

HIDDEN FLAWS MEASUREMENT OF THIN TITANIUM-ALUMINUM BONDED PLATES USING ULTRASONIC TECHNIQUES

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Abstract: This work presents the results for searching the slight flaws between the bonded plates made of titanium (Ti) and aluminum (Al) by using the ultrasonic techniques. For the sake of environment protection, metals, instead of plastics, are preferable for the outer covering of 3C (Computer, Communication, and Consumer) products. Among them, titanium, which is light and strong and will not corrode easily, is a good choice. But, applying only Ti will cost too much. In order to reduce the cost and maintain the good quality of the final products, bonded plates that made of both Ti and Al are used. The bonded plates are mad by sticking thin Ti plate to a thicker Al plate. Because there may be some air chambers formed between these two plates during the process, the bonded plates will crack or bounce back when they are used to make the products. However, we find it is feasible for using the ultrasound to detect the flaws in the thin Ti-Al bonded plates. Transducers of different frequencies according to the thickness of the examined metal plates are tested. The time- and frequency-domain analyses indicate that the flaws can be located. In this study, 20 MHz ultrasonic transducers are used to search for flaws. When the ultrasonic wave is excited upon the plate from the side of Al, a flaw can not be distinguished. But if the ultrasonic wave is excited from the side of Ti, a flaw can be found. As to the thicker bonded plate, when the ultrasonic wave is excited upon the plate from the side of Al, three dominant frequencies will appear at 4.8 MHz, 8.3 MHz, and 12.3 MHz if there is a flaw. We conclude that ultrasonic method can be used to examine the flaws in the very thin Ti-Al bonded plates.

Introduction: In order to increase the quality of their products, many manufacturers used a large amount of costly metal on the outer covers of their products. For the sake of balance between cost and quality, products made of two kinds of metal bonded plates are developed. Among them, Ti and Al are the most popular combination. Although the material and technique of cementation develop very well, it is still unable to avoid the occurrence of flaws. To find flaws and save the cost as well, basic ultrasonic testing equipment instead of expensive and large testing instrument is used.

Nishiwaki [1] has developed a method to find the flaws inside the bonded plates. It is a method for measuring the thickness of the thin-coated layer and detecting the separation of the coated layer from the base material. Nishiwaki used a focusing type ultrasonic transducer which had to be fastened to a very precise instrument. Besides, the coated part was dipped into water to get the effect of delay. The reason is like using delay line transducers to solve the problem of unclear signal in the near field of ultrasonic waves. Considered from the aspect of the cost of equipment and the speed of measurement, this method is not suitable for our purpose.

Another method is using delay line transducers. Delay line transducers are contact type transducers covered by a layer of acrylics wear plate. A contact type transducer is easily limited by the near field of ultrasonic wave transducers. And because Ti is usually very thin (0.1 mm), it is impossible to find flaws from the side of Ti. But a delay line transducer can solve the problem. It is more convenient to use than the method of Nishiwaki. But the price of a delay line transducer is more expensive.

The third method is using contact transducers. Limited by near field as mentioned above, sound wave transmits in the way of plane wave. On the same surface, the phrase is the same while the intensity is different. Because the intensity of sound press varies very complicatedly in near field, it is not suitable for detecting small flaws. So contact transducers are not applied to measure the thickness of Ti from the side of Ti. But if the purpose is only to find flaws in bonded plates, contact transducers can be used. The flaws will reflect sound wave to transducers and the echo signals are likely to appear in the dead zone of near field, if flaws are right under the transducers, the echo signals are definitely different from those signals reflected from other

positions that without flaws. The flaws in metal bonded plates can be located from the time- and frequency-domain analyses by using the contact type transducers.

Research Method: First the relation between wave velocity and wave length of ultrasonic wave is shown as follows:

$$\lambda = \frac{c}{f}, \quad (1)$$

where c is the velocity of sound wave passing through the tested object. f is frequency and λ is wavelength. When the air gap between the plates is too thin and the thickness of Ti is less than one wavelength, it will be very hard to determine whether a flaw exists from echo. The wave velocity of sound wave passing through Al is 6320 m/s and that passing through Ti is 6100 m/s. If a 20 MHz sensor is used, the wavelength of sound wave passing through Al is 0.316 mm and that passing through Ti is 0.305 mm. So the thickness of Ti is less than one wavelength as shown in Fig. 1. Table 1 shows the properties of sound wave in different materials [2, 3].

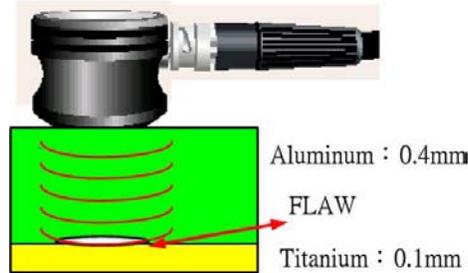


Figure 1: The cross section of bonded plates.

Table 1: Acoustic properties of materials

Material	Longitudinal Velocity (m/s)	Acoustic Impedance (Kg/m ² s x 10 ⁶)
Al	6320	17.06
Ti	6100	27.69
Air	344	0.00004

Next the transmission of ultrasonic wave passing through different materials should be known. The acoustic impedance of Ti is 27.69 (Kg/m²s x 10⁶), the acoustic impedance of Al is 17.06 (Kg/m²s x 10⁶) and the acoustic impedance of air is 0.00004 (Kg/m²s x 10⁶). The formula of acoustic impedance is as follows.

$$Z = c\rho \quad (2)$$

The ultrasonic wave reflection coefficient (R) is calculated by the following formula.

$$R = \left[\frac{Z_1 - Z_2}{Z_1 + Z_2} \right]^2 \quad (3)$$

The sound wave transmits between Ti and Al, its reflection coefficient is 0.056. When sound wave reflects from Ti to air, its reflection coefficient almost equals to 1. Similarly, when sound wave reflects from Al to air, its reflection coefficient almost equals to 1. So the sound wave in materials will reflect totally if it propagates into the air. But only 5.6% of sound wave is reflected on the surface of Ti and Al, and its transmission rate is up to 94.4%.

On the line of sound axis, the distance between the strongest point and sound source is called near field distance (N). The field whose distance is shorter than N is called near field, the field whose distance is longer than N is called far field. In near field, sound wave transmits in the way of plane wave. Near field distance is calculated by the formula:

$$N = \frac{D^2 - \lambda^2}{4\lambda}$$

(4)

where D is the diameter of the transducer, λ is wavelength. On the same plane, the phase is the same while the intensity is different. Because the intensity of sound pressure varies very complicatedly in near field, it is not suitable for detecting small flaws. In far field, sound pressure will dampen with the increase of distance. About 1.6 times longer than N , if the distance increases double and the sound pressure is half. In far field, sound wave transmits in the way of sphere wave [3].

The transducers used in the experiment is M116 of PANAMETEICS, whose diameter is 3 mm [4]. If the measurement is made from the sides of titanium, N equals to 7.3 mm; if from the side of Al, N equals to 7.04 mm. It is evident from Table 2 that the thickness of Ti and Al in the whole samples is far less than near field distances. In this study, the signals in near field will be detected and the flaws will be positioned from the time- and frequency-domain analyses.

Experiment: The equipment used in the experiment is Squarewave Pulsar/Receiver 5077PR of PANAMETEICS™, Agilent™ 54622A digital storage oscilloscope, and M116 ultrasonic transducer (PANAMETEICS™, 20 MHz, 3 mm diameter). Figure 2 shows the block diagram of measurement system. First, from 5077PR a pulse is sent to the transducer which will transfer the electrical signals into pressure wave. Vaseline, as a couplant, is applied to the transducer. Sound wave is transmitted into the Ti-Al bonded plate. Then, the transducer turns echo into electrical signal which is amplified 50 dB by 5077PR. Finally, the signals will be stored and displayed by the oscilloscope.

Table 2 shows the samples used in the experiment. Sample 0 is a well-cemented Ti-Al bonded plate, which is used as the contrast sample. The thickness of Ti on sample 1, 2 and 3 is 0.1 mm. The thickness of Al on sample 1 is 0.5 mm, 0.4 mm on sample 2 and 0.8 mm on sample 3. The thickness of Ti on sample 4 and sample 5 is 0.5 mm. The thickness of Al is 0.4 mm and 0.8 mm. The method in the experiment is to excite ultrasonic both sides of the samples, move the transducer and observe the echo signals on time- and frequency-domain.

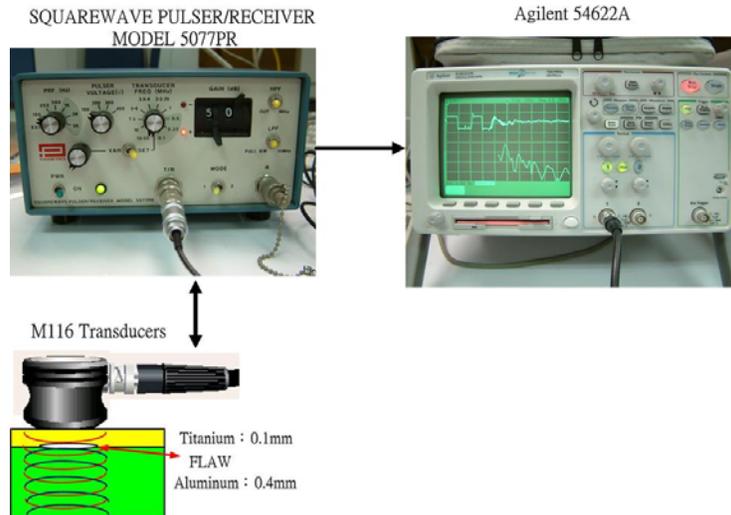


Figure 2: The block diagram of measurement system.

Table 2: The specification of samples that used in the experiments.

Sample Number	Specification
0	Well-cemented Ti: 0.27 mm Al: 0.56 mm
1	Japan Ti: 0.1 mm Al: 0.5 mm

2	Japan Ti: 0.1 mm Al: 0.4 mm
3	Japan Ti: 0.1 mm Al: 0.8 mm
4	U.S.A. Ti: 0.5 mm Al: 0.4 mm
5	U.S.A. Ti: 0.5 mm Al: 0.8 mm

Results and Discussion: The first experiment is on sample 1. The ultrasonic wave is excited from the side of Al. The position of flaws on every sample was marked in advance, as shown in Fig. 3. Figure 4(a) shows the echo at the position of a flaw. Figure 4(b) shows the echo at the position without flaw. Figure 5(a) shows the echo of time- and frequency-domain at the position on a flaw. Figure 5(b) shows the echo of time- and frequency-domain at the position without flaw. As it can be seen, it is hard to tell the difference between Figs.4(a) and 4(b), nor is the difference between Figs. 5(a) and 5(b). Therefore, it is difficult to tell if a flaw exists from the ultrasonic wave excited from the side of Al. As shown in Fig. 6, the thickness of Ti is only 0.1 mm. The distance is far less than the length of wave (0.305 mm). So from the sound wave to the flaw or to air, the echo wave is almost the same. The main frequency at the position of a flaw or elsewhere shown from spectrum analysis (Fig. 5) is between 7.5 MHz and 13.5 MHz[5][6].



Figure 3: Sample 1(Ti 0.1 mm, Al 0.5 mm).

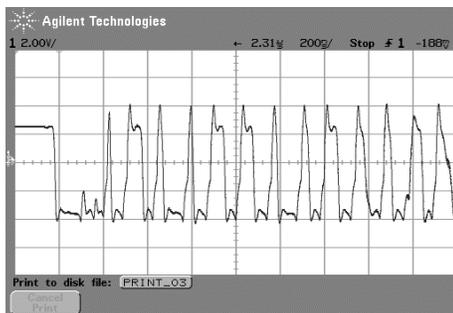


Figure 4(a): The echo at the position on a flaw.

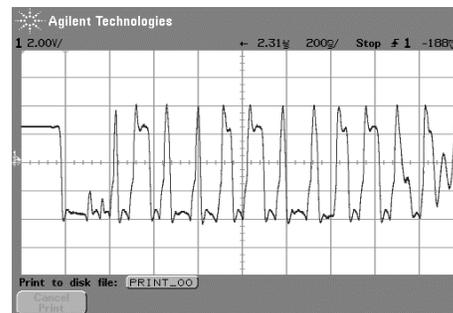


Figure 4(b): The echo not at the position of a flaw.

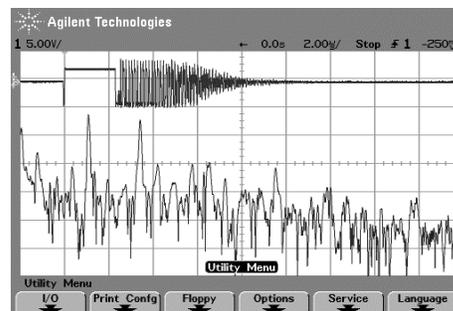
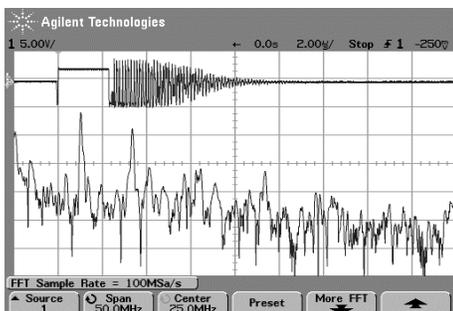


Figure 5(a): The time- and frequency- domain echo at the position on a flaw.

Figure 5(b): The time- and frequency- domain echo at the position without a flaw.

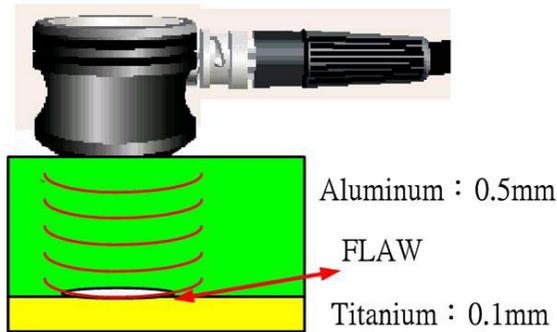


Figure 6: The ultrasonic wave excited from the side of Al.

The second experiment is on sample 1 again. But the ultrasonic wave is excited from the side of Ti. Figure 7(a) shows the echo at the position of a flaw. Figure 7(b) shows the echo at the position without a flaw. Figure 8(a) shows the echo of time- and frequency-domain at the position of a flaw. Figure 8(b) shows the echo of time- and frequency-domain at the position without a flaw.

The difference between Fig. 7(a) and Fig. 7(b) is very obvious. There are more echoes when the transducer is at the position without flaw. Or we can say that the attenuation is less for the later case (*i.e.* without flaw). Same phenomenon can be observed between Fig. 8(a) and Fig. 8(b). Therefore, it may be possible to know if a flaw exists from the side of Ti as shown in Fig. 9. The thickness of Al is 0.5 mm, longer than the wave length.

The sound wave excited upon the flaw and upon air will produce different echoes. Their difference lies in the thickness which is twice thicker than that of Al. Moreover, the thickness of Ti is only 0.1 mm, which is possibly near dead zone of sound field. Thus its echo is almost the same with the echo which is produced by sound wave excited directly upon air, shown in Fig. 10. According to time- and frequency-domain analysis (Fig. 8), the main frequency at the position of a flaw is 4.2 MHz; elsewhere the main frequency is 7 MHz.

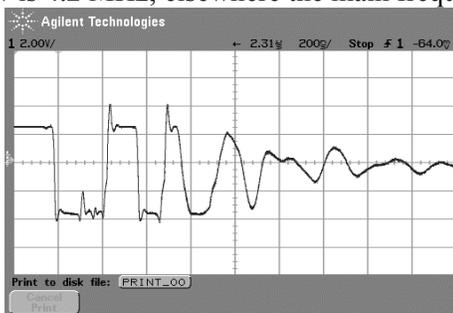


Figure 7(a): The echo at the position of a flaw.

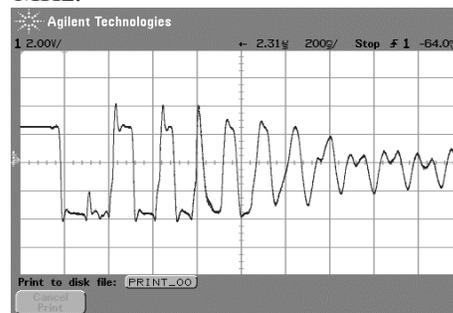


Figure 7(b): The echo not at the position of a flaw.

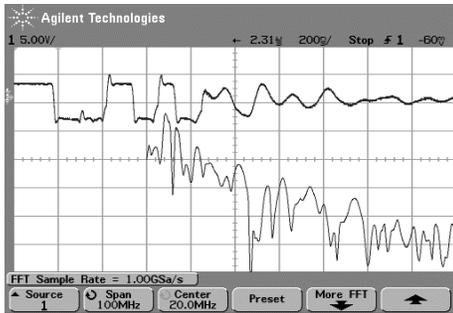


Figure 8(a): The time- and frequency- domain

echo at the position of a flaw.

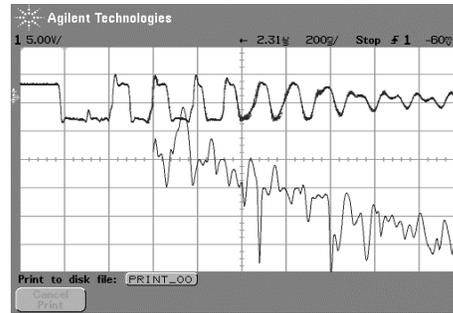


Figure 8(b): The time- and frequency-

echo at the position without a

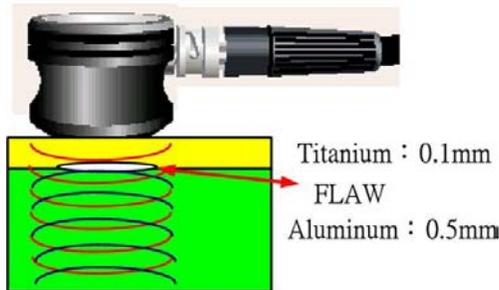


Figure 9: The ultrasonic wave recited from the side of Ti.

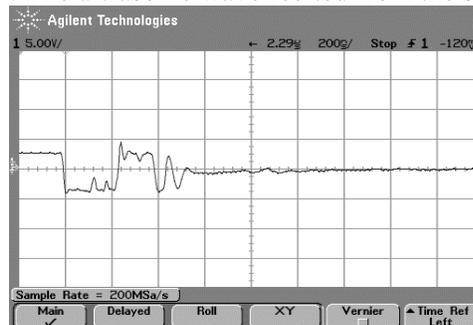


Figure 10: The echo which is produced by sound wave excited directly upon air.

Compare the signals received from sample 0, the well-cemented Ti-Al bonded plate. Figure 11 (a) shows the echo waveform excited upon the side Al. Figure 11 (b) shows the echo waveform excited upon Ti. Because sample 0 is well-cemented with no flaws, the echo are very similar to each other. After the measurement from sample 1 to sample 4, similar results are gotten. The conclusion is that ultrasonic wave should be excited upon the side of Ti in order to find flaws. When there is a flaw, a lower frequency (4.2 MHz) will appear on spectrum. If there is no flaw, a higher frequency (7 MHz) will appear. Finally, according to the different thickness of each sample, an information band of spectrum can be constructed. A flaw can be identified if the lower frequency appears. And a flaw can also be identified from the echo.

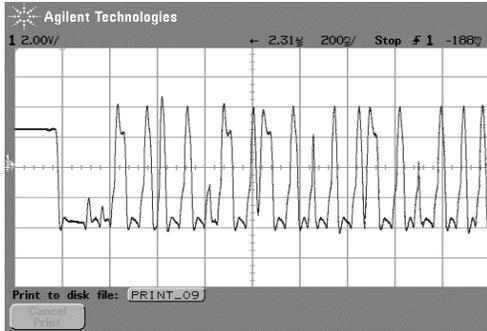


Figure 11(a): The time domain waveform excited upon the side Al of sample 0.

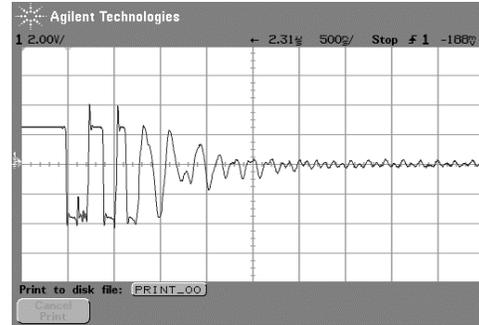


Figure 11(b): The time domain waveform excited upon the side Ti of sample 0.

Only sample 6 (Fig. 12: Ti 0.5 mm, Al 0.8 mm) is different from the others. Because the thickness of Ti is bigger than one wave length, a flaw can be found by the ultrasonic wave which is excited upon the side of Al. Because sample 6 has enough thickness for sound wave to reflect and refract, its echo is more complicated. From Figs.13(a) and 13(b), the following features are observed. At the position of a flaw the echo wave will be destructed and attenuate quickly. Elsewhere the echo is attenuated slowly. From the time- and frequency-domain analyses, the following features are found. When there are flaws, there are three main frequencies at 4.8 MHz, 8.3 MHz, and 12.3 MHz. When there are no flaws, three main frequencies are at 8.8 MHz, 12.3 MHz, and 16.3 MHz. So as long low frequency signals appear, flaws can be positioned.



Figure 12: Sample 6 (Ti 0.5 mm, Al 0.8 mm).

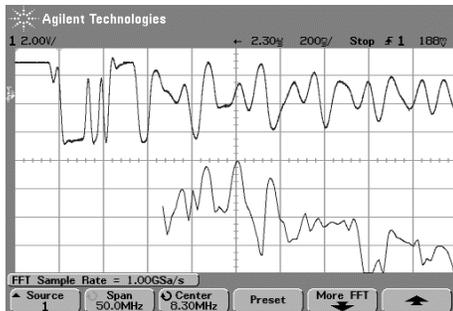


Figure 13(a): The echo of time- and frequency-domain at the position of a flaw.

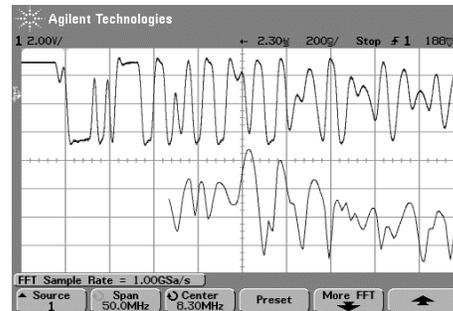


Figure 13(b): The echo of time- and frequency-domain not at the position of a flaw.

Conclusions: According to the analyses of time- and frequency-domain signals from the experimental results of six samples, the following conclusions are obtained. In the measurement of thinner bonded plates, ultrasonic wave should be incited from the side of Ti because of the effect of wavelength and near field. It is observed that the echo of time domain is attenuated quickly at the position of a flaw but slowly elsewhere. It is also observed from the spectrum that the dominant frequency is 4.2 MHz at the position on a flaw but 7 MHz elsewhere. In the measurement of thicker bonded plates, ultrasonic wave should be incited from the side of Al. At the position of flaws, three dominant frequencies will appear at 4.8 MHz, 8.3 MHz, and 12.3 MHz. If not at the position of flaws, three dominant frequencies will appear at 8.8 MHz, 12.3 MHz, and 16.3 MHz. The above results provide an easier and quicker access to locate slight flaws in Ti-Al bonded plates.

Acknowledgements: This work was supported by the National Science Council, Taiwan, R.O.C. under contract No. NSC 92-2212-E-006-087.

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