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Nondestructive Evaluation of Toughness for In-Service Superheater Tubes of Fossil Fuel Boiler

F. Nogata, K. Seo, M. Kusaka
Himeji Institute of Technology, Himeji, Japan

H. Takahashi
Tohoku University, Sendai, Japan

Y. Hirose*
Kanazawa University, Kanazawa, Japan

Sae-Wook Oh*
Dong-A University, Pusan, Korea

K. Matsui
Ishikawa Seisakusho Co. Ltd., Kanazawa, Japan

ABSTRACT

Mechanical properties of structural materials for high temperature use, such as turbine rotor and boiler tubing, degrade during long-term service operation. It is important to detect toughness degradation by means of a nondestructive and simple technique from a field test viewpoint. In this study a chemical-etching technique is developed to detect material degradation. An etching test using a picric acid solution with a wetting agent was found to have great potential for the nondestructive evaluation of grain boundary embrittlement caused by carbide and sigma precipitation in SUS 316 stainless steels. The feasibility of this estimation procedure was determined showing the relationships between Charpy impact energy (CVN) and grooving width (W_{GS}), and creep damage ratio (Φ) and W_{GS}. Superheater tubes of fossil fuel boiler were tested on site to demonstrate the validity of this etching test.

INTRODUCTION

In general, the toughness of structural materials degrades with time of service for high temperature use. Therefore there is a great need to estimate the toughness degradation that has occurred, in order to assess the integrity and remaining life of the structures. The material degradation, such as embrittlement, softening, hardening, and so on, can have a significant effect on the reliability and economical efficiency of chemical plants and fossil power plants. Since it is not possible to take large specimens from an operating plant to evaluate the plant toughness, the establishment of nondestructive or relatively nondestructive techniques is especially needed. Authors have established (Nogata et al., 1987, 1991) the procedures for estimating in-service toughness degradation of structural components made from CrMo and CrMoV steels, by a chemical-etching technique using the special picric acid solution. It was concluded that the etching technique has great potential for the nondestructive estimation of grain boundary embrittlement caused by phosphorus segregation in CrMo and CrMoV steels.

Austenitic stainless steels ordinarily have excellent corrosion resistance properties when used at temperatures where sensitization is slow. However, if they are exposed to high temperature (500-700°C) for a long time, intergranular corrosion is produced. For high temperature sections (565°C) of superheater tubes in fossil fuel power plants, SUS 316 and SUS 321 stainless steels are generally used as component materials. Although this type of steel has excellent oxidation resistance and creep strength, in fact, superheater tubes are often replaced with new ones before the end of designed lifetime, because many craters of about 1.5-mm depth and cracks on the outside surface are found during inspection (Saito et al., 1986). The type of deterioration is mainly intergranular embrittlement caused by the precipitation of hard particles as carbides and sigma phase and by other effects. We tried to detect intergranular embrittlement, and the consequent degradation of toughness, by applying the etching test established for CrMo and CrMoV steels.

In the present work, the feasibility of the etching technique was determined showing the relationship between grain boundary width (W_{GS}) revealed by the etching and Charpy impact energy (CVN), and W_{GS} and creep damage ratio (Φ). The validity of the technique for estimating material degradation is demonstrated by showing the data obtained on site from superheater tubes in an electric generating power plant.

*ISOPE Member.

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KEY WORDS: Nondestructive testing, on-site test, superheater tube, assessment of remaining life, material degradation, creep life, fossil fuel boiler.

CHEMICAL ETCHING TECHNIQUES FOR NONDESTRUCTIVE TOUGHNESS EVALUATION

Experimental Method

Chemical-etching techniques

Chemical-etching test used is the same technique established