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Nonlinear Acoustic Evaluation during Creep Progress in Cr-Mo-V steel with EMAR

EMAR 法を用いた Cr-Mo-V 鋼のクリープ進展中の非線形超音波量の変化

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1. Introduction

Creep is one of the most critical factors on structural materials used in fossil power plants component and progresses the damage from the inside of a material rather than the surface.[1)] Therefore, nondestructive evaluation (NDE) with ultrasonic method required to assess material degradation during creep progress.

In this study, we monitored surface-shear-wave nonlinearity throught the creep life of metals with electromagnetic acoustic resonance (EMAR).[2)] EMAR is a contactless resonance method using an electromagnetic acoustic transducer (EMAT) [2)]. The measured surface-wave nonlinearity detected the peak at approximately 30% of creep life.

2. Samples and experimental condition

We performed creep test under 25 MPa at 923K in air using cylindrical specimens; its gauge section was 14 mm in diameter and 60 mm long. The specimens were rolled in longitudinal direction. The material of the specimens was commercially available JIS-SNB16, which was heated at 1283K for 2h, air-cooled, heated at 1223K for 2h, oil-quenched, heated at 963K for 6h, and then air-cooled. It has an optimum fine-grained bainitic structure for service at elevated temperatures. Addition of 0.25 % Vanadium results in stable dispersion of Vanadium Carbide (V_4C_3). This steel is commonly used for high temperature bolts. At room temperature and 923K, the 0.2% proof stresses of the material were 778 and 253MPa, the tensile strengths 834 and 304MPa, the breaking elongation values 22.0 and 41.2%, respectively. The chemical composition of the material is shown in ref. 3.

Figure 1 shows the magnetostrictively coupled EMAT [2)] designed for the axial shear wave in ferromagnetic materials. It is consisted of solenoidal coil to supply the biasing magnetic field along the axial direction and meander-line coil surrounding the cylindrical surface to induce the dynamic field in the circumferential direction. The total field oscillates about the axial direction at the same frequency as the driving currents and produces a sheering vibration through the magnetostrictive effect, resulting in the axial-shear-wave excitation. The same coil works as a receiver through the reverse mechanism.

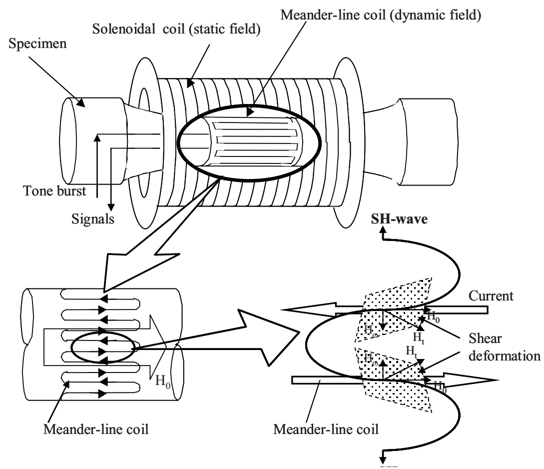

Fig.1 Axial-shear-wave EMAT consisting of a solenoid coil and a meander-line coil surrounding the cylindrical surface. The magnetostrictive mechanism causes the axial surface SH wave.

3. Nonlinear acoustic measurement with EMAR

We used the first resonance mode at approximately $f_1^{(49)}$ =3.9MHz; penetration depth is estimated to be 0.5mm. We defined the maximum amplitude of the first resonance peak as the fundamental amplitude, A_1. We then excited the axial shear wave by driving the EMAT at half of the resonance frequency ($f_1/2$), keeping the input power unchanged. In this case, the driving frequency does not satisfy the resonance condition and the fundamental component does not produce a detectable signal. However, the second-harmonic component having double frequency (f_1) satisfies

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the resonance condition and the resonance spectrum of the received signal contains a peak at the original resonance frequency[4)], as shown in **Fig. 2**. We defined this peak height as the second-harmonic amplitude A_2 to calculate the nonlinearity A_2/A_1. The magnitude ratio of A_2/A_1 varied on the order of 10^{-3}. These measurements were made possible using the system for nonlinear acoustic phenomena (SNAP) manufactured by RITEC.

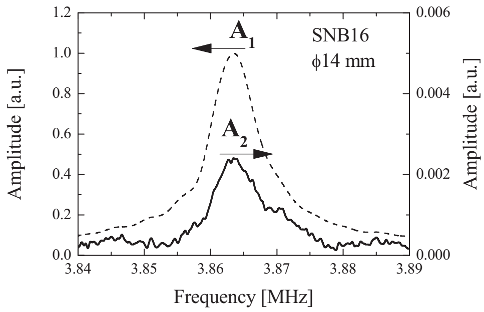

Fig.2 Resonance spectra of the fundamental and second- harmonic components of axial shear wave (n=49).

4. Result and Discussion

In metals without cracks, the possible factors contributing to higher harmonics arise nonlinear elasticity due to lattice anharmonicity and inelasticity due to dislocation movement. These two effects are inseparable in actual nonlinear measurements. Both generate higher harmonics, among which the second harmonic usually predominates. **Figure 3** shows relation of the square of the fundamental wave amplitude, A_1^2 and the second-harmonic amplitude, A_2, that is, $A2 \propto A_1^2$. We measured A_1 and A_2 by changing the driving voltage. It demonstrates the linear relationship between A_2 and A_1^2. This inclination shows a peak at around 30% of creep life fraction. The inclination is proportional to the dislocation density Λ times the fourth power of the loop length L ($A_2/A_1 \propto \Lambda L^4$) [5)] and is caused by the multiplication and rearrangement of dislocation.[6)] Normalization of A_2 in terms of A_1^2 removes the influences of liftoff, frequency dependence of the transduction efficiency, and other anomalies.

5. Conclusion

We summarize our conclusion as the following,

1) A combination of the magnetostrictive EMAT and resonance method enables us to detect the second harmonic amplitude of surface-shear wave without contact.
2) The nonlinearity shows its peak at approximately 30% of the lifetime, which was independent of the stress and which was interpreted as due to the microstructural changes, especially dislocation mobility
3) Assessment of damage advance and prediction of remaining creep life of metals may potentially be facilitated by nonlinear acoustics measurement with EMAR.

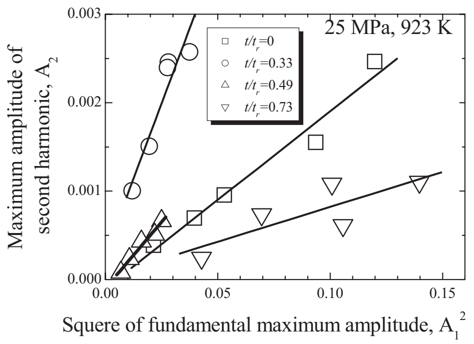

Fig.3 Relationship between A_2 and A_1^2 at t/t_r=0, 0.33, 0.49 and 0.73 (25MPa, 923K).

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