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A Method to Quantify Thermal Ageing Effect on Fracture Toughness of Cast Stainless Steel (CF8M)

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1. Introduction

In nuclear power plants, structural components are aged for operating time. To assess instability of these components, actual mechanical properties for component materials are required. There are several standard specimen test methods to obtain mechanical properties. However, sampling large amount of material from structural component would be dangerous causing damage to the structures.

This paper proposes the methodology to predict thermal ageing effect on fracture toughness with sub-sized specimen tests using FE (damage) analyses. Section 2 summarizes the experiment in this study. Section 3 describes the methodology to predict tensile properties and fracture strain models for FE (damage) analyses. Simulated FE results applying the methodology in this paper are compared with experimental data in Section 4. Section 5 concludes the presented work.

2. Experiments

In this work, a cast austenitic stainless steel (CF8M) was considered and thermally aged at 400^{o}C. The specimens were aged during three kinds of thermal ageing time, 1,000, 5,000 and 10,000 hours. Small punch (SP) tests and C(T) tests were conducted for virgin and aged materials. Disc-type SP specimens with the diameter of 10mm and thickness of 0.5mm were used in the tests. C(T) specimens with the thickness of 25mm and the width of 50mm were used to conduct fracture toughness test.

3. Methodology

3.1 Tensile Property

Using SP test data and FE analyses, the tensile properties for each aged/non-aged CF8M material were predicted and are shown in Fig. 1. There are three material constants, E (Young's modulus), *K*, *N*, in tensile property constitutive equation. These constants can be found using FE elastic-plastic(or perfectly plastic) analyses. More detailed procedures to predict tensile property from SP test data can be found in Ref.[1].

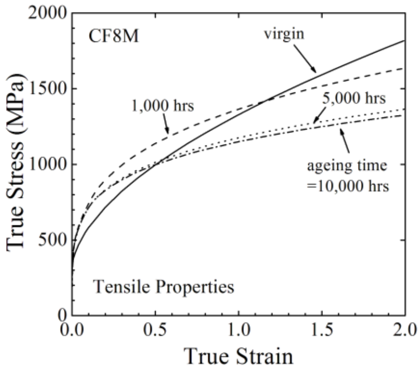

Fig. 1. True stress-true strain curves for virgin and thermally aged CF8M materials.

3.2 Multi-axial Stress Fracture Strain Model

In this paper, the multi-axial stress fracture strain model is considered for ductile fracture FE simulations. This model is well known as 'stress-modified fracture strain model', and already studied with FE analyses in Ref.[2-4]. To determine this damage model, notched tensile tests with several notch radii are commonly used. Multi-axial stress fracture strain model for non-aged (virgin) CF8M materials was determined using notched tensile tests in previous studies, and is represented in Fig. 2 with solid line.

To predict multi-axial stress fracture strain model using SP test data, the concept of thermal ageing constant was introduced. For the first step of multi-axial stress fracture strain prediction methodology, one point in Fig. 2 with open circular symbol was calculated from SP test data using FE analyses (see Ref.[1]). And next, thermal ageing constant values corresponding to each ageing time are multiplied to multi-axial stress fracture strain model equation of virgin material. Predicted multi-axial stress fracture strain model for 1,000 hours aged material using this methodology is shown in Fig. 2 with dash line.

Fig. 3 shows the thermal ageing constant values from each ageing time with circular symbols. In Fig. 3, the fact that the ageing constant value for 10,000 hours ageing materials is higher than 5,000 hours. Therefore, it can be concluded that CF8M materials already thermally saturated in 5,000 hours ageing. Solid line in Fig. 3 represents fitted thermal ageing constant curves for CF8M materials.

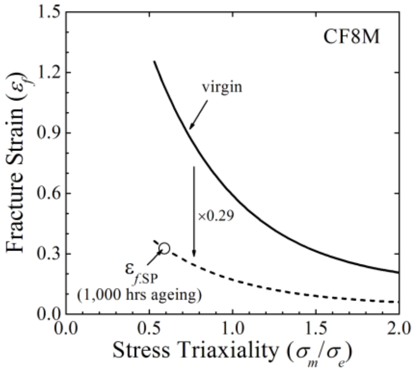

Fig. 2. Multi-axial stress fracture strain curves for virgin and 1,000 hour thermally aged CF8M materials.

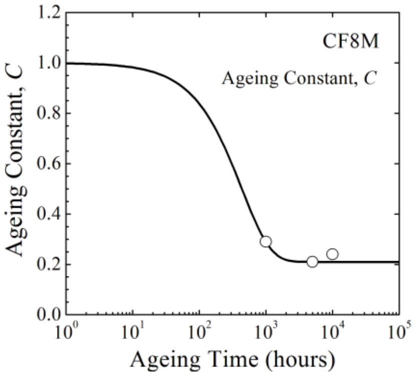

Fig. 3. Thermal ageing constant values for each ageing time and fitted curve.

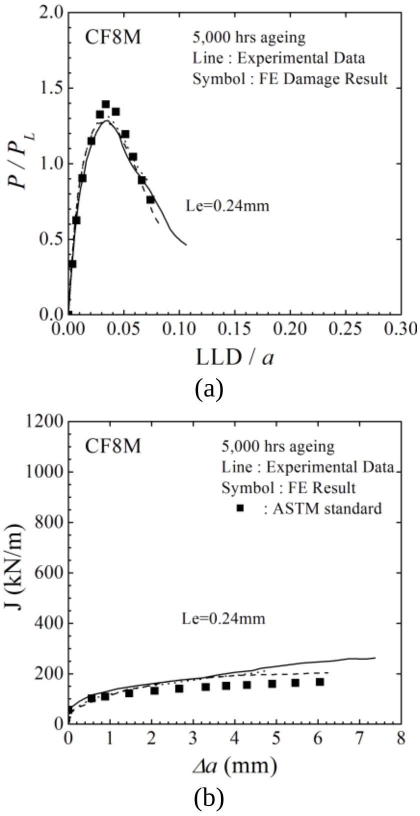

Fig. 4. Comparison of experimental C(T) results with simulated ones using FE damage analyses: (a) normalized load-load line displacement curves and (b) J-R curves

4. Validation

To validate the methodology in this paper, FE damage analysis results were compared with C(T) test data for each thermal ageing CF8M material. Crack initiation and propagation were simulated by stress reducing technique using commercial software ABAQUS and user-subroutine UHARD. More detailed information about this technique can be found in Ref.[2-4].

Fig. 4(a)-(b) show the simulated C(T) test results comparing with test data for 5,000 hours thermal ageing material. Fig. 4(a) and (b) are correspond to normalized load-load line displacement curves and J-R curves, respectively. It can be found that the simulated results agree well with test data.

5. Conclusions

This paper suggests the methodology to quantify thermal ageing effect on fracture toughness using SP test data and FE damage analyses. Virgin and three kinds of aged CF8M materials are considered, and the tensile properties for each material are predicted from SP test data. The multi-axial stress fracture strain models can be determined with thermal ageing constant. To validate the methodology in this paper, C(T) tests for each (non) aged materials are simulated using FE damage analyses. Simulated results are compared and agree well with test data.

ACKNOWLEDGMENTS

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