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Creep-induced Nonlinear Ultrasonic changes in ASME Gr. 122 Heat Resistant Steel Welded Joint

ASME Gr. 122 鋼溶接継手のクリープによる非線形超音波特性の変化

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1. Introduction

ASME Grade 122 (11Cr-0.4Mo-2W-CuVNb) has been used for boiler components in ultra-supercritical (USC) thermal power plants at approximately 873 K. The creep life of the welded joints in this steel decreased as a result of Type IV creep damage that forms in the heat-affected zone (HAZ) under long-term use at high temperatures[1]. We applied nonlinear ultrasonics for evaluation Type IV damage and microstructural degradation in welded joint for high Cr ferritic heat resisting steels. The nonlinear ultrasonics holds the potential of becoming the primary means of characterizing creep in metals [2,3], because it is capable of probing the change of dislocation structure during creep. Its sensitivity to microstructural evolutions during creep is often higher than that of linear properties. We elucidated the relationship between microstructural change and the evolutions of two nonlinear acoustic characterizations; resonant frequency shift [4] and three-wave mixing [5], with electromagnetic acoustic resonance (EMAR) [6] throughout the creep life in the welded joints of ASME Grade 122 by conducting creep rupture and interrupted creep tests at 873 K.

2. Experimental

The material investigated in this study is the Gr.122 steel; (11Cr-0.4Mo-2W-CuVNb steel) plate with 30 mm thick [1]. The plate was welded by gas tungsten arc (GTA) welding using a double U groove. After welding, post-weld heat treatment (PWHT) was conducted for 75 min at 1018 K for the plate. To clarify the relationship between nonlinear acoustic characterizations and the formation and evolution process of creep damage in the welded joint, interrupted creep tests were conducted using a thick plate type specimen (L-welded joint) of 24.5 x 24.5 mm^2 in cross-section and 120 mm gauge length for the steel weld [3]. The creep test were interrupted at several time steps of rupture life (t_r) at 873 K and 100 MPa for the steel welds (t_r=16,340h), where a typical

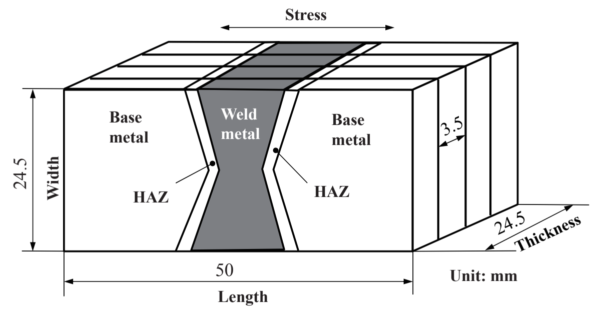

Fig. 1 Plate specimen with 3.5 mm thick for measurement for nonlinear acoustic characterizations.

Type IV failure was observed. Tests were interrupted at approximately 0.46, 0.82, 0.92, 0.96, 0.98 of rupture life. As shown in **Fig. 1**, plate specimen with 3.5 mm thick for measurement for nonlinear acoustic characterizations was cut from the interrupted L-welded joints.

We measured evolutions of the acoustic nonlinearities with the nonlinear resonant ultrasound spectroscopy (NRUS)[4], and three-wave-mixing technique[5] throughout the creep life in the welded joint with an electromagnetic acoustic transducer (EMAT) [6]. We used bulk-shear-wave EMAT, which transmits and receives shear wave propagating in thickness direction of a plate specimen.

NRUS analyses the dependence of the resonance frequency on the strain amplitude while exciting the sample at relative low amplitude[4]. By observing the relative frequency shift, it is possible to have a measure of internal degradation of the microstructural properties of the material. That is, NRUS, the resonant frequency of an object is studied as a function of the excitation level. As the excitation level increases, the elastic nonlinearity is manifest by a shift in the resonance frequency.

Three-wave-mixing technique is based on the fact that material nonlinearities cause interaction between two intersecting ultrasonic waves [5]. Under certain conditions, this can leads to the generation of a third wave with a frequency and wave-vector equal to the sum or difference of the

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incident wave frequencies and wave-vectors, relatively. This is much less sensitive to system nonlinearities due to spatial selectively, modal selectively, and frequency selectivity. We applied this three-wave-mixing technique to EMAR, which was a combination of the resonant acoustic technique with EMAT. Two EMATs were faced and set in the thickness direction of the sample. Different resonance frequencies; f_n, f_m (n, m: resonant modes, $m>n$) were generated by two EMAT, respectively. The difference or sum frequency, $f_n \pm f_m$ was measured by one EMAT. Because material nonlinearity showed independence of the excitation level, the amplitude of the interaction resonant wave A_3, at $f_n \pm f_m$ was normalized to the product of the two input resonant amplitudes A_1 and A_2 . In this study, we measured the amplitude, A_3 at the resonant frequency, f_m-f_n. In selection of resonance mode, n, m, the numbers were prime numbers or not with common divisor or common multiple. We measured resonant frequencies for resonant modes with using the systems for a nonlinear acoustic phenomenon (SNAP) manufactured by RITEC.

3. Results

We measured the evolutions of two nonlinear acoustic nonlinearities with NRUS, and three-wave-mixing technique, ultrasonic attenuation and velocity in HAZ with EMAR as creep progress. In this measurement in three-wave-mixing, we chose resonant frequencies, f_5, f_8 as input resonant frequencies. We measured the amplitude A_3 of the incident frequency, f_8-f_5. Shown in **Fig.2** are relationships (a) the nonlinearity with three wave mixing, $A_3/(A_1A_2)$, (b) the nonlinearity with NRUS at f_5, f_8, $\Delta f/f_0$, (c) attenuation coefficient, αs at f_5, f_8, and (d) relative velocity, $\Delta V/V_0$ at f_5, f_8 ($\Delta V=V-V_0$, V: velocity, V_0: initial velocity) at HAZ in Gr. 122 steel welded joint and creep life ratio, t/t_r (t: creep time). $A_3/(A_1A_2)$ decreased from the beginning of creep, gradually increased from t/t_r =0.5 to 0.8. After that, it rapidly increased to failure (Fig.2 (a)). The amplitude A_3 was around the hundredth's place of A_1, A_2. $\Delta f/f_0$s decreased from the beginning to t/t_r =0.5, then, showed a minuscule increase from t/t_r =0.5 to 0.8. After that, they increased to failure (Fig.2 (b)). The changes of αs showed same trends of $\Delta f/f_0$s. (Fig.2(c)) $\Delta V/V_0$s gradually increased decreased to t/t_r =0.8, and slightly decreased until rupture (Fig.2 (d)). The total increase in velocity is about 2.0 %.

4. Conclusion

We investigated the relationship between microstructural change and the evolutions of two nonlinear acoustic characterizations; resonant frequency shift and three-wave mixing, with EMAR throughout the creep life in the welded joints of ASME Grade 122. Two nonlinear acoustic parameters and ultrasonic attenuation decreased from the start to 50% of creep life. After slightly increased, they rapidly increased from 80% of creep life to rupture. We interpreted these phenomena in terms of dislocation recovery, recrystallization, and restructuring related to the initiation and growth of creep void, with support from the SEM and TEM observation.

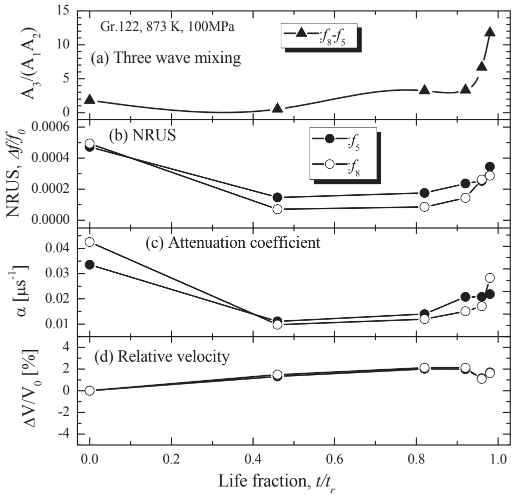

Fig. 2 Evolutions of (a) the nonlinearity with three wave mixing, (b) the nonlinearity with NRUS, (c) attenuation coefficient and (d) relative velocity at HAZ in ASME Gr. 122 steel welded joint during creep (873 K, 100 MPa).

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