Influence of Fatigue Damage on NDE of Plastic Strain in RAFM Steel using Electromagnetic NDE Methods

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ABSTRACT

In this study, the influence of fatigue damages on relationship between plastic deformations and NDE experimental signals for the RAFM steel was studied experimentally. For samples with different residual plastic strains, low circle fatigue testing was conducted to introduce some fatigue damage, and magnetic NDT signals of the magnetic Barkhausen noise, magnetic incremental permeability and the magnetic flux leakage method were then measured. It was found that the low circle fatigue damage has no significant influence on correlation between plastic strain and NDE signals.

1. Introduction

The under construction ITER is a giant international program for the peace application of nuclear fusion energy that is regarded as a promising clear and sustainable energy for future human society. Tokamak is considered as the most suitable approach for controllable nuclear fusion. During operation of Tokamak reactors, plastic deformation inevitably occurs in their in-vessel components due to giant unexpected load such as major plasma disruption or an large earth quack, which has significant impact on the structural integrity. Thus, establishment of a reliable non-destructive evaluation (NDE) technique for the structural material of fusion reactors is of great importance. Reduced-Activation Ferritic/Martensite (RAFM) steel[1], which is considered as one of the most important candidate structural materials for ITER test blanket module and future DEMO plants because of its features of low activation, excellent mechanical property and good micro-structural stability. In previous works of authors, the validity of three typical magnetic NDE techniques, i.e., the magnetic Barkhausen noise (MBN), the magnetic incremental permeability (MIP) and the magnetic flux Leakage (MFL) method for evaluating the plastic deformation in the RAFM steel has been demonstrated [2] in laboratory environment. Since the operation of ITER is of pulsed mode which may cause fatigue damage in in-vessel structures in practice, it is necessary to clarify the influence of fatigue damage on the NDE of plastic deformation in the in-vessel components in order to apply the magnetic NDE methods in practical fusion power plants The aim of this paper is to clarify this influence through experiments.

2. Methods

To study influence of the fatigue damage on the quantitative NDE of plastic deformation in RAFM steel, NDE experimental signals were measured for test-pieces of different residual plastic deformations after fatigue testing of different circles. 4 samples of RAFM steel in shape shown in Fig.1 were firstly fabricated and processed with proper heat treatment in order to realize a free strain state of the material. Then, different levels of residual plastic strians (0%, 0.6%, 1.8% and 4.8%) were applied to the specimens with a tensile material testing machine. After that, different cycles of fatigue damage (0, 100, 500, 1000, 2000, 5000, 10000 cycles) with a loading stress range of 50 MPa to 500 MPa were applied to each sample respectively, and NDE experiments using an integrated measurement system of magnetic Barkhausen noise (MBN), magnetic incremental permeability (MIP) and magnetic flux leakage (MFL) developed by authors [3] were carried out during each loading gap, i.e., the test-pieces were measured after they were unloaded from the testing machine.

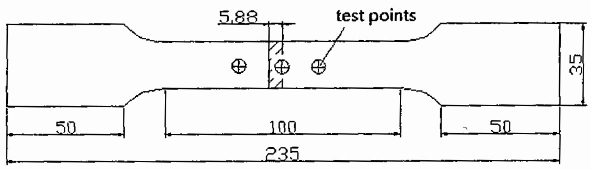

Fig. 1 The geometry of specimens

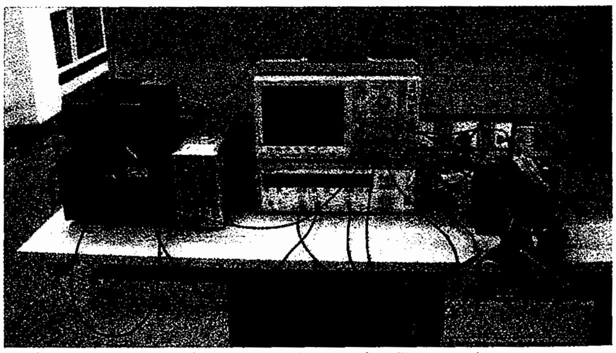

Fig. 2 Integrated MBN, MIP and MFL testing system

The integrated MBN, MFL and MIP measurement system as that shown in Fig.2 was adopted in the NDE measurements [3]. The MBN, MIP and MFL inspection systems share the same electromagnetic (EM) magnet unit that consists of a function generator, a power amplifier, U shaped permalloy yoke and a group of excitation coils wounded on the yoke legs. The function generator provides sinusoidal exciting signals of low frequency less than 1 Hz, and the signal is amplified by the power amplifier to provide strong current to drive the exciting coil of the EM magnet. The EM magnet is attached on one side surface of the specimen to magnetize the test-piece along its length direction and generate

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different magnetic status in the specimen. On the other hand, a pick-up unit consisting of two coaxial coils and a Hall sensor are designed and fabricated to measure the MBN, MIP and MFL response signals. A mutual induction ECT probe with a cylinder magnetic core is adopted for the MBN and MIP measurements, while the Hall sensor set between the yoke legs is used to measure the change of leakage magnetic field as MFL signals.

3. Results and Discussions

The typical NDE experimental results are shown in Fig.3, where Fig.(a) is the MBN results vs fatigue circles for different plastic strains, (b) the MIP results and (c) the measurement results of the MFL method. In the figures, the Root Mean Square (RMS) representing the intensity of MBN signals, the imaginary peak value of the MIP butterfly trajectory representing the maximum local permeability and *K* factor of MFL signals representing the distortion level of leakage magnetic field during magnetization procedure are taken as the feature parameter of each NDE method respectively. From the measurement results shown in the figures, one can find that the feature parameters of these three magnetic NDE methods all show a downward tendency with the increasing plastic deformation before fatigue damage is introduced, which is consistent with previous results of authors [2]. In the case of the sample without any residual plastic deformation, the RMS of MBN method, imaginary peak value of MIP butterfly trajectory and *K* factor of MFL method drop dramatically as large as 100 times at a low cycle number. Then all the signals of the 3 NDE methods change relatively slowly with the increasing loading cyclic numbers. On the other hand, in the case for samples with residual plastic deformation, despite the strain levels were different, tendency and change rates of these NDE signals were only limited influenced by the fatigue damages. In general, the influence of the fatigue damage on the NDE signals is far smaller than the influence of residual plastic deformation on the NDE signals in samples with residual plastic deformation for the RAFM steel.

4. Concluding Remarks

As conclusion, the experimental results reveals that fatigue damages have some impact on the specimens free of plastic strains at the very beginning while only have limited influence on specimens with relative large residual plastic deformation for the RAFM steel. Among the three magnetic MDE methods, the MFL methods has the best stability and repeatability for NDE of the plastic strains in structures of the RAFM steel.

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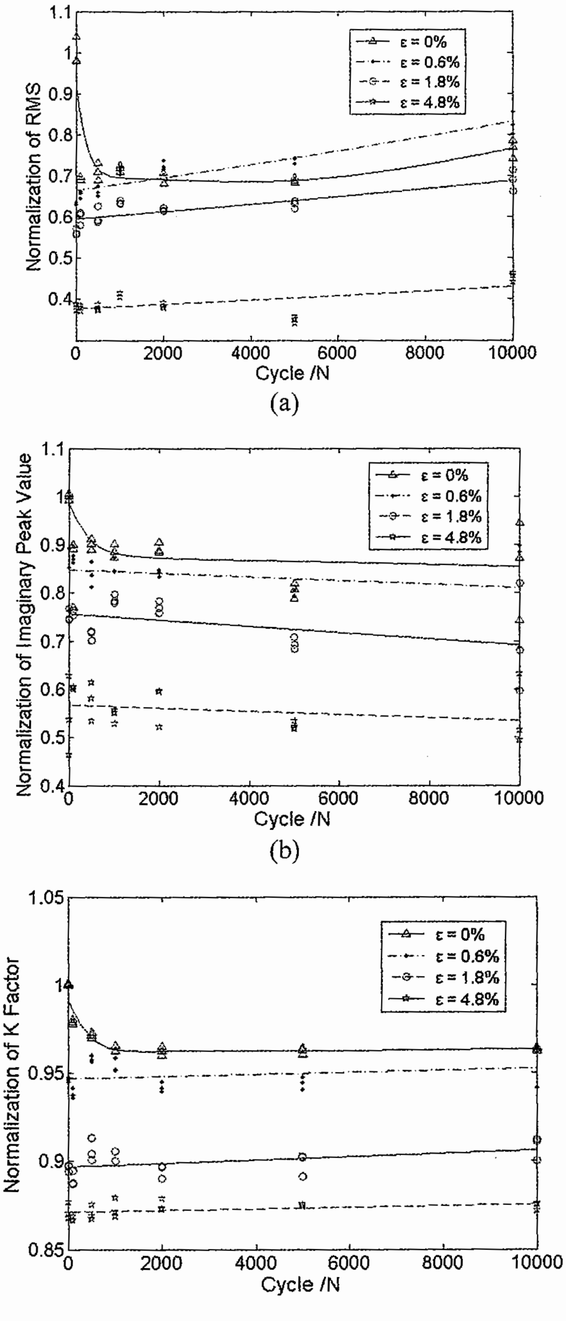

Fig. 3 Experimental results of magnetic NDE signals vs number of fatigue loads for different states of residual strains, (a) results of the MBN testing, (b) results of the MIP testing, (c) results of the MFL testing.

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