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Characterization of Tempering Behaviour of Modified 9Cr-1Mo Steel by Ultrasonic Lamb wave Mixing

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Abstract

This work demonstrates the use of mixing of ultrasonic Lamb waves to characterize the tempering behaviour in metallic plate. Lamb wave mixing has been used to measure the generated second harmonic during tempering of mod.9Cr-1Mo steel plate. As-received material is normalized at 1080^0C and then tempered in the temperature range of $600 ^- 850^0C$ with a step size of 50^0C for 1.5hrs and followed by furnace cooling. Lamb wave mixing technique has been used to assess the tempering behaviour of this material. Nonlinear ultrasonic parameter β which is the ratio of 2nd harmonic amplitude to the multiplication of the fundamental amplitudes is determined from the mixing wave at each temperature and correlated with microstructural characteristics. It is seen that this nonlinear acoustic parameter (β) is sensitive towards coherency strain generated between precipitate and matrix during tempering.

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1. Introduction

Nonlinear ultrasonic (NLU) technique has already shown to be a promising technique to characterize the microstructural characteristics during degradation/ heat-treatment [1-3]. Conventional ultrasonic technique generally relies on the linear behavior of stress-strain relationship; whereas, NLU derives itself from the nonlinear Hooke's law that is dominated by higher order elastic constants. Initial pure sinusoidal wave gets distorted and generates higher order harmonics when encounters nonlinearities within the materials. But, the major problem in NLU technique is to distinguish between the material nonlinearity and other external nonlinearities from instrumentations, couplant etc. as the main objective is to evaluate the nonlinearity generated within material during deformation/ heat-treatment. Works have been started on collinear or non-collinear mixing of bulk waves within materials under certain resonance conditions to generate a third wave which carries the information of the nonlinearity from the mixing zone [4, 5]. In this work, two Lamb wave modes of different frequencies (ω_1 & ω_2) are allowed to mix under certain resonance conditions within the material to generate third type of harmonic waves of frequencies ($\omega_1 \pm \omega_2$). The generated mixing wave carries the information of the material nonlinearities from the mixing zone. So, attempt has been made to characterize the tempering behavior of modified 9Cr-1Mo steel by mixing two Lamb waves and the result has been compared to our earlier work on study of tempering behavior of this same material using nonlinear Lamb wave technique [6]. Initial feasibility study of Lamb wave mixing has been performed by D J Lee et al. [7]. Some aspects of guided wave mixing have also been discussed by C J Lissenden et al. [8].

1. Experiment

The mixing of multiple waves in the presence of nonlinearities within a material generates combinational frequencies. Two mutually interacting waves of frequencies f1 and f2 will generate other combinational frequencies of 2f1, 2f2, (f1±f2) and higher harmonics accordingly. Single mode waves are desirable for mixing due to multimode and dispersive nature of Lamb waves. In this work, S0 mode was chosen of frequencies 0.73 MHz and 0.41 MHz due to their non-dispersive nature to detect (0.73 + 0.41)= 1.14 MHz . The as-received plate was machined to make rectangular shape of thickness 2mm. The other dimensions were kept same as in [6]. Higher harmonic measurement by mixing of two Lamb wave modes was done using high power pulser RAM 5000 from RITEC Inc. Fig. 1 shows the schematic of the experimental set-up for the higher harmonic measurement using Lamb wave mixing. A centre frequency of 1 MHz broadband transducer was used as transmitter and 2.25 MHz broadband transducer was used as receiver.
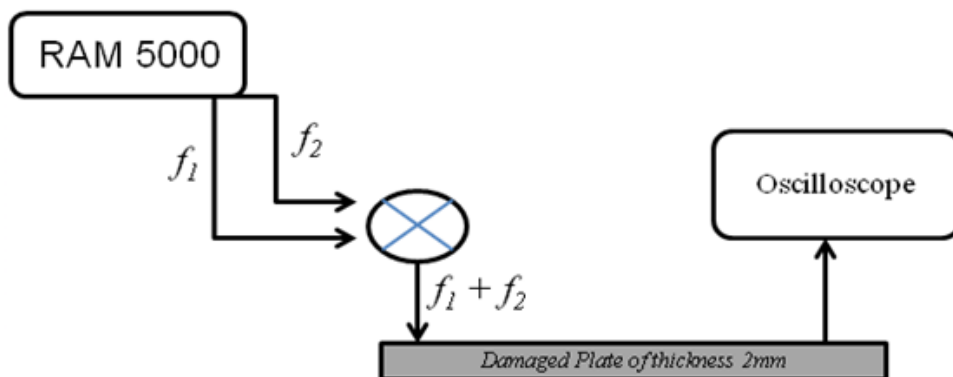

Fig. 1: Schematic of the experimental set-up for Lamb wave mixing technique

2. Results and Discussion

Figure-2 shows a typical multimode, non-stationary type received mixing signal and the Fast Fourier Transformation of the received signal shows the presence of sum frequency component (1.14 MHz) along with two fundamental frequencies (0.41 & 0.73 MHz) [fig.-3].
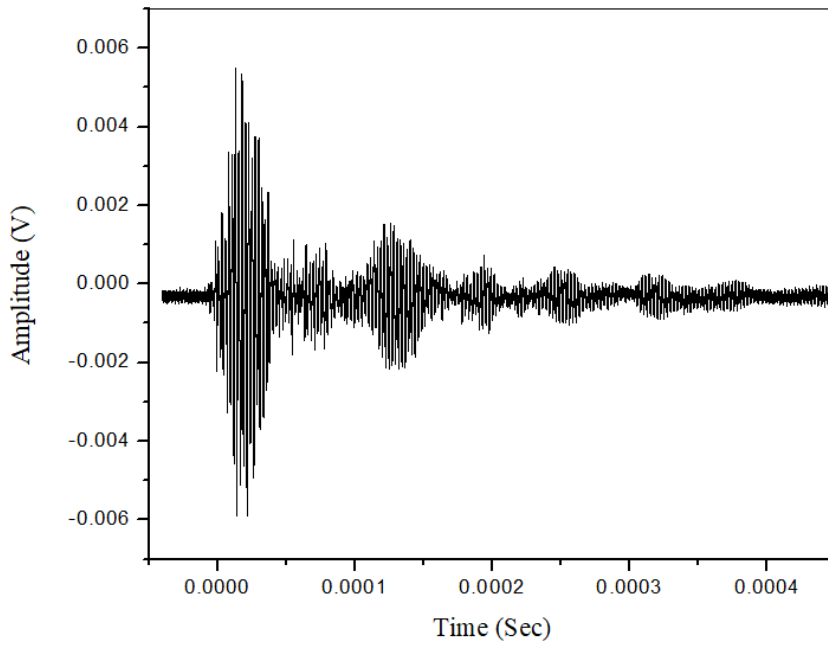
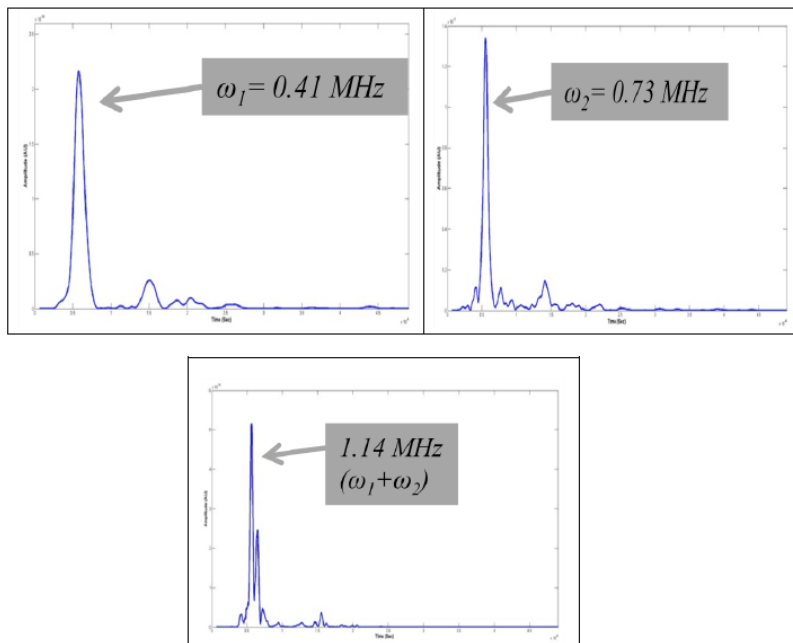**Fig. 2:** Typical multi-mode non-stationary type received signal

Fig. 3: Fast Fourier Transformation of the received signal shows the presence of sum frequency component

Evolution of various types of carbides (mainly $M_{23}C_6$ [M= Cr] and MX [M= V. Nb and X= C, N] type) may be seen to occur during tempering [6]. Precipitation of these types of carbides controls the coherency strain between

precipitates and matrix which in turn makes changes in the nonlinear acoustic parameter. Fig.- 4 shows the variation of relative change in acoustic nonlinearity parameter using Lamb wave mixing and hardness with tempering temperatures. Relative change in β has been defined as $\left(\frac{\beta-\beta_0}{\beta_0}\right)$, where $\beta = \left(\frac{A_3}{A_1A_2}\right)$ and β_0 is the nonlinear ultrasonic parameter at initial condition (as-received); A_1, A_2 and A_3 are the amplitude of the two fundamental frequencies and sum frequency components respectively [9].
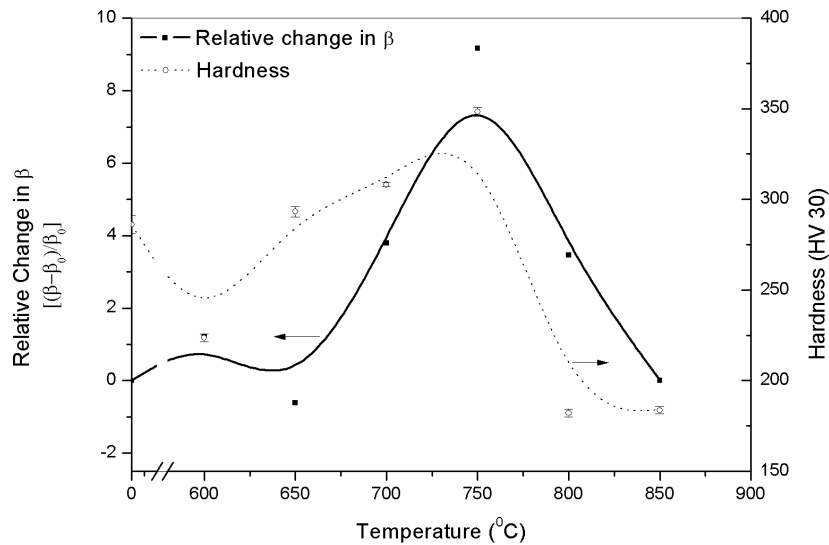

Fig. 4: Variation of relative change of acoustic nonlinearity parameter evaluated from Lamb wave mixing along with hardness with tempering temperatures

Figure-4 shows that variation of relative change in β is much smoother than the variation that was obtained in our earlier work [6]. Here also, it is seen that precipitate matrix coherency strain controls the variation in β and 750^0 C could be the optimum tempering temperature for obtaining maximum strength/ flow stress of this material [6].

3. Conclusion

Effect of tempering temperatures on the Lamb wave mixing signal was studied. Two Lamb wave modes were allowed to mix under resonant conditions to generate a third type of wave of sum frequency of the fundamental waves.
The variation of relative change in β is smoother than the variation of β obtained from direct nonlinear Lamb wave measurement.

Acknowldgements

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