AFI-2019
November 6-8, 2019, Sendai, Miyagi, Japan

OS20-14

Modelling Materials Behavior for Advanced Electromagnetic Non Destructive Testing Techniques

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ABSTRACT

Creep phenomenon is an important feature to assess in high temperature applications, although the correlations with microstructure and magnetic behaviour remain unclear. In this work, 12%Cr-Mo-W-V creep test samples (used in thermal power plants) are investigated using three electromagnetic inspection techniques. Magnetic parameters based on the results are then evaluated in comparison to the microstructure. Additionally, a modified Jiles-Atherton model has been used to numerically reproduce experimental results from Magnetic Incremental Permeability (MIP), Magnetic Barkhausen Noise (MBN) and standard B(H) measurements. All the three techniques exhibit different responses in understanding creep and the modelling parameters derived from the adapted Jiles-Atherton Model parameters are then correlated to the microstructure information. Some suitable parameters are then shortlisted according to the application technique.

1. Introduction

In ferromagnetic materials, magnetic domain walls interact with microstructure over similar mechanisms as dislocations do [1- 3]. This fundamental observation is the basis of micro-magnetic materials characterization. Coupling between the stress and magnetic field is the main and important feature of the ferromagnetic materials consisting of various small magnetic domains in its microstructure [4]. Conventional Eddy current testing has been extensively used for the ferromagnetic materials characterization but when it comes to creep damage detection, it becomes difficult to distinguish between the changes caused by the actual creep damage and from the signals generated by other sources like, cracks, surface roughness, hardness etc.

In this research three different electromagnetic techniques are applied to the 12 different samples from three different categories with different temperature and stress treatments. Magnetic Incremental Permeability (MIP) is used to investigate samples as it is highly sensitive to stress. On the other hand, Magnetic Barkhausen Noise being sensitive to the mechanical changes in the materials, is also used to analyse the samples in addition to standard B(H) curve measurements. Finally, ferromagnetic hysteresis models such as dry friction quasi static model, Preisach model, Jiles-Atherton model, which are based on magnetic induction B versus applied magnetic field strength H, are implemented to get the simulated data based on experiments. For instance, MIP technique is related to the dynamic permeability of the material when applying a bias excitation field, and the resulting ferromagnetic minor loop modelling requires advanced modelling techniques. Having a physical interpretation, the J-A model [5] is modified to derive modelling parameters which are then evaluated against the microstructure of the test samples. Finally, experimental data obtained using different techniques applied to creep samples are presented, and the relevant ferromagnetic model is given.

It is shown that using appropriate model, it is possible to assess model parameters directly from the magnetic signals. The objectives of these simulations are to improve magnetic signatures interpretations in co-relation to microstructure. Using Jiles-Atherton model, it is shown that 3 out of 5 parameters can be obtained from the magnetic curves. Their correlation to microstructure information is discussed. Such parameters are foreseen to constitute indicators of damaging independent of the experimental setup. Table 1 below shows the ruptured samples treatments and conditions from three different categories.

Table 1 Ruptured samples description.

Sample number	Stress [MPa]	Temp [°C]	Test time [h]	LMP*
1	343	550	2205.7	19215
2	201	600	1725.9	20289
3	98	650	1736.8	21453

**Larson Miller Parameter*

2. Results

Experimental results based on three techniques will be presented in detail and how the models are adapted to a particular method will also be presented. Fig.1(a) & 1(b) show the MIP curves and MBN curves evolution for the ruptured samples from each category of samples. It is observed that there is a clear distinction between the samples from different categories. However, in case of B(H) it was observed that it was difficult to distinguish the samples with different test times but same temperature treatment. It was revealed that MIP showed highest sensitivity amongst all the three different testing techniques to microstructural changes in terms of magnetic parameters such as coercivity, permeability etc. However, while using the $MBN_{energy}(H)$ curves instead of classical V_{rms} approach, the MBNenergy(H) curves demonstrated that there is a decrease in its amplitude when the rupture is closer. All such parameters are

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investigated in terms of microstructure of the samples. For instance, in case of lower temperature treated samples, the number of precipitates show an increasing tendency with the increase in the rupture level of the samples. On the other hand, for the higher temperature treated samples, the number of precipitates show a decreasing tendency with the increase in the rupture level of samples.

To further quantify the results obtained from the

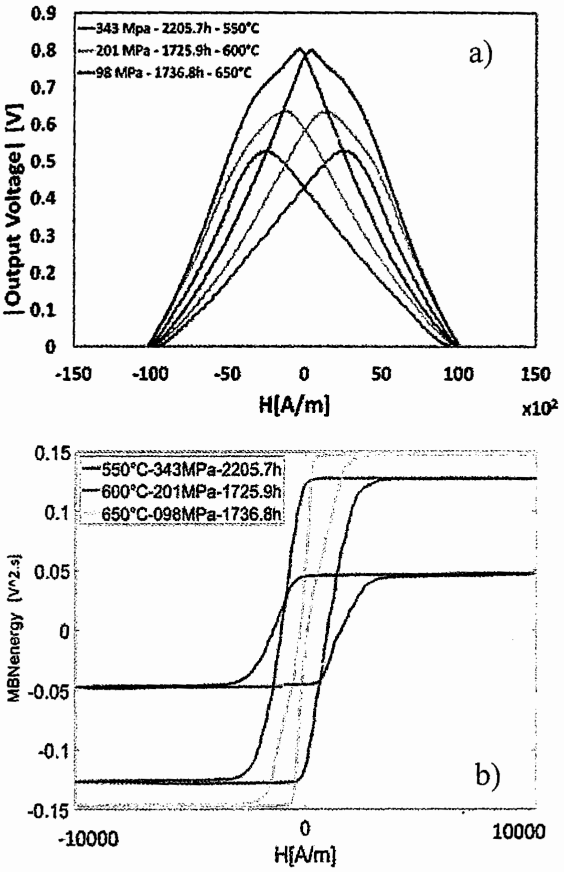

Fig. 1 (a) MIP curves for the three differently treated ruptured samples [6]. (b) Evaluation of ruptured samples from different temperature categories.

magnetic signatures of the materials, models like Preisach and Jiles-Atherton are implemented. Because of the physical basis, Jiles-Atherton theory based model is finally chosen to simulate the MIP signatures as a first step as detailed in [7]. Modelling these curves gives access to different parameters, each of which has physical meaning, according to the Jiles-Atherton theory. The modelling technique will help in overcoming the issue of lack of standards in NDT, irrespective of the experimental set-up involved. The modeling becomes significantly important in the field of non-destructive testing since it will not only help to understand the physics behind but will also help to reduce the tedious and expensive treatment of samples to get microstructural information.

While fitting to the experimental data, the 5 J-A parameters can be used as degrees of freedom in the simulation process. Fig. 2(a) shows evolution of one of the J-A parameters 'k' in case of MBN vs. Precipitation number for differently treated samples. It is quite evident that the energy required (k) to break the pinning site is larger in case of higher number of precipitates. After the determination of these parameters, Pearson correlation coefficient is evaluated against different mechanical and microstructural parameters as shown in Fig. 2(b).

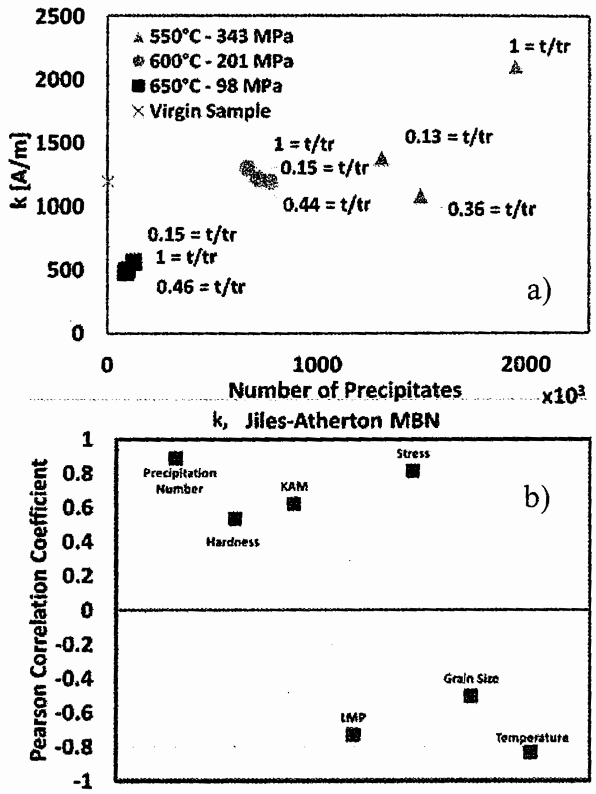

Fig 2 (a) Evaluation of 'k' J-A parameter vs. precipitations, (b): Pearson correlation coefficient for 'k' vs. microstructure and mechanical properties.

Acknowledgments

Institute of Fluid Science from Tohoku University are gratefully acknowledged by the authors through the General Collaborative Program project #J19Ly05.

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