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Harmonic Imaging of Plastic Deformation by Local Resonance
水浸局部共振高調波法による薄板塑性変形度の画像化

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1. Introduction

The conventional ultrasonic pulse-echo techniques are widely used for nondestructive evaluation of structures and medical diagnosis. This technique is based on the acoustic impedance difference at the interface between dissimilar materials. However, it fails to evaluate materials degradation[1)], fatigue and creep damage in the early stage, where the acoustic impedance difference is very small.

To the contrary, the effect of plastic deformation (dislocation density) on 2nd harmonic amplitude was measure with nonlinear ultrasonic technique[2)] by finite amplitude of tone-burst wave. In this measurement, piezoelectric sensors were bonded on a sample, therefore, harmonic imaging of plastically deformed region was impossible. In the last decade, kissing bond[3)], creep damage, fiber/matrix local debonds[4)], and nonmetallic inclusions[5)] are imaged by nonlinear ultrasonics with commercial transducers. These damage and abnormalities accompany some gaps greater than nanometer. Recently, the author visualized solidification boundaries of arc welds and spot welds, which have no gaps with an immersion harmonic imaging technique.

In this paper, we demonstrate the validity of higher harmonic imaging technique for visualize local plastic deformation in a perforated steel strip by using an immersion local resonance technique.

2. Harmonic generation

The stress-strain relation of polycrystalline metals is modeled as shown in Fig. 1(a). Even for regular lattice, the nonlinearity appears due to nonlinear force-displacement relations of attractive and repulsive atomic forces. The sound velocity is proportional to $(E/\rho)^{1/2}$, where E and ρ denote Young's modulus and density. Roughly speaking, therefore the velocity in compressive phase is higher than one in the tensile phase. This results in the waveform distortion shown by solid curve in Fig. 1(b), when a sinusoidal tone-burst wave is transmitted. In frequency domain, thus, higher harmonics are excited in addition to the fundamental frequency component.

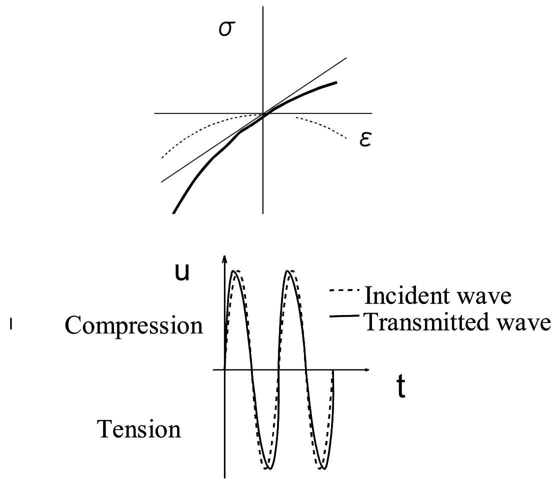

Fig. 1 Nonlinear stress-strain response of nonlinear elastic continuum (a) and waveform distortion (b) .

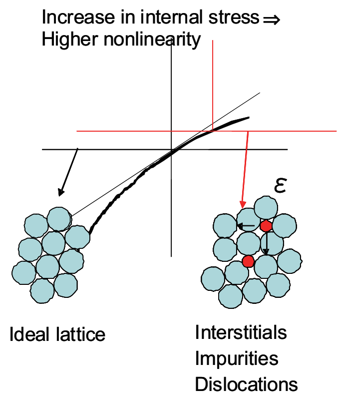

Fig. 2 Increase in nonlinearity due to imperfection in crystalline.

When the lattice is distorted by interstitial atoms, impurities, and/or dislocations, the non-linearity increases by internal tensile as shown in Fig. 2. Moreover, the nonlinearity would be risen by grain boundary , micro voids, micro cracks and residual stress.

3. Sample and experimental apparatus

Uniaxial tensile plastic strain of 10, 20 and 30% were given for SUS304 strips with a hole in the center. The original plate thickness was 7mm, but it was reduced by machining to 5mm for removing thickness variation due to plastic deformation.

An immersion higher harmonic imaging

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system[3] was used for delineating plastically deformed region. A focused transducer of which diameter, focal length and frequency are 13, 76 and 10MHa was used for transmitting a long tone-burst wave of a resonance frequency and for receiving harmonics through an analog high-pass filter.

The harmonic amplitude and time to a peak amplitude were imaged with the Insight Flexscan software.

4. Harmonic images of plastically deformed region

The geometry of plastically deformed strip and the higher harmonic image are shown in the upper and lower half of Fig. 3. A resonance frequency of 6.26MHz and cycle numbers of 80 were selected. A 30MHz analog high pass filter was inserted in receiving circuit before A/D conversion. Just beneath the elliptic hole, the bright area corresponds to large amplitude of higher harmonics which are excited at highly deformed plastic region. Along the horizontal axis with no plastic strain, higher harmonic is not excited. Figure 4 shows the amplitude spectra at the point + in Fig. 3. The peak spectrum is 31.4MHz, which is 5th harmonic of the incident tone-burst wave frequency. The frequency interval is 3.13MHz which is a half of incident resonance frequency. Tenth harmonic of the sub-harmonic of the incident frequency is superposed on 5th harmonic of the incident frequency in the plastically deformed region. On the contrary, the frequency interval at the white dot in Fig. 5 remains 6.26MHz which is the incident frequency.

The image of plastic region for a strip subjected to tensile plastic strain of 10% is shown in Fig. 6. The extent of plastic region is clearly smaller than that of Fig.3.

5. Conclusions

Plastically deformed region in SUS strip is visualized by the local resonance harmonic imaging method. This method could be applied for detecting and imaging dislocations in SiC or GaN wafers. By combining higher harmonic backscattering technique, we will be able to image defect of kissing bond type as well as heterogeneities in materials.

Acknowledgement
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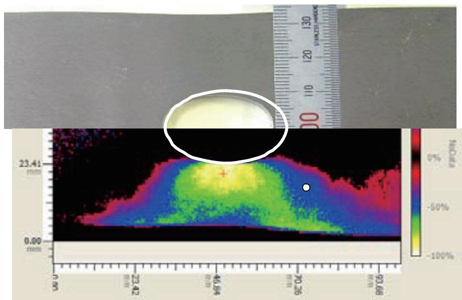

Fig. 3 Harmonic images of plastic deformation. Plastic strain 30%.

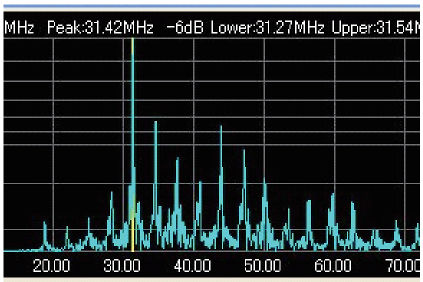

Fig. 4 Amplitude spectra at point + in Fig.3.

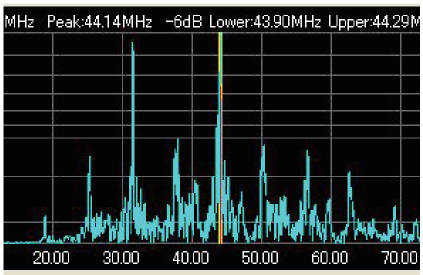

Fig. 5 Amplitude spectra at point.○ in Fig.3.

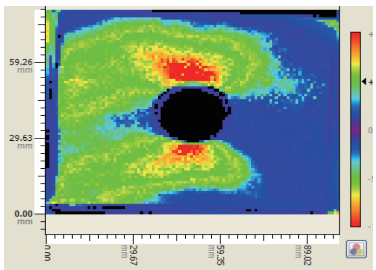

Fig. 6 Harmonic images of plastic deformation. Plastic strain 10%.