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Nonlinear acoustics induced by plastic strain in stress concentration area

応力集中部に生じる塑性ひずみ誘起による非線形超音波特性

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1.Introduction

Structural discontinuities are widely existed in high temperature structures of nuclear and fossil-fuel power plants, aero and space equipment, and so on. Engineering experiences have demonstrated that the structural failure commonly originated from these geometric discontinuities. At these zones, stress and strain distributions are very complicated. Generally, notched specimens is usually employed for the investigation of structural discontinuity effect in practice. It is well known that the notch can cause the multiaxial stress and strain at the root.

In this study, we applied nonlinear ultrasonics for detection of plastic deformation at the notch root under multiaxial stress, which is capable of probing the change of dislocation structure[1)]. 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 [2)] and harmonic componets[3)], with electromagnetic acoustic resonance (EMAR) [4)] throughout tensile test in a duralumin, JIS-A2017-O at room temperature.

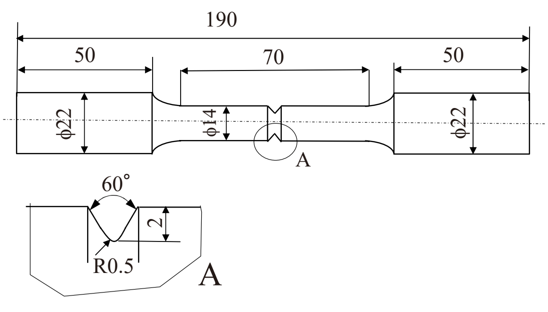

Fig.1 Shape of notched sample

2. Experimental

The material of the specimens was commercially available JIS-A2017-O aluminum alloy. To clarify the relationship between nonlinear acoustic characterizations and the strains at notch root, interrupted tensile tests were conducted using a cylindrical type specimen of ϕ14 mm, 70 mm at gauge section which a circumferential V grooved notch with root radius of 0.50 mm (**Fig.1**). Elastic stress concentration factors (Kt) is 3.6. The tensile tests were interrupted at two different nominal stress: 40%, 50% of rupture stress. Direction of tensile load was paralleled to rolling direction. After unloading of tensile load, acoustic nonlinearities were measured. Furthermore, elasto-plastic analysis around the notch root was performed using the finite element method (FEM).

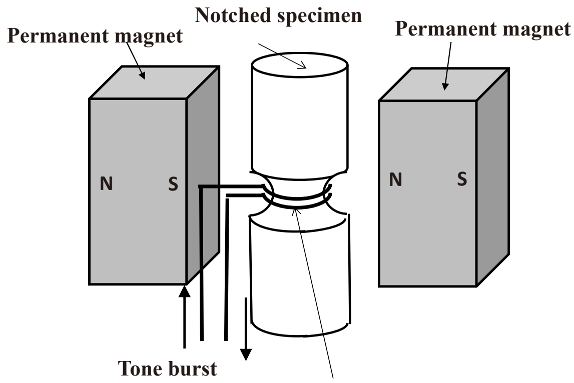

Fig.2 The Lorentz-force mechanism causes an axial-shear-wave EMAT.

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)[4)]. 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 a pair of permanent magnets arranged with radial polarity of alternating sign from one magnet to next and solenoidal coil surrounding circumferential V grooved notch. (**Fig 2**).

NRUS analyses the dependence of the resonance frequency on the strain amplitude while exciting the sample at relative low amplitude[3)]. By

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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.

Measurement metohd for harmonic components with axial-shear-wave EMAT was decribed in ref [4]. 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.

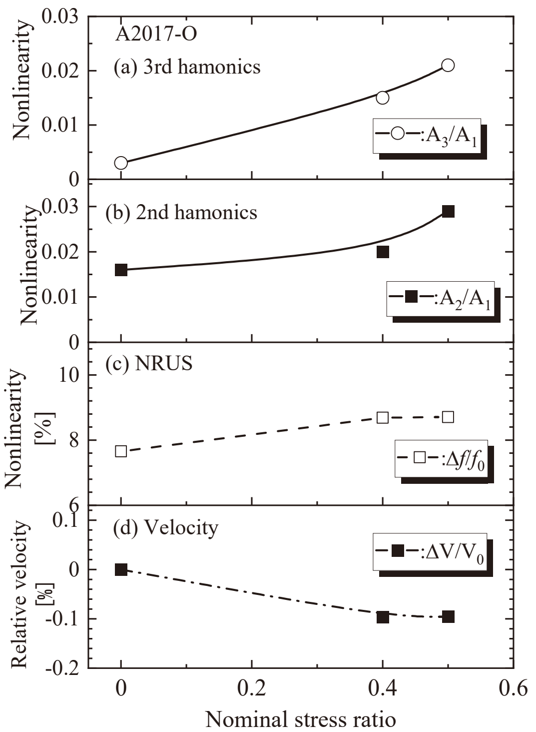

Fig.3 Evolutions of (a)(b) the nonlinearity with harmonics, (c) the nonlinearity with NRUS and (d) relative velocity at notch root during tensile test for A2017-O.

3. Results and discussion

We measured the evolutions of two nonlinear acoustic nonlinearities with NRUS, and harmonic components, and velocity of notched specimen with EMAR in tensile tests. Shown in **Fig.3** are relationships (a) (b) the nonlinearity with 2nd ,3rd harmonics, A_3/A_1, A_2/A_1 at f_1 (1) (c) the nonlinearity with $\Delta f/f_0$ at f_1 (1) and (d) relative velocity, $\Delta V/V_0$ at f_1 (1) ($\Delta V=V-V_0$, V: velocity, V_0: initial velocity) at interrupted different nominal stress. As increase in stress, A_3/A_1, A_2/A_1 increase (Fig.3 (a), (b)). $\Delta f/f_0$ show same trends as harmonic components (Fig.3 (c)). $\Delta V/V_0$ sharply decreased as stress increases. The total decrease in velocity is about 0.1 %. It is considered that these changes are resulted from an increase in dislocation density due to local plastic deformation due to stress concentration at the notch root[5,6]. In the future, we will clarify the relationship between and nonlinear ultrasonic characteristics at notch root and the strain under multiaxial stress by elasto-plastic analysis .

4. Conclusion

We investigated the evolutions of two nonlinear acoustic characterizations; resonant frequency shift and higher harmonics with EMAR throughout tensile test in notched A2017-O, an aluminum alloy. Two nonlinear acoustic parameters increased as stress increases. We interpreted these phenomena in terms of dislocation movement due to local plastic deformation due to stress concentration.

References

1. K. Y. Jhang, Inter. J. Precision Eng. & Manufacturing **11** (2009), 123.
2. K. E-A Van Den Abeele and J. Carmeliet, Res. Nondestructive Eval. **12** (2000) 31.
3. A. Hikata, F.A. Sewell Jr., and C. Elbaum, Phys. Rev. **151**(1966) 442.
4. M. Hirao and H. Ogi, *EMATs for Science and Industry: Nondestructive Ultrasonic Measurements*, (Kluwar Academic Publishers, 2003), p1.
5. A. Granato and K. Lücke, J. Appl. Phys. **27** (1956) 583.
6. H. Hirao, J. Jpn. SNDI. **56** (2007) 292.