Study on the determination of elastic modulus of amorphous alloy by the acoustic method

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Abstract. This paper studys on the determination of elastic modulus of amorphous alloys by acoustic method. The method is simple and effective, convenient and fast, non-destructive and has strong practical significance. A cantilever beam structure is selected, and the non-contact acoustic measurement and analysis system is composed of MM 210 microphone, DT9837 series data acquisition unit, computer and dewesoft7.0 software. The vibration of the specimen is generated by the transient vibration, which generates a sound wave, and the inherent frequency is obtained by the sensor data acquisition and software analysis. According to the theoretical formula of the inherent frequency of the cantilever beam, the elastic modulus of the amorphous alloy is calculated, at the same time, the measurement results are compared with the three-point bending test method. Finally, the finite element method is used to verify the inverse analysis.

Introduction

Amorphous alloy is a new type of alloy material, which was published in the twentieth century 60~70s, and it is used in the process of ultra rapid cooling technology to directly cool the liquid metal into solid material. Amorphous alloys have completely different performance characteristics compared with conventional metal materials, including low melting point, high strength, high toughness, high wear resistance, etc. These properties make it gradually applied in people's daily consumer goods, such as high wear-resistant audio video heads, golf clubs, high-end watches, fishing rod [1] and other products prepared by the use of amorphous alloy.

The elastic modulus of amorphous alloy is an important parameter in studying the mechanical behavior of amorphous alloy, so the research on its detection in terms of theory and application of amorphous materials are of great significance[2].At present, in view of elastic modulus' measurement of the amorphous alloy material can be divided into static method, ultrasonic water immersion focusing method, dynamic method such as 3 class[3],these methods adopt different measuring principle, each has different scopes of application. Aiming at the limitations of these methods, according to air vibration caused by the vibration of an object will form sound wave [4-5], this paper studys on the determination of elastic modulus of amorphous alloys by acoustic method. The method is simple and effective, convenient and fast, nondestructive and has strong practical significance.

In this paper, the elastic modulus of amorphous alloys was tested by the traditional three-point bending test method [6], to verify the validity of the acoustic measurement method. Finally, the finite element method is used to verify the inverse analysis.

Experimental principle and experimental platform

Three-point bending test. Test instrument of three-point bending test is carried out on 50 kN Zwick Roell electronic universal material testing machine, precision instrument grade is 0.5, the beam velocity control accuracy is 0.05%, the displacement resolution is 0.0122 µm, internal measurement channels synchronous sampling frequency is equal or great than 400 kHz.

Cross section as the rectangular specimen is freely placed in two support roller radius of 5 mm, the pressure head of a hard alloy circular rod with a radius of 5mm is applied to a concentrated load that cause the specimen to bend and not to break the specimen. The whole process is loaded into 2N and the loading rate is 1mm/min. According to the mechanical properties test method of the metal bending , the formula for calculating the elastic modulus of specimen is shown in Eq. 1.

$$E = \frac{Ls^3}{48I}\left(\frac{\Delta F}{\Delta f}\right) \qquad (1)$$

In the formula: Ls is the fulcrum span, which is fixed to 32 mm; F is the load; f is the specimen deflection; I is the bending moment of specimen, $I = \frac{1}{12}WH^3$, W is the specimen width, H is the specimen thickness.

Acoustic experimental test. Cantilever beam is fixed at the pedestal , pedestal is great quality which is relative to the cantilever beam, and thus it does not affect the inherent resonant frequency of the beam. As long as the inherent resonant frequency of the cantilever beam can be measured in free oscillation, the elastic modulus of cantilever beam can be calculated. According to the inherent frequency equation of the cantilever beam[7], is shown in Eq. 2.

$$f_i = \frac{(\beta_i L)^2}{2pL^2}\sqrt{\frac{EI}{\rho A}}(i = 1,2,3) \qquad (2)$$

The elastic modulus E of the material can be obtained is shown in Eq. 3.

$$E = \frac{4\pi^2 f_i^2 L^4 \rho A}{(\beta_i L)^4 I} \qquad (3)$$

In the formula: A is the cross-sectional area of the cantilever beam, A= W × H, W is the width and H is the thickness of the cantilever beam, I is the cross-sectional moment of inertia of rotating around its axis of symmetry, $I = \frac{1}{12}WH^3$, ρ is the density of amorphous alloy, L is the cantilever beam length, all parameter of unit is mm.

The experimental block diagram of cantilever beam by acoustic method is shown in Fig. 1.

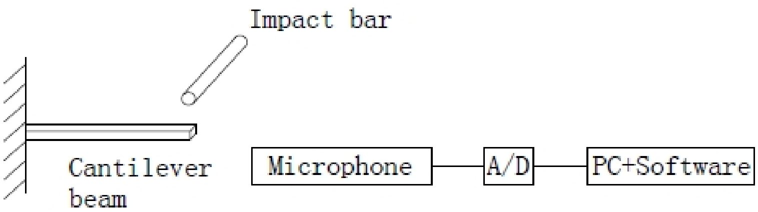


Fig. 1 The experimental block diagram of cantilever beam by acoustic method

Used instruments are as follows

Microphone: MM210 type, 3.5Hz-20kHz frequency response, sensitivity range:15dB-135dB.

Data acquisition: DT9837 type, 4 channel analog input and BNC connection, A/D conversion accuracy 24 bit, signal measurement range 0-52.7KHz.

Computer: Hasee D1 K450N-i5.

Signal acquisition and analysis software: dewesoft 7 software, the selection of single track, sampling frequency 50KHz, signal analysis with FFT operation length N=16384.

Dewesoft hardware matches dewesoft^{TM} software produced by dewesoft company in Austria, is a new generation of data acquisition system based on network, which has the standard of modular, dual core ADC and digital high isolation technology. This software has a powerful mathematical calculation and analysis of processing capacity, not only online real time processing, but also can store data flexibly and conveniently for post processing. In the modal analysis module, the dewesoft software interface is to set up the filter, the signal trigger type, and the structure is excited by the excitation, the hardware data is collected, and the inherent frequency of the structure is analyzed by FFT spectrum.

The concrete process is to build the experimental platform of transient vibration, the thin slice specimen of amorphous alloy is clamped and fixed at one end, made of a cantilever beam, and the microphone sensor is parallel to the axis of the cantilever beam, the sampling rate is 1.5-2cm, the sampling rate is 50KHz, and the measurement unit is Pa. The rectangular specimen is knocked by impact bar made of hard plastic, the cantilever beam receives the pulse excitation, it will emit impact sound and excite the specimen to lateral vibration. We can measure the pressure signal of sound through the microphone, the data acquisition convert the sound pressure signal to electrical signal, and then data acquisition and spectrum analysis are implemented through the dewesoft software. The resonant frequency of the cantilever beam is obtained, that is, the inherent frequency, the elastic modulus is calculated by the Eq. 3.

Test results and comparison

The static elastic modulus value of three-point bending test. Test specimen with three dimensions respectively are (1) L = 74.03 mm, W = 9.41 mm, H = 1.10 mm ;(2) L = 74.28 mm, W = 9.19 mm, H = 1.14 mm; (3) L = 74.61 mm, W = 9.19 mm, H = 1.09 mm, elastic modulus is obtained through the calculation of formula (1), and calculate the average. The known elastic modulus E = 86.7 GPa, it is concluded that the relative error is shown in Table 1.

Table 1 The method of three-points bending test to measure elastic modulus

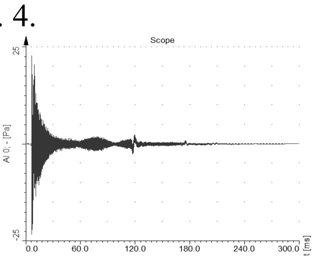
Elastic modulus（GPa）				Relative error %
1st	2nd	3rd	Average	
92.2	91.8	91.4	91.8	5.9

The average value of the elastic modulus is 91.8GPa in Table 1, and the relative error is 5.9%, and the error value is relatively large, but it is basically in accordance with the requirements. But the three- point bending method has the characteristics of instability, large range of fluctuation, the existence of accidental error, and the detection speed is slow.

Acoustic method to measure the elastic modulus. Taking into account that the amorphous alloy system is constrained by size, the cantilever beam should not be too long, because the long cantilever beam is due to their own bending deformation that will also affect the results. And if the cantilever beam is too short，it may make the error is bigger. Because it occurs in the cross section of the shear force and the vibration of the specimen during the rotation of the specimen. Therefore the test selection of amorphous alloy test size for length L=72.5mm, width W=10mm, height H=1.2mm, material density r =6660kg/cm3, the experimental apparatus is shown in Fig. 2.

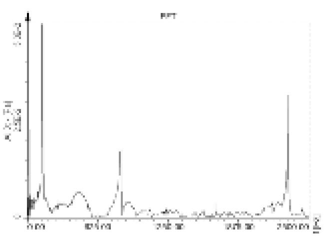
Fig. 2 Amorphous alloy elastic modulus test apparatus

It acquires acoustic signal by using the microphone sensor , the A/D convert the sound pressure signal to electrical signal and the dewesoft software analysis it, it will return the time domain response waveform and frequency domain response waveform, which will be shown respectively in Fig. 3 and Fig. 4.



time / s

Fig. 3 Cantilever beam time domain response



frequency / Hz

Fig. 4 Cantilever beam frequency response

According to Figure 4, the first three inherent frequency values can be obtained. By calculating the average after three measurements, the corresponding elastic modulus of amorphous alloy can be calculated by Eq. 1, is shown in Table 2. Since the elastic modulus is 86.7GPa, the relative error is less than 3%.

Table 2 Material inherent frequency and the elastic modulus

Order	Inherent frequency/Hz				Elastic modulus/GPa	Relative error %
	1st	2nd	3rd	Average		
First order	131.2	131.2	131.2	131.2	84.2	2.8
Second order	828.6	827.0	828.6	828.1	85.4	1.5
Third order	2311.7	2310.2	2310.2	2310.7	84.8	2.2

The Simulation Analysis of Finite Element

The inherent frequency which obtains by acoustic method is an experimental modal value. It is a computing mode value and it can be obtained by using the finite element software to analyze the cantilever beam, with the finite element modal, which is a inherent frequency when the specimen is under cantilever beam constraint. Both reflect the same inherent properties of the specimen, just in a different way in theory and experiment. Based on the known elastic modulus value, take the value of amorphous alloy Poisson's ratio μ as 0.38, use the finite element software Ansys Workbench14.5 to apply the calculation modal analysis on cantilever beam, it will respectively return the first three inherent frequencies. After comparing the theoretical and actual measured values, the following Table 3 can be shown like this.

Table 3 Comparison Cantilever beam natural frequency

Order	Measured value/Hz	Calculated value/Hz	Finite element value/Hz	Relative error between measured and finite value %
First order	131.2	133.1	133.8	2.0
Second order	828.1	834.3	836.8	1.1
Third order	2310.7	2336.3	2342.0	1.4

From which, the first order finite element has the maximum relative error between the analysis and measured value, but only 2.0%, indicating the consistency of three different method. To validate the correctness of using cantilever structure to measure the elastic modulus of amorphous alloy, do the free modal test on the specimen by using the transient excitation method, where the length L equals 78.0mm, width W equals 9.6mm, height H equals 1.0mm. As a result, the first order bending inherent frequency will be 618.0Hz. By the inverse analysis of finite element, the elastic modulus is 88.9GPa, existing a relative error of 2.5% with the known value of 86.7GPa, proved the correctness of the test method.

Conclusion

Three-point bending static test on elastic modulus has an error of 5.9%, reflecting a great data fluctuation and slow detection speed; while the acoustic method has an error less than 3%, showing the stable data, rapid detection, and accurate results.

According to the first three inherent frequencies of cantilever beam by acoustic measurement, combined with theoretical calculations and finite element analysis, the elastic modulus of the amorphous alloy goodness of fit is good, and the relative error is small by using finite element free modal inverse analysis , then it verifies cantilever beam the reliability of measurement methods. This method is suitable for thin and short specimen.

The entire system includes a microphone sensor, data acquisition, computer, dewesoft7.0 software and cantilever beam base structure, the use of non-contact measurement method, without an acceleration sensor, it can prove that the method is simple and effective, convenient and fast, nondestructive and has strong practical significance.

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