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Nonlinear ultrasonic properties due to plastic strain induced at stress concentrations in an aluminum alloy

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1.Introductuion

The effect of notches on static and fatigue strength is an important issue in the strength design of mechanical elements, because the members of mechanical devices and structures are subjected to welds, notches, and other cross-sectional changes that can easily become the starting points for plastic deformation and failure under static or cyclic loading. In these notches, the stress and strain distributions become very complex. In general, notched specimens are usually used to investigate the effect of notches in structures. It is well known that notches cause multiaxial stresses and strains in the root zone.

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 plastic strain at root zone analyzed by the Finite Element Method (FEM) 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 JIS-A5052-BD-H34, a medium-strength Al-Mg alloy, at room temperature.

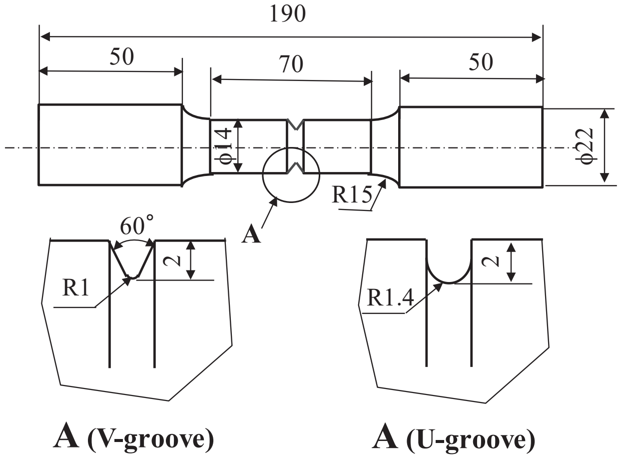

Fig.1 Shape of 2 types of notched samples

2. Experimental

The material of the specimens was commercially available JIS-A5052-BD-H34, Al-Mg 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 1 mm and U grooved notch with root radius of 1.4 mm (**Fig.1**). Elastic stress concentration factors (Kt) are 2.5 and 2.3, respectively. The tensile tests were interrupted at two different nominal stresses: 50%, 80% of tensile strength. 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, Femtet manufactured by Murata Software.

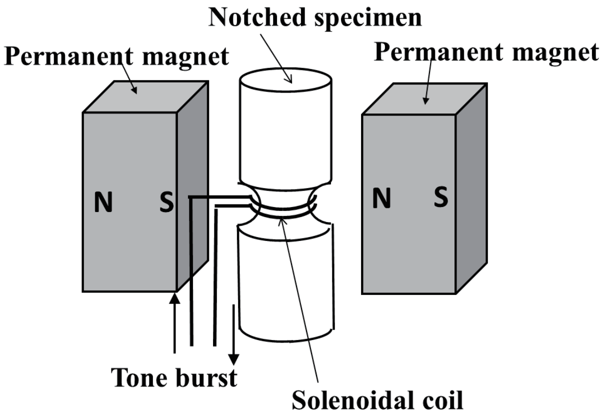

Fig.2 The Lorentz-force mechanism causes an axial-shear-wave EMAT

We measured evolutions of the acoustic nonlinearities with the nonlinear resonant ultrasound spectroscopy (NRUS) [2)], and harmonic components [3)] 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 paramagnetic material, the axial shear wave can be generated by the Lorentz-force mechanism using a pair of permanent magnets (two poles) and a solenoid coil surrounding circumferential U or V grooved notch. (**Fig 2**). Axial-shear-waves are circumferentially propagating surface SH waves that are deflected in the axial direction. The solenoid coil was made of enamel-coated wire with ϕ 0.2 mm and wound four times around the bottom of the notch.

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NRUS analyses the dependence of the resonance frequency on the strain amplitude while exciting the sample from relatively low to high amplitudes[3)]. 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.

Measurement method for harmonic components with axial-shear-wave EMAT was described in ref 4). From this method, we measured the first resonance peak as the fundamental amplitude, A_1 and peak height as second-harmonic amplitude, A_2, to calculated the nonlinearity A_2/A_1. These measurements were made possible by the system for nonlinear acoustic phenomena (SNAP) manufactured by RITEC Inc.

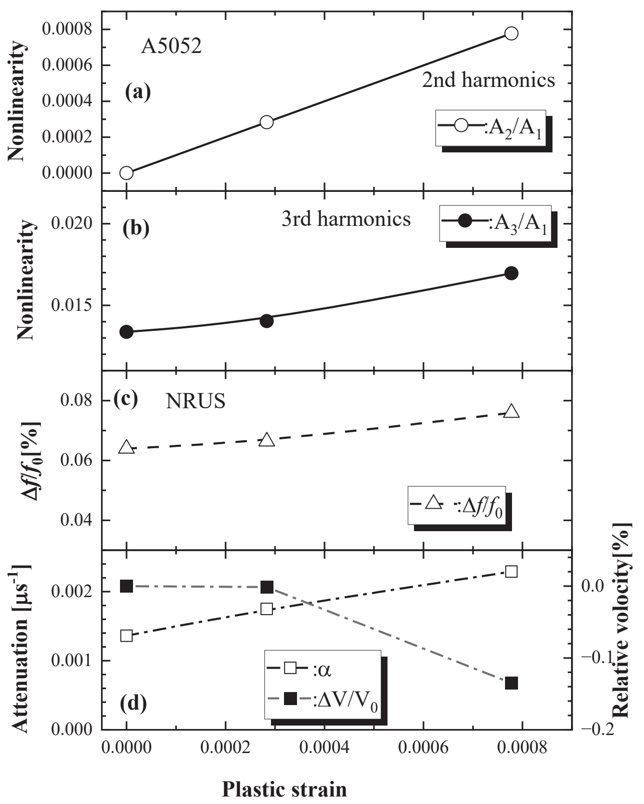

Fig.3 Evolutions of (a)(b) the nonlinearity with harmonics, (c) the nonlinearity with NRUS and (d) attenuation coefficient and relative velocity at notch root for the U-grooved-notched specimen in A5052-BD-H34 during tensile test.

3. Results and discussion

We measured the evolutions of two nonlinear acoustic nonlinearities with NRUS, and harmonic components, attenuation coefficient and relative velocity of notched specimen with EMAR in tensile tests. The relationship between the nonlinear ultrasonic properties, attenuation coefficient, and relative velocity and the amount of plastic strain around the notch root determined by FEM analysis of the U-grooved-notched specimen is shown in **Fig.3**. A_2/A_1, A_3/A_1, and $\Delta f/f_0$ increased with the amount of plastic strain [Fig.3(a)-(c)] and increased rapidly around 8×10^{-4} of strain (80% of the tensile strength). α showed a similar trend [Fig.3 (d)]. $\Delta V/V_0$ tended to decrease with increasing strain, but the rate of change was less than 1% [Fig.3 (d)]. This trend was also observed for the V-grooved-notched specimens. 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)].

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 plastic strain increases. We interpreted these phenomena in terms of dislocation movement due to local plastic deformation due to stress concentration.

References

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