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INFUENCE OF DISLOCATIONS AND RESIDUAL STRESS ON NONLINEAR RESONANCE SPECTROSCOPY EXPERIMENTS

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ABSTRACT

Resonance ultrasound spectroscopy has been used for material characterization such as measuring elastic constants of single and polycrystalline materials. An extension of this technique which utilizes higher amplitudes and different boundary condition called Nonlinear resonance ultrasound spectroscopy has become popular for understanding dynamic response of materials, specifically, highly nonlinear, hysteretic materials like geomaterials. Recent advances have used this for nondestructive material characterization of metallic and composite structures, along with nondestructive evaluation. NRUS typically looks for a frequency shift with increasing excitation amplitudes.

The present work explores the influence of residual stress on NRUS experiments using cold rolled low carbon steel with varying thickness. The acoustic nonlinearity parameter was measured using an analytical inversion approach proposed earlier. A comparison of the beta of samples, showed that they followed a linear pattern. Next, the samples were heat treated for stress relieving but annealing. The beta measurements were repeated and a decrease in beta could be observed. A second round of heat treatment was carried out, and beta was measured again. The post heat-treated betas were all nominally similar irrespective of thickness. The results were also compared against with X-Ray diffraction measurements. The Hikata-Chick-Elbaum dislocation model was further used to study the effect of internal stress.

Keywords: Nonlinear resonant ultrasound spectroscopy, vibration, residual stress.

1. INTRODUCTION

The term Nonlinear Resonance Ultrasound Spectroscopy was first coined by Paul Johnson and Robert Guyer [1]. This method belongs to a class of techniques called Nonlinear Elastic Wave Spectroscopy (NEWS) which uses finite strain amplitude waves to characterize materials. The research group from Los Alamos has published several articles on the use of NRUS for both material characterization and damage detection [2,3]. Several articles explored the non-classical nonlinearity exhibited by certain materials such as intact geo-materials and damaged materials. A clear distinction between linear, classic nonlinear, and non-classical nonlinearity can be found in the literature from a NRUS context [4]. For a linear material as the excitation amplitude increases, the resonant frequency does not shift and remains constant. A classic nonlinear material exhibits a quadratic softening phenomenon (resonant frequency decreases) with increasing strain amplitude, and the frequency shift can be described using the classic nonlinear coefficients (β, δ). The non-classical nonlinear material exhibits a linear softening phenomenon with increasing strain and the frequency shift is controlled by a hysteretic parameter.

The classical nonlinear response has been captured using nonlinear Duffing's equation, and this in-turn can be derived from first principles, and parametrized [4] using a forced vibration model. The present work will use this model along with the Hikata-Elbum-Chick dislocation model for beta to understand the influence of dislocations and internal stress on the NRUS response of cold rolled steel.

2. MATERIALS AND METHODS

The NRUS setup used for testing is shown in Figure 1. A magnetostrictive actuator was used to excite the sample in a particular frequency range. The sample was directly mounted onto the actuator head at its geometric center using wax as shown in the figure. This type of mounting was observed to produces a double cantilever type of boundary condition, which was later confirmed with a linear finite element analysis. A lock-in amplifier outputs a sinusoidal output, which was amplified by audio amplifier, and the amplified output was used to drive the actuator. An accelerometer was used to measure the vibration amplitude, by mounting it on the edge of the sample. The accelerometer output was obtained using a signal conditioner, which was then fed into the lock-in amplifier. The lock-in uses its internal reference waveform and the output from the

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accelerometer to precisely track the frequency and the corresponding amplitude.

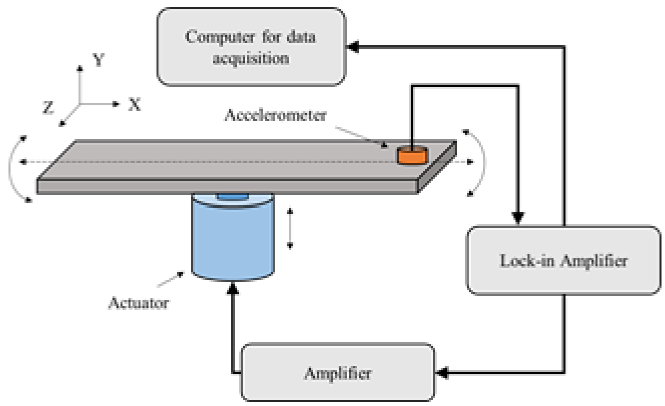

FIGURE 1: PERCENTAGE OF PAPERS THAT SHOULD BE FORMATTED CORRECTLY

The samples were cold rolled and drawn, low carbon 1018 steel of different thickness, ranging from 3.175mm, upto 9.525mm. Table 1 shows the thickness of the samples. All the samples are 12.7mm wide, and 155mm long. The samples were tested as received without any heat treatment from a commercial supplier.

Sample name	Thickness in inches (mm)
S1	0.125" (3.175)
S2	0.1875" (4.76)
S2.5	0.25 (6.35)
S3	0.3125" (7.937)
S4	0.375" (9.525)

3. RESULTS AND DISCUSSION

The beta of each sample was measured by capturing the nonlinear resonant frequency shift and substituting into the the forced vibration model developed earlier:

$$\alpha_e = {(8\sigma\omega(hp'')^2)}/{(12p^2\varepsilon^2)} \quad (1)$$

The definitions of each parameter can be found elsewhere [4]. This would give us the measure of the experimental frequency shift, which can be substituted into the model to obtain beta of the sample. Fig. 2 shows the beta of the samples measured using this technique before any heat treatment. A nominally linear trend could be observed for beta vs thickness, with the thinnest sample exhibiting beta values of 8, while the thickest sample exhibiting beta of close to 50.

Next, the samples were tested with X-Ray diffraction (XRD) in the 2theta configuration to obtain peaks at various incident angles. One of those peaks which is known to correspond to steel was chosen and peak width, i.e. full width at half of maximum amplitude was measured. It is known that the peak shift and width are known to be affected by residual stress. Fig. 3 shows the peak width for each sample prior to heat treatment. On the contrary, the peak shift showed little to no change, and so those results were not used. The samples were only tested on their end face using XRD.

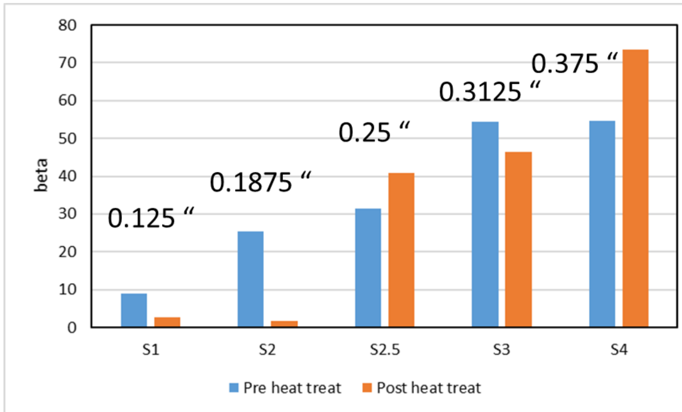

FIGURE 2: PERCENTAGE OF PAPERS THAT SHOULD BE FORMATTED CORRECTLY

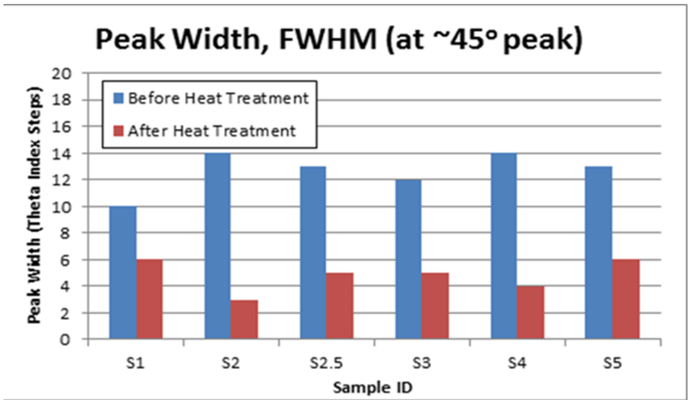

FIGURE 3: PERCENTAGE OF PAPERS THAT SHOULD BE FORMATTED CORRECTLY

After the NRS and XRD measurements, the samples were heat treated by annealing them at 900C for 2 hours, followed by oven cooling. Although the samples were different thickness, they were all bundled together while treatment and subjected to the sample soak time. Post heat-treatment, the samples were once again tested using the NRUS and XRD measurements.

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The post heat treatment beta values were different compared to prior heat treatment. The beta of S1 and S2 were nominally similar ~2, but the other samples were still the same. In some cases like the S4, the beta increased compared to pre heat treatment. The XRD results shows that the peak width decreased after heat treatment. If the stress is relieved, then a decrease in peak width is expected, so this is consistent with our observation. The beta measurements using NRUS seem to show similar results as well.

4. CONCLUSION

While XRD is a local measurement, which can only penetrate to a few microns below the surface, NRUS is a global measurement which can investigate the bulk properties of the structure. This is possibly the reason for some samples to show a decrease in beta, but other don't, although the XRD results show that the internal stress in all samples decreased.

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