Biaxial Residual Stress Evaluation Using FEA-based Indentation Behavior Simulation and Machine Learning

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1. Introduction

The residual stress commonly presented in various components in nuclear power plants has both negative and beneficial effects on structural safety. It is necessary to measure the residual stress in the components for safety evaluation [1]. Residual stress tests [2] include various destructive and non-destructive methods. Among them, the indentation method is a minimally invasive approach that can be conveniently used to determine the residual stress of structural materials in service. However, because of the analytical problems in solving elastoplastic behavior, empirical equations with limited applicability have been used.

In the present study, the influence of biaxial residual stress on indentation behavior was studied using computational mechanics. Also, biaxial residual stress prediction models were generated using a deep-learning algorithm (convolutional neural network: CNN).

2. Indention Behavior Simulation

The indention behavior in a component under biaxial residual stress was calculated through elastic-plastic finite element analysis (FEA). The FEA was performed using ABAQUS Version 2022, and Fig.1 shows the finite-element mesh. From the indentation load versus depth curve (*P-h* curve) obtained by FEA, indentation parameters such as the ratio of reversible work (W_e) to total work (W_t) performed by the indenter, loading curvature (C) and power law depth exponent (m) were derived. The relationship between residual stress, stress ratio and indentation parameters was investigated, and the W_e/W_t was presented in Fig. 2.

3. Biaxial Residual Stress Prediction Model

A methodology is proposed to estimate both the residual stress and the stress ratio using the convolutional neural network (CNN) deep learning algorithm. A series of FEAs were performed for the various residual stresses. The *x*- and *y*-directional residual stress ranged from 10 to 400 MPa with increments of 10 MPa, and then the indentation database consisted of a 1600 dataset of *P-h* curve. Fig. 3 shows the prediction performance of the residual stress prediction model. The prediction model estimated the residual stress with 14.5 % of standard deviation.

3. Conclusions

In the study, the effect of biaxial residual stress on indentation behavior was studied, and then biaxial residual stress prediction models were developed using a CNN deep learning algorithm. The results provide important insights for developing a more precise biaxial residual stress prediction model for actual nuclear components.

Acknowledgment

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References

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[2] Y.H. Lee, and D. Kwon, Estimation of biaxial surface stress by instrumented indentation with sharp indenters, Acta Materialia, 52, pp. 1555-1563, 2004.

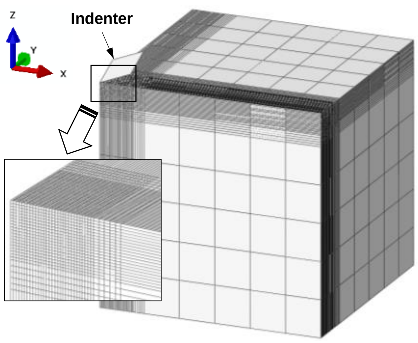

Fig. 1. Finite element mesh for indentation simulation.

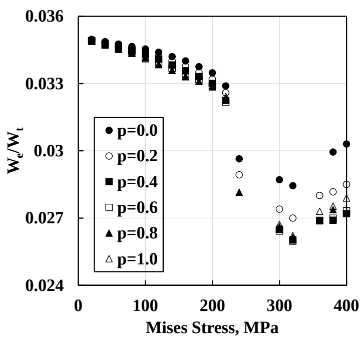

Fig. 2. Effect of residual stress and stress ratio.

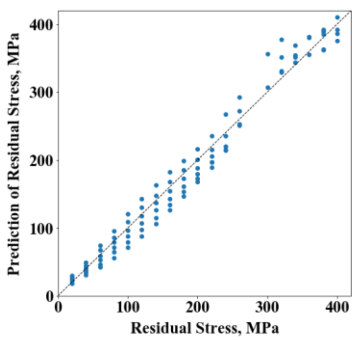

Fig. 3 Prediction of biaxial residual stress