The Effect of Uniaxial Stress on Material Properties Change of Aluminum Sample

NGUYEN LE VAN, NGUYEN HOAI
Department of Mechanical Engineering, Da Nang College of Technology, Da Nang, Viet Nam
Email: van.nguyenle87@gmail.com, hoainguyen.tme@gmail.com

Abstract: The stress state affects to material properties, the Elastic modulus and Poisson's ratio decrease under tensile stress. In this research, we study the effect of uniaxial stress to material properties change in Aluminum sample. The Laser ultrasound technique (LUT) is used to generate ultrasound wave propagating in medium under different level stress. The wave velocity is depend on the type of material, fatigue, temperature and stress state. The ultrasound wave velocity increases under tensile stress and vice versa. We use the transducer to get waveform signal, B-scan domain. The dispersive curve of ultrasound wave is received by using Fast Fourier transform (FFT) to analyse B-scan signal. The particle swarm optimization algorithm (PSO) is used to invert the dispersive curve to obtain the material properties under different level uniaxial stress.

Keywords: *Material properties, Fast Fourier Transform, Elastic modulus, Poisson's ratio, Laser ultrasound technique, Particle swarm optimization*

Introduction:

The material properties are depend on chemical ingredient. But they are unstable and change due to stress state. In this research, we study about the change of material properties includes Young modulus and Poisson's ratio of Aluminum samples under uniaxial stress. The tensile stress was provided by Mechanical Testing System (MTS). The Laser Ultrasound Technique (LUT) was used to detect and analysing the change of material properties via the change of wave velocity or the different of dispersion curve of ultrasound wave. The LUT can generate almost of wave includes Lamb wave, Surface wave, Acoustic wave, Rayleigh wave with wide range of frequency. It uses the light beam to impact sample, even we can use the optic fiber to detect the ultrasound wave. This is noncontact method. So, we can apply it for all of material with any shape of surface, especially, it very useful for hot temperature samples.

Materials and Methods:

A. Theory

In this study, we use Particle Swarm Optimization (PSO) algorithm to invert material properties of Aluminum sample. Particle Swarm Optimization (PSO) algorithm was developed by Eberhart and Kennedy. It based on the social behavior of birds flocking or fish schooling. The algorithm of PSO emulates from behavior of animals societies without any leader in their group or swarm but they have communication together. A flock of animals that have no leaders will find food randomly, by following one of the members of the group that has the closest position with a food source. The flocks achieve their best condition simultaneously through communication among members who already have a better situation. Animal which has a better condition will inform it to its flocks and the others will move simultaneously to that place. This would happen repeatedly until the best conditions or a food source discovered. The process of PSO algorithm in finding optimal values follows the work of this animal society. Particle swarm optimization consists of a swarm of particles, where particle represent a potential solution. The most optimist solution can be worked out in particle swarm optimization algorithm by the cooperation of each individual. The particle without quality and volume serves as each individual, and the simple behavioral pattern is regulated for each particle to show the complexity of the whole particle swarm.

Position of particle is influenced by velocity. Let $x_i(t)$ denote the position of particle *i* in the search space at time step t; unless otherwise stated, *t* denotes discrete time steps. The position of the particle is changed by adding a velocity $v_i(t)$ to the current position.

$$x_i(t+1) = x_i(t) + v_i(t+1)$$

Where, the velocity calculated by:

$$v_i(t+1) = v_i(t) + c_1 r_1 \left(localbest(t) - x_i(t)\right) + c_2 r_2 \left(globalbest(t) - x_i(t)\right)$$

Where: r_1, r_2 are random numbers, between 0 and 1.
c_1, c_2 are accelerate numbers, equal 2.
localbest(t) is the best remembered individual particle position.
globalbest(t) is the best remembered swarm position.

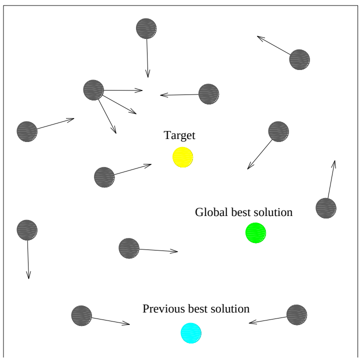

Figure 1: Particle motion of PSO algorithm

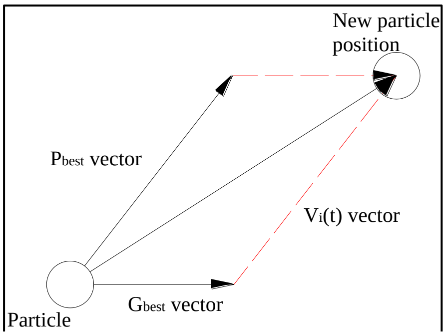

Figure 2: Particle speed

B. Experiments

The Aluminium sample was used in this study, this is isotropic material. It was cut from rolling plate and show on in figure below.

Figure 3: Aluminium sample

The size of Aluminium sample size is 25x180 (width x length) and 0.5mm of thickness.

Table 1: Aluminum properties (matweb.com)

Elastic of Modulus (GPa)	Poisson's ratio	Density (g/cc)
68.9	0.33	2.7

A Laser ultrasound technique system (LUT) was used for generator the Lamb wave propagating inside material. The LUT includes a pulsed Nd:YAG laser, the pulsed Nd:YAG laser with a wavelength of 532 nm, an energy about 400 mJ, and 0.7 mm beam diameter, is used for the generation of ultrasonic acoustic waves propagating inside Aluminium sample. The pulsed laser has a maximum repetition rate is up to 10 kHz a longitudinal transducer to receiver ultrasound wave, a pulse-receiver, a computer with fast A/D converter to control the system. The 5 MHz longitudinal transducer are utilized to detect ultrasound. The computer controls the step motor and the Nd:YAG laser beam on straight line of 10mm. The scanning line is parallel with the rolling direction and applied stress direction.

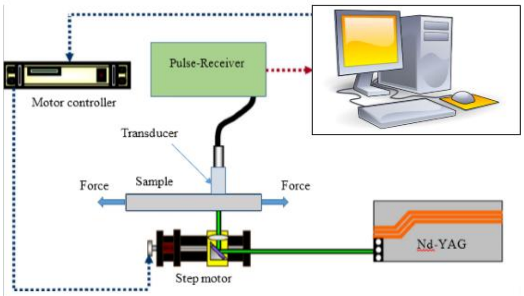

Figure 4: Scheme of experiment system

We using A – scan and B – scan method to do experiment, first of all, we get wave form from A – scan, and using B – scan to analyse wave form and receive B –scan domain with different colours. The scanning in 10mm straight line with 200 steps. The direction of scanning is parallel with stress direction and rolling direction. The Fast Fourier Transform was use to change position – time domain to dispersion curve of ultrasound wave, that is the velocity – frequency domain.

To obtain the effect of uniaxial stress to material properties change, we using MTS to provide tensile stress for Aluminium sample. Because, the tensile yield strength of Aluminum is 276MPa, so the maximum of tensile applied stress is 100MPa with 10MPa for each step increase. At each step of tensile stress, we use LUT and invert the material properties. A program of Labview was used to analyse the dispersive curve of Aluminum sample and invert the material properties.

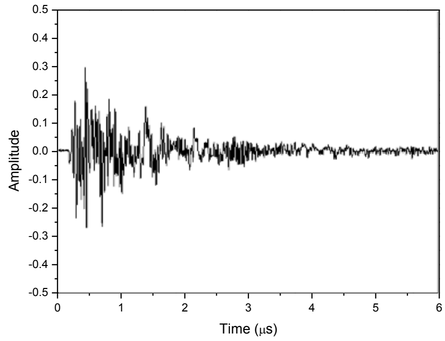

Figure 5: Waveform of Aluminium sample

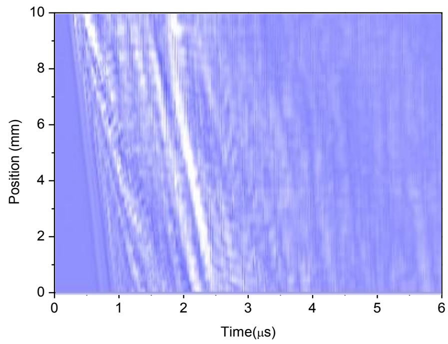

Figure 6: B - scan of Aluminium sample

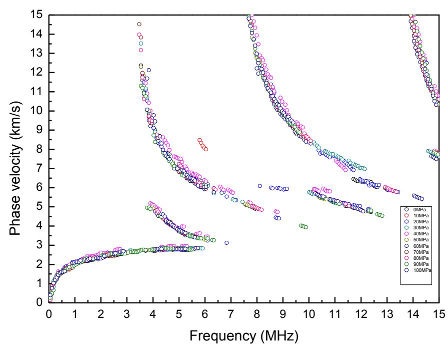

Figure 7: Dispersion curves of Aluminium sample

Results and Discussion:

The Young modulus of Aluminum sample decrease when tensile stress which parallel with scanning direction and rolling direction increase

The Young modulus is 69.4MPa at free applied stress. It will be decrease when the applied tensile stress increase. The Young modulus is 65.7MPa at 100MPa of stress. It was show on table 2.

Table 2. Young modulus and Poisson's ratio of Aluminum sample

Applied stress (MPa)	0	10	20	30	40	50	60	70	80	90	100
E (GPa)	69.6	69.6	69.5	69.2	68.6	68.3	67.5	67.3	66.8	65.7	65.2
ν	0.333	0.332	0.332	0.333	0.332	0.332	0.332	0.330	0.331	0.330	0.330

The Young modulus decrease about 5.8% under 100MPa increase of applied tensile stress. The effect of uniaxial stress is not clearly at low stress (from 0 to 30MPa), the Young modulus decrease very small. But, at high applied stress upper 30MPa, the effect of stress become clearly. It was show on figure 8.

The result of this research is similar with previously published such as Jonhson (1998) [3], M. Qasmi., (2006) [2], Chang (2009) [13]. In previous studied, the Elastic modulus of thin film decrease when the applied stress increase.

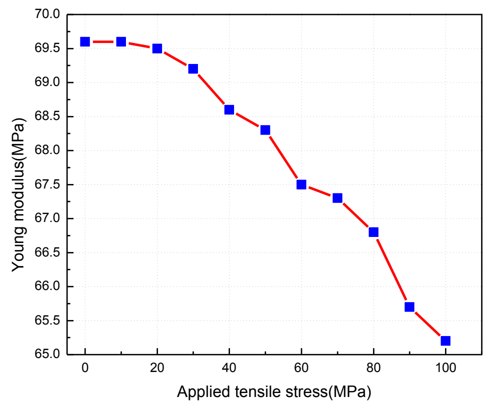

Figure 8: Young modulus – Uniaxial stress relation

The Poisson's ratio doesn't change when the tensile stress increase, it has a little change at high applied stress, but the change value is small. It can be explain by the increase of temperature of sample by laser beam.

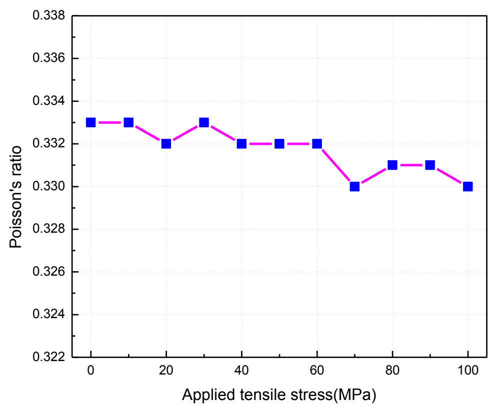

Figure 9: Poisson's ratio of Aluminum sample

Conclusion:

Laser ultrasound technique followed by a PSO inversion was used to measure Elastic modulus in uniaxial states (tensile stress) in Aluminum samples.

The Young modulus decrease at the axial stress increase. While the Poisson's ratio doesn't change under axial stress.

References:

[1] Mohammadi OUAFTOUH, Marc DUQUENNOY., (2013) "Characterisation of Surface Residual Stress using High Frequency Rayleigh Waves" 13th International Symposium on Nondestructive Characterization of Materials (NDCM-XIII) , 20-24 May 2013, Le Mans, France

[2] M. Qasmi., (2006) "Effect of the residual stress on the determination through nanoindentation technique of the Young's modulus of W thin film deposit on SiO2/Si substrate", Journal of Surface & Coatings Technology 200 (2006) 4185– 4194.

[3] C.A. Johnson and J.A. Ruud., (1998) "Relationships between residual stress, microstructure and mechanical properties of electron beam–physical vapor deposition thermal barrier coatings", Journal of Surface and Coatings Technology 108–109 (1998) 80–85.

[4] J. Kennedy and R. Eberhart., (1995) "Particle swarm optimization", International Conference on Neural Network, Perth, WA, pp. 1942 - 1948 vol.4 , 1995.

[5] N. Hsu., (1974) "Acoustical birefringence and the use of ultrasonic wave for experimental stress analysis", Third SESA International Congress, Los Angeles, CA, 1974.

[6] A. Zeiger and K. Jassby., (1982) "Measurement of acoustoelastic coefficients of Rayleigh wave in steel alloys", Journal of Nondestructive Evaluation, Vol. 3, No. 2, 1982.
[7] D. Husson., (1985) "A perturbation theory for the acoustoelastic effect of surface waves", Journal of Applied physics, 57, 1562 (1985).
[8] J. Ditri., (1996) "Stress distribution determination in isotropic materials via in inversion of ultrasonic Rayleigh wave dispersion data", International Journal Solids Structures vol.33, No. 17, pp. 2437-2451, 1996.
[9] K. Demachi., (2011) "Numerical simulation of residual stress measurement with acoustic wave". E-Journal of Advanced Maintenance Vol.2 (2010/2011) 160 -167.
[10] M. Ouaftouh., (2013) "Characterization of surface residual stress using high frequency Rayleigh waves", *(NDCM-XIII)* , 20-24 May 2013, Le Mans, France.
[11] Yeh and Yang., (2011) "Characterization of mechanical and geometrical properties of a tube with axial and circumferential guided waves", Journal of Ultrasonics 51 (2011) 472–479.
[12] D.C. Hurley, V.K. Tewary, A.J. Richard., (2001) "Thin-film elastic-property measurements with laser-ultrasonic SAW spectrometry", Journal of Thin Solid films, 398 –399 (2001) 326–330.
[13] Chang., (2009) "Effect of residual stress on mechanical properties and interface adhesion strength of SiN thin films", 4th International Conference on Technological Advances of Thin films and Surface Coating, Volume 517, Issue 17, 1 July 2009, Pages 4857–4861.