is already known. Therefor, we can obtain the elastic-plastic properties (σ_y, n) from Eqs. (4) and (5).

3. Forward analysis

In this paper, the finite element simulation were performed using ABAQUS(6.9-1). The indenter is assumed rigid and the specimen is semi-infinite. The friction coefficient was taken to be 0.1 and as mentioned before, the Poisson's ratio fixed as 0.3. In the forward analysis, the parameters are varied over a large range to cover essentially all engineering materials, with $\overline{E}/\sigma_R$ from 3 to 3000 and n from 0.1 to 0.5. As mentioned before, owing to the value of elastic modulus is already known, therefor, only the loading curve is needed for measuring the plastic parameters in this paper.

Representative load-displacement curves obtained from FEM analysis are given in Fig. 2. The Fig. 2. shows the curves for $E/\sigma_R = 60$ with different n.

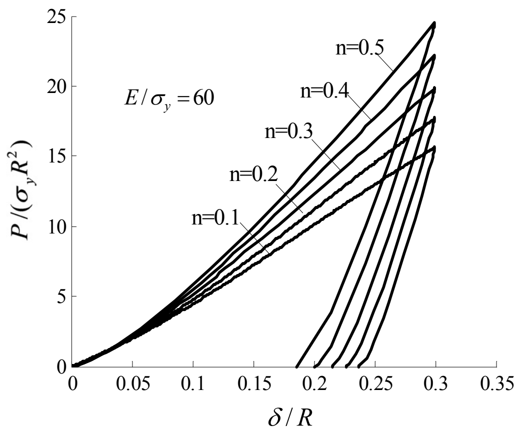

Fig .2. Normalized indentation load-depth curves

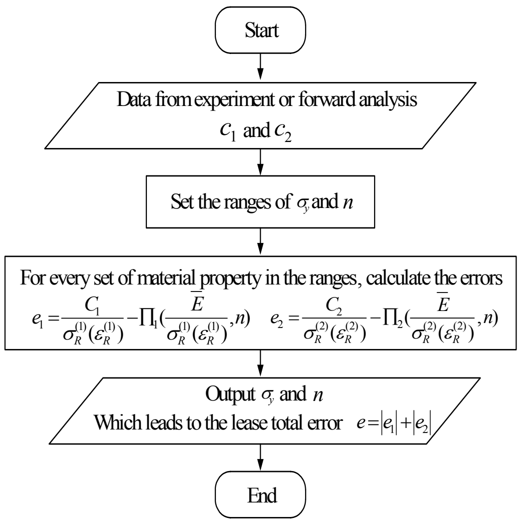

Fig .3. The flow chart of reverse analysis

4. Reverse analysis

For a given spherical indentation test with $\delta_{max}/r = 0.3$, C_1 and C_2 can be measured from experiment. Then reverse analysis based on equations (4) and (5) to solve the plastic properties (σ_y, n). Fig. 3 is the flow chart of reverse analysis.

5. Conclusion

Spherical indentation has the potential for measuring the elastic-plastic properties of bulk materials by just using one simple impression test, and it work well for a large range of materials. For the wide range of material properties investigated in this paper, the error between reverse analysis result and original input data less than 10% in most cases. Therefor, the reverse analysis have fairly accuracy for measuring the material properties.

Acknowledgement

This work was funded at the Ministry of Land, Transport and Maritime Affairs as an effort to develop the construction and transportation technology research which task is entitled "Center for Concrete Corea(05-CCT-D11)."

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