Creep Damage Evaluation of a Nickel-based Superalloy Using Nonlinear Ultrasound

非線形超音波法を用いた Ni 基超合金のクリープ損傷評価

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1. Introduction

Nickel-based superalloy Inconel 718 has high temperature strength effect of γ″(Ni_3Nb) phase below approximately 973 K. Inconel 718 is characterized by a decrease in creep strength due to the disappearance of γ″ phase.

In this study, we applied nonlinear ultrasonic for evaluation creep damage and microstructural degradation in γ″ for Inconel 718 plate specimen. The nonlinear ultrasonic holds the potential of becoming the primary means of characterizing creep in metals[1,2], 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 nonlinear acoustic characterizations three-wave interacting[3], with electromagnetic acoustic resonance (EMAR)[4] throughout the creep life time, nonlinearly was relationship change in dislocation density. **X**‐ray diffraction supported this view.

2. Experimental

The material investigated in this study is the Inconel 718 was subjected to solid solution treatment (ST) at 1253 K for 1 h, air cooling after holding, and the aging conditions were 991 K for 8 h, cooling rate after holding at 56 deg/h, and 894 K, air cooling after holding for 8 h. After that, creep specimen shown in **Fig. 1** was cut out. Mechanical properties at room temperature were following; tensile strength 1343 MPa, hardness 382 HB, Elongation17 %. To clarify the relationship between nonlinear acoustic characterizations and the formation and evolution process of creep damage in Inconel 718, interrupted creep tests interrupted at several time steps of rupture life (tr) at 1033 K and 310 MPa, 973 K and 200 MPa for the specimen (tr=351 h, 1,795 h), where a failure was observed. Tests were interrupted at approximately 20, 40, 60, 80, 100% of rupture life.

We measured evolutions of the acoustic nonlinearities with the nonlinear three-wave-interaction method throughout the creep life in the gauge section with an electromagnetic acoustic transducer (EMAT). We used bulk-shear-wave EMAT, which transmits and receives shear wave propagating in thickness direction of a plate type specimen. Three-wave-interaction method 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 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-interaction method to EMAR, which was a combination of the resonant acoustic technique with EMAT. So far Two EMATs were faced and set in the thickness direction of the sample. We developed a technic to measured with only one EMAT measured three-wave interaction method.

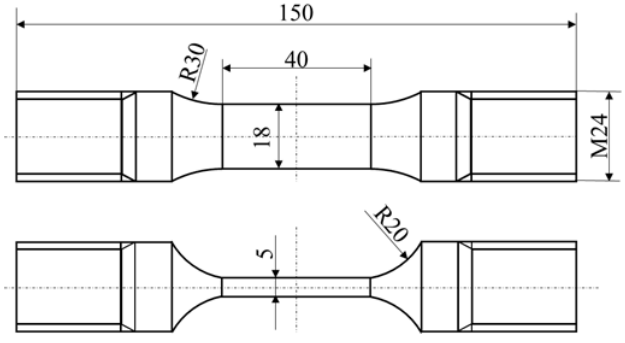

Fig.1 Inconel 718 Creep specimen. Unit: mm.

Different resonance frequencies; f_n, f_m (n, m: resonant modes, m>n) were generated by two coils, respectively. The difference or sum frequency, $f_n \pm f_m$ was measured by one coil. Because material nonlinearity showed independence of the excitation level, the amplitude of the interaction resonant

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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. References

Figure 2 shows the evolutions of the nonlinearity in three-wave-interaction, $A_3/(A_1A_2)$, ultrasonic attenuation, α, relative velocity, $\Delta V/V_0$ and dislocation density observed by X-ray diffraction during creep life time. A_1 is amplitudes at the 5th (f_5 around 1.52 MHz,), A_2 that at 9th (f_9 around 2.75 MHz), A_3 that at incident wave (f_9+f_5). $A_3/ (A_1A_2)$ rise dramaticaly increases rapidly from 60 % of the creep life ratio. After peak $A_3/ (A_1A_2)$ decreased near the rupture. $\Delta V/V_0$ decreased sharply to 20 % and then gradually decreased creep progress. Evolutions of α shows the gradually increase of the 60 % of life time. α is increased sharply until rupture. Dislocation density rapidly increased to 20 % of life time after creep. Dislocation density showed peak near the 80 % of life time.
This phenomenon shows three-wave interaction methods nonlinearity $A_3/ (A_1A_2)$, attenuation α, dislocation density as creep progress was related to the microstructure change, especially, dislocation mobility during creep life.

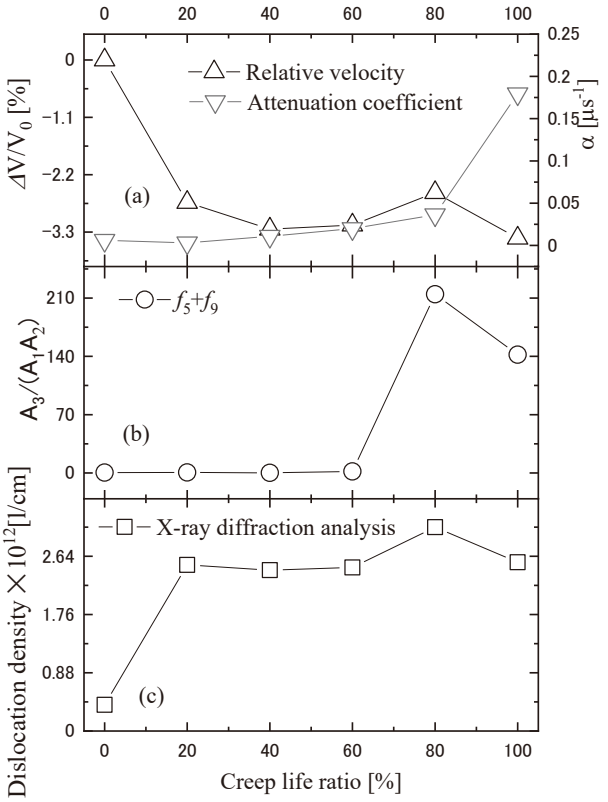

Fig.2 Evolution of (a) attenuation coefficient, relative velocity, (b) the nonlinearity with three-wave interaction, and (c) dislocation density analysis by X-ray diffraction half-power band width method at during creep life. (1253[k], 200[MPa])

4. Conclusion

We investigated the relationship between microstructural change and the evolutions of nonlinear acoustic characterization three-wave interaction, with EMAR throughout the creep life in the Inconel 718. Nonlinear acoustic parameter and ultrasonic attenuation increased from the start of creep life. they rapidly increased from 60 % of creep life to rupture. We interpreted these phenomena in terms of dislocation recovery, recrystallization, and restructuring related to the $\gamma''(Ni_3Nb)$ phase collapse, with support from the X-ray diffraction observation.

Assessment of creep damage advance and microstructural change of metals may potentially be facilitated by nonlinear acoustics measurement with EMAR.

References

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