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Evolutions of nonlinear acoustics induced by plastic strain in an austenitic stainless steel

オーステナイト系ステンレス鋼の塑性ひずみに誘起された非線形超音波特性の変化

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1. Introduction

Most enngineering structutes and components experience plastic strain during service. The motion and multiplication of dislocations play an important role in controlling the mechnical properties, such as strength, ductility an so on. Plastic strain has been , which were limited to specific materials and detection for large deformation on the surface, and required to preprocessing1). Therefore, the new detection method is expected.

In this study, we applied nonlinear ultrasonics for detection of plastic deformation, which is capable of probing the change of dislocation structure2). Its sensitivity to microstructural evolutions during plastic deformation 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 3) and harmonic componets4), with electromagnetic acoustic resonance (EMAR) 5) throughout tensile test in an austenitic stainless steel JIS-SUS304 at room temperature.

2. Experimental

The material of the specimens was commercially available JIS-SUS304 austenitic stainless steel, which was heated at 1283K for 0.5h, and then water-cooled. To clarify the relationship between nonlinear acoustic characterizations and the strains, interrupted tensile tests were conducted using a cylindrical type specimen of ϕ14 mm, 80 mm at gauge section. The tensile tests were interrupted at seven different strains. **Figure 1** shows interrupted points at stress-strain curve in tensile tests; before yield point, at yield point, at 4-points between yield point and tensile strength, and at tensile strength. Direction of tensile load was paralleled to rolling direction. After unloading of tensile load, acoustic nonlinearities were measured. After measurement of acoustic properties, we observed microstructural change by EBSD (electron backscattering diffraction) and magnetic properties

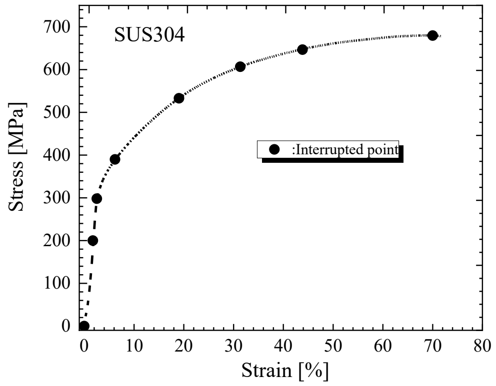

Fig. 1 Interrupted strain-stress condition in tensile test (SUS304).

We measured evolutions of the acoustic nonlinearities with the nonlinear resonant ultrasound spectroscopy (NRUS) 3), and harmonic components 5) throughout the tensile test with an electromagnetic acoustic transducer (EMAT)5). We used axial-shear-wave EMAT, which travels in the circumferential direction along the cylindrical surface of a circular rod or pipe specimen. For a nonmagnetic material, the axial shear wave can be generated by the Lorentz-force mechanism using permanent magnets arranged with radial polarity of alternating sign form one magnet to next and solenoidal coil surrounding the cylindrical surface. (**Fig 2**).

NRUS analyses the dependence of the resonance frequency on the strain amplitude while exciting the sample at relative low amplitude3). By observing the relative frequency shift, it is possible to have a measure of internal changes 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.

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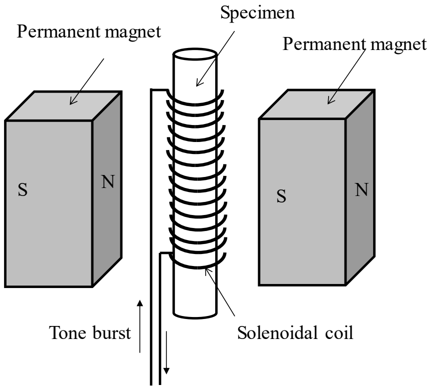

Fig.2 The Lorentz-force mechanism causes an axial-shear-wave EMAT.

Measurement metohd for harmonic components with axial-shear-wave EMAT was decribed in ref $^{5)}$. From this method, we maesured the first resonance peak as the fundamental amplitude, A_1 and peak height as socond-harmonic amplitude, A_2, to calculated the nonlinearity A_2/A_1. These measuremnt were made possible by the system for nonlinear acoustic phenomena (SNAP) manufactured by RITEC Inc.

3. Results

We measured the evolutions of two nonlinear acoustic nonlinearities with NRUS, and harmonic components, ultrasonic attenuation and velocity with EMAR in tensile tests. Shown in **Fig.3** are relationships (a) (b) the nonlinearity with 2nd ,3rd harmonics, A_2/A_1, A_3/A_1 at f_1 (c) the nonlinearity with $\Delta f/f_0$ at $f_1^{(1)}$ (d) attenuation coefficient, α, and relative velocity, $\Delta V/V_0$ at f_1 ($\Delta V = V - V_0$, V: velocity, V_0: initial velocity) at interrupted different strain conditions. As increase in strain, A_2/A_1, A_3/A_1 increase and shows peak just after yield stress (Fig.3 (a), (b)). The maximum value at peak is ten times larger than that before tensile test. α and $\Delta f/f_0$ show same trends as harmonic components (Fig.3 (c) and (d)). $\Delta V/V_0$ sharply decreased just after yield stress. after slightly decreased, it increased until tensile strength (Fig.3 (d)). The total decrease in velocity is about 10 %. Martensite transformation was induced by strain during tensile test in SUS304. By the transformation, SUS 304 showed magnetic after yield stress. The change of acoustic properties in Fig.3 was coincident with the start in magnetic. That is support from the EBSD observation and change of magnetic properties.

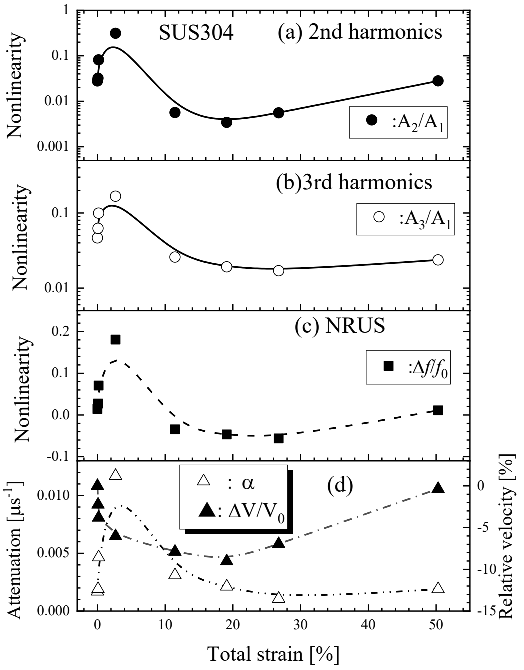

Fig.3 Evolutions of (a)(b) the nonlinearity with harmonics, (c) the nonlinearity with NRUS, (d) attenuation coefficient and relative velocity during tensile test for SUS304.

4. Conclusions

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 tensile test in an austenitic stainless steel JIS-SUS304. Two nonlinear acoustic parameters and ultrasonic attenuation increased from the start to yield stress rapidly decreased. We interpreted these phenomena in terms of dislocation movement and magnetic during tensile test, with support from the EBSD and magnetic observation.

References

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