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DETECTION OF KISSING BOND IN EXTRUDED ALUMINUM BY LASER-ULTRASOUND

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ABSTRACT. Kissing bond defects can occur in solid state joined metals, like friction stir welded aluminum or hollow aluminum extrusions produced by means of porthole dies, and its nondestructive detection is crucial for many structural applications. In this paper, high frequency ultrasound generated and detected by lasers is applied to detect kissing bonds in extruded aluminum parts. It is found that an echo from the kissing bond discontinuity could be detected when the system has a signal-to-noise ratio (based on the backwall echo) of at least 40 dB in the frequency range of a few hundred MHz.

Keywords: Laser-ultrasonics, kissing bond, hollow extrusion
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INTRODUCTION

The zero volume defect known as kissing bond may reduce considerably the mechanical properties of materials and is often related to failures in structural components. Kissing bonds are a recurrent and often unsolved problem for the nondestructive testing [1]. Although frequently related to adhesion bonding, kissing bonds also can occur in metal joining, like friction stir welding [2,3] and extrusions [3,4]. In extrusions, kissing bond defects can occur in transverse weld seams resulting from the billet-to-billet transition, or in longitudinal weld seams in hollow aluminum extrusions that are formed when the metal streams flowing around the mandrel in the die are rejoined through a process of solid-state bonding. This paper deals with the latter case. Being a bulk, almost zero-volume defect, attempts at nondestructive detection of kissing bond have been done mostly with the ultrasonic technique. The mostly 'in contact' interface in kissing bonds makes the reflection coefficient of ultrasonic waves very small [5] and this reflection coefficient should increase with increasing frequency. This paper reports the detection of a kissing bond defect using high frequency ultrasonic waves generated and detected by lasers.

EXPERIMENTAL SETUP

The part to be tested is a section of an aluminum extrusion profile that is produced on a direct extrusion press, utilizing a porthole die. The alloy grade is 6082 and the part is supplied in T6 temper condition. Figure 1 shows a section of the extrusion with its zone of interest inside the ellipse and the top picture shows this zone after mechanical loading through drift expansion testing. Although the material will actually maintain its strength up to values near the yield point, it will subsequently fracture with only minimal plastic deformation (i.e. ductility ~ 0); the fracture surface is very smooth, without any traces of contamination, porosity, etc. Good samples can be plastically deformed and thus exhibit a degree of ductility.

The laser ultrasonic configuration used in the tests is depicted in Figure 2. As the weld-seam with possible defective interface is almost parallel to a flat external surface (see fractured surface in Figure 1), a pulse-echo approach with generation and detection superposed was chosen.

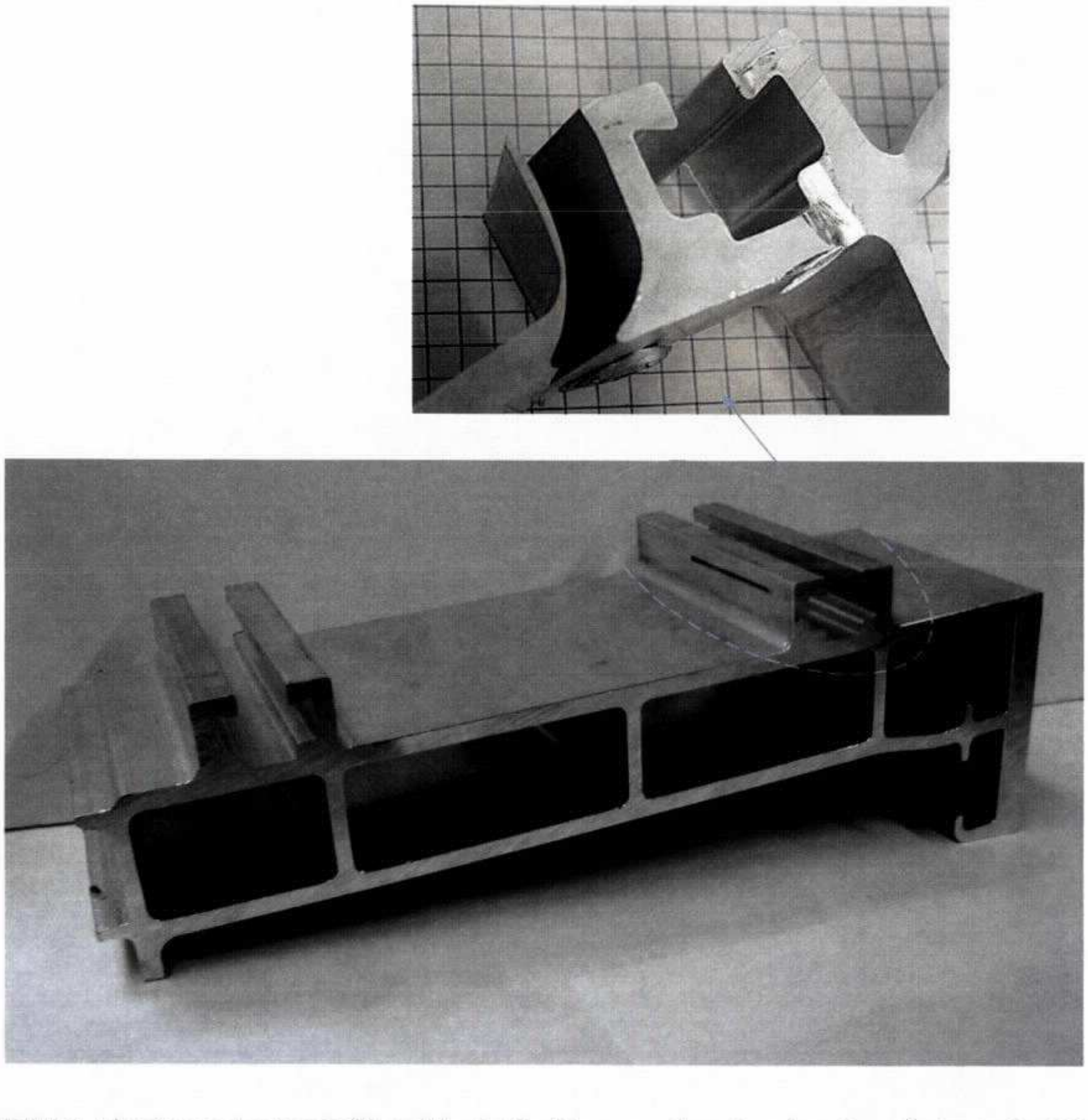

FIGURE 1. Aluminum extrusion profile and the detail of the zone where there is an imperfect extrusion joint.

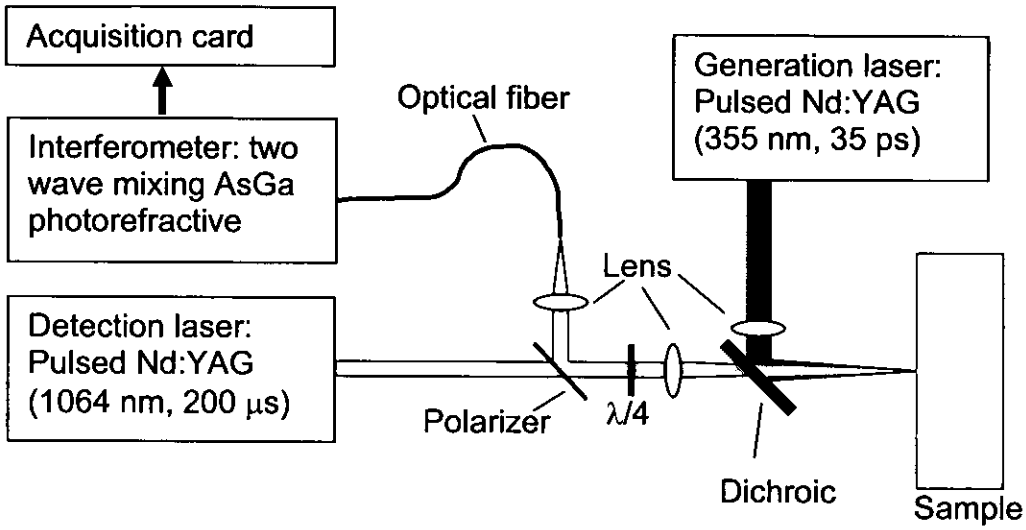

FIGURE 2. Optical configuration of the experimental setup.

The generation laser pulse has a duration of about 35 ps, which allows the efficient generation of higher frequencies ultrasound waves than normally used nanosecond pulsed Q-switched lasers. The detection was done with a high power long pulse Nd:YAG combined with a two-wave mixing AsGa photorefractive interferometer. In order to reduce the duration of signal related to the generation and also to better use the dynamic range of the acquisition card, a high-pass filter of about 100 MHz was put between the interferometer and the acquisition card.

RESULTS AND DISCUSSION

Figure 3a shows an ultrasonic signal obtained in a sample with kissing bond. Other than the two backwall echoes (at about 1.8 and 3.6 μs), a small echo at about 0.4 μs is also visible as indicated by the arrow. Figure 3b shows the same signal amplified of 20 dB where the echo can be better observed. This echo was found to come from the interface with the kissing bond, as it consistently appears in defective parts and does not appear in non-defective parts. Also the echo appears in the position consistent with the depth of the kissing bond in the extrusion sample. Note that this echo is about 26 dB weaker than the first backwall echo and consequently a high signal-to-noise ultrasonic system is needed to be able to detect this echo. Figure 4 shows two B-scan images where the kissing bond interface can be clearly observed. The interface is parallel to the surface in the extrusion direction, as expected, but slightly curved on the section normal to the extrusion direction.

It was found that to be able to detect the kissing bond echo, the ultrasonic system must have good response to high frequencies. For example, with the same detection configuration, if a 6 ns laser is used for generation instead of a 35 ps laser, the kissing bond echo disappears in the noise. Figure 5 show the amplitude spectrum of an echo reflected from the kissing bond interface and the spectrum of a backwall echo from an aluminum plate of equivalent depth. The aluminum plate echo spectrum shows the overall frequency response of the system. The echo spectrum from the kissing bond interface has more energy at higher frequencies, which clearly shows the high pass filter character of this interface.

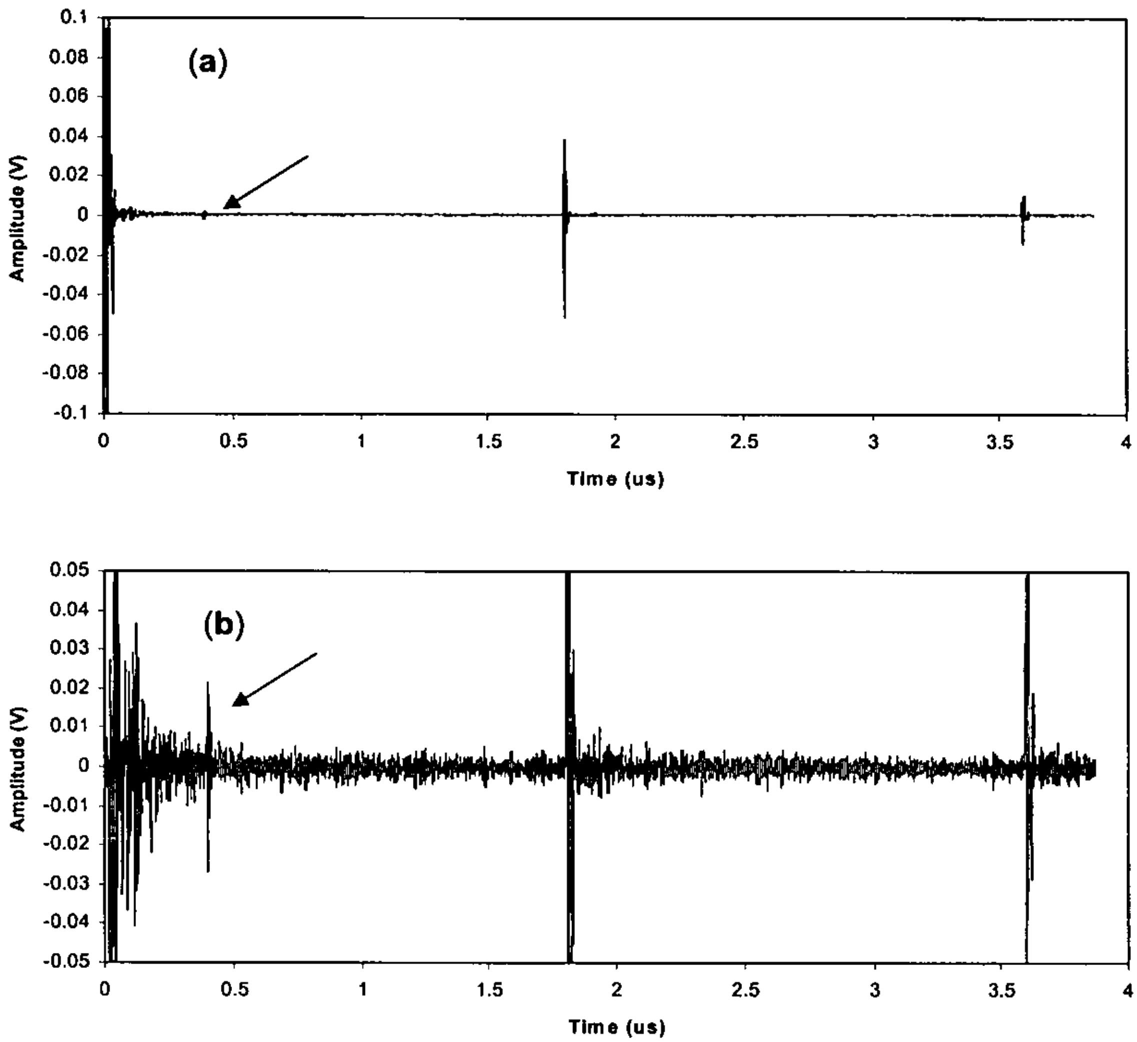

FIGURE 3. Ultrasonic signals obtained in a defective material (a) and the same signal amplified (b).

The signals shown in Figure 3 are obtained from an average of 25 laser shots to have a better signal-to-noise ratio. Averages of more than 25 shots have not shown to improve significantly the signal-to-noise ratio, due to the degradation of the surface conditions that is related to the ablation at generation. The physical mechanism behind the worse performance should be a smaller amount of detection light collected and the larger attenuation of higher frequencies due to the surface roughness.

The thermoelastic generation, although having much lower generation efficiency, should allow an averaged signal with indefinite number of laser shots. Figure 6 shows a signal produced in the same conditions as those of Figure 3, except for generation laser pulses of lower energy to be in the thermoelastic regime and averaged for a thousand laser shots. Compared to the signal produced in the ablation regime, the thermoelastic signal seems to have an even better signal-to-noise ratio and the amplitude of the interface echo seems to be higher compared to the backwall echo. This could be due to a higher generation efficiency of higher frequency components in the thermoelastic regime in metals. As lasers with a low energy but high repetition rate (often in the kHz) are becoming commercially available, working in the thermoelastic regime seems to be a very interesting and practical alternative.

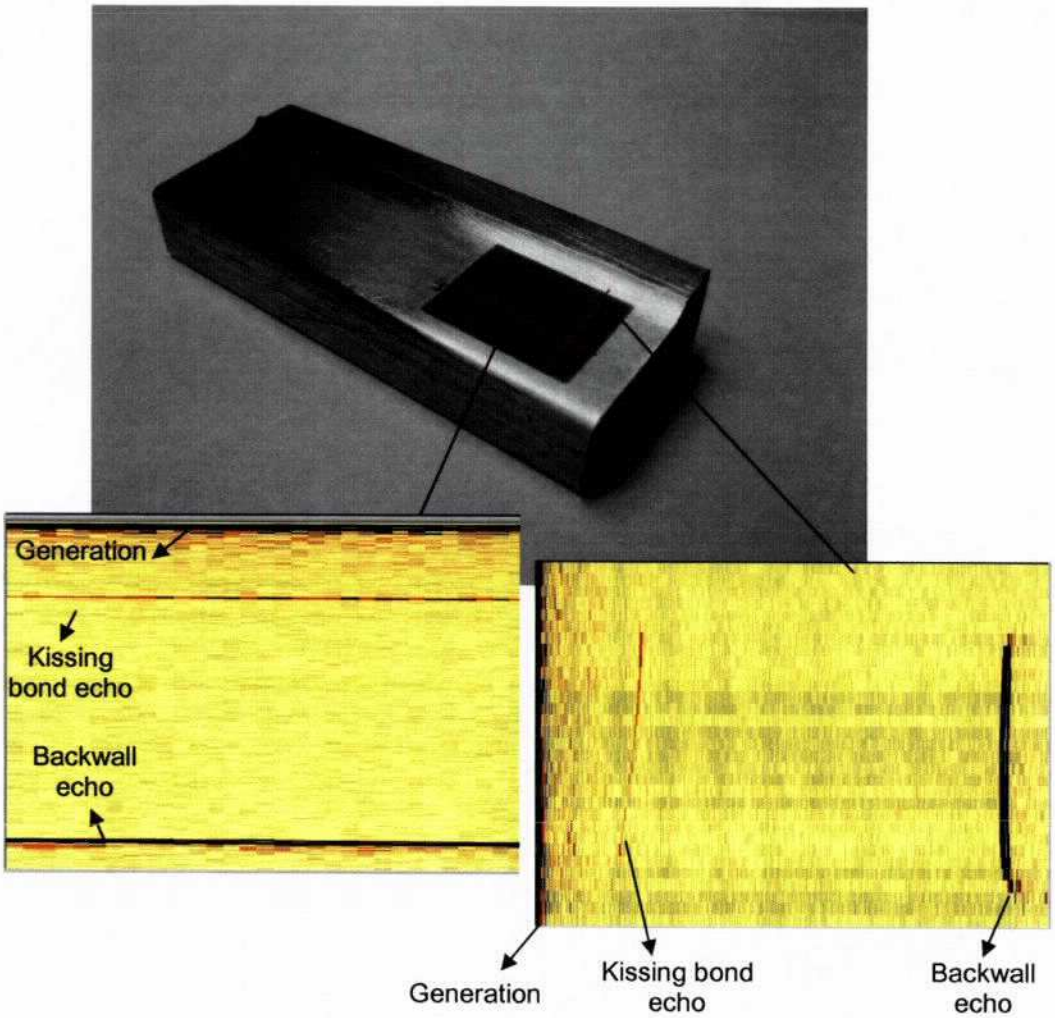

FIGURE 4. B-scan images of two perpendicular sections of a defective extrusion section.

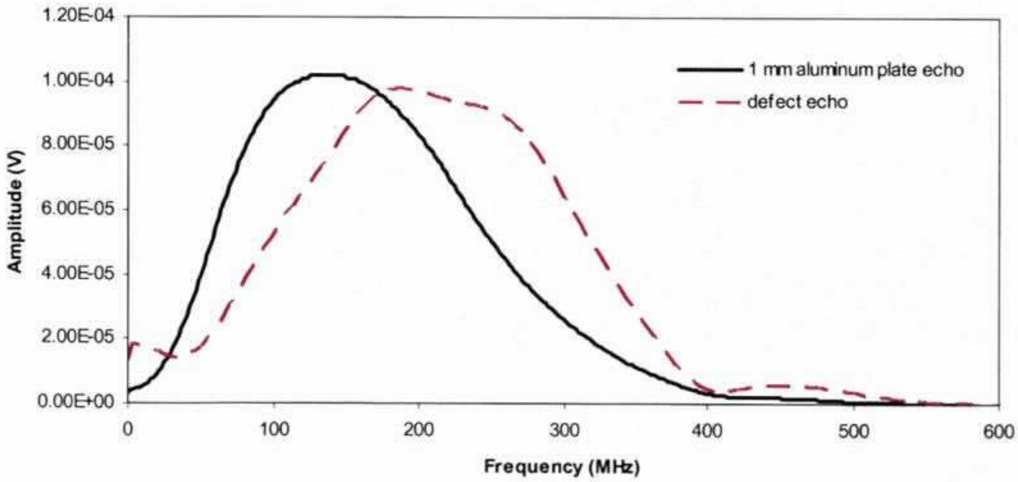

FIGURE 5. Amplitude spectra of an echo reflected from the kissing bond interface (dashed line) and of the backwall echo from an equivalent depth aluminum plate (solid line).

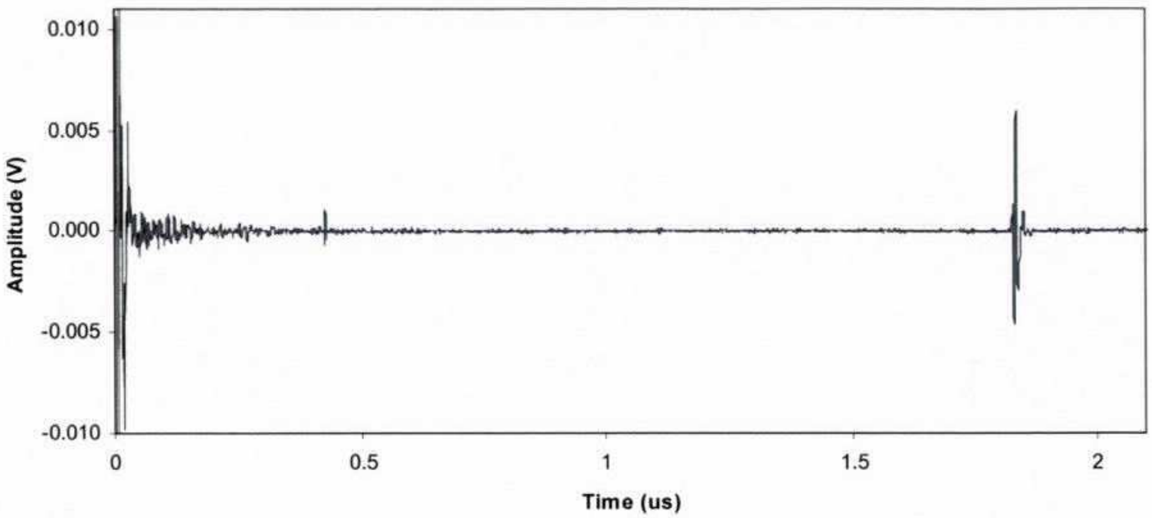

FIGURE 6. Ultrasonic signal obtained for a defective sample in the thermoelastic regime averaged for a thousand laser shots.

The nature of the kissing bond interface for aluminum extrusions is not clear. Figure 7 shows SEM images with two different magnifications of a cross section where the kissing bond plane is indicated by arrows. The voids (dark circles) distributed mostly randomly are produced by the chemical etching. We can observe, in some regions, the presence of a very thin aluminum oxide layer (as determined by EDS), but not everywhere along the interface. As this oxide layer is very thin, it is not clear if it is continuous all over the interface or if it exist only in a few regions. Also, as there is no air during the interface formation inside a well designed extrusion die, no oxide layer is supposed to be formed [3] and it is presumed that the kissing bond defects are the result of (transient) unsound metallurgical solid bonding conditions, e.g. an insufficiently high pressure on the bond plane or a too low straining of the bond area after initial bond formation, leading to a new surface generation. Reference 3 reports that even if there is no oxide formed on the joining surfaces, a kissing bond interface can be produced if the level of shear for a complete metallic bond is not reached.

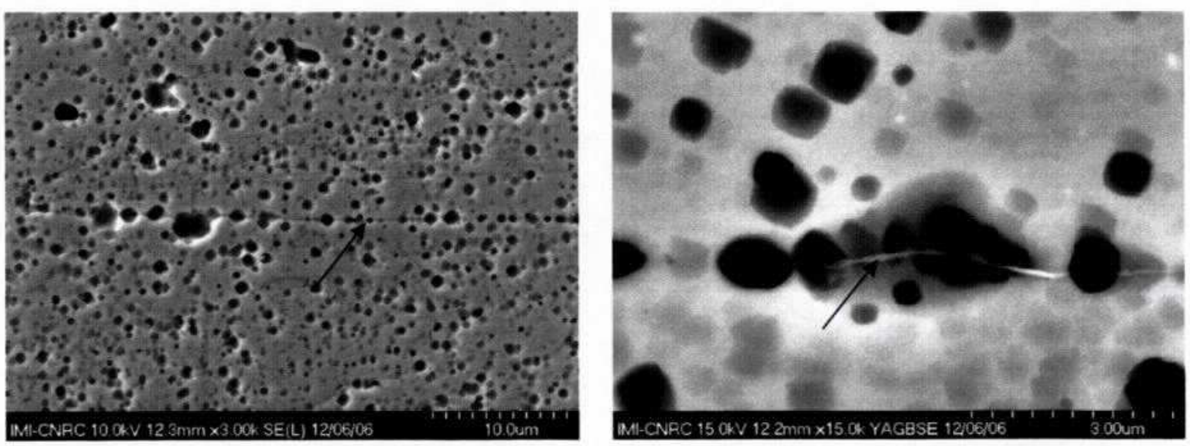

FIGURE 7. Scanning electron microscopy images of the kissing bond interface of the tested sample.

A simple model for an aluminum oxide interface in an aluminum matrix shows that the reflection coefficient is very dependent on frequency and on the interface thickness, as observed in Figure 8. But the reflection coefficient, found by comparing the backwall echo and the interface echo of Figure 3, indicates an aluminum oxide interface of about 500 nm. This is about one order of magnitude thicker than the oxide layer found by SEM microscopy (Figure 7) and supports the hypothesis that the kissing bond in this case is not solely related to an oxide interface.

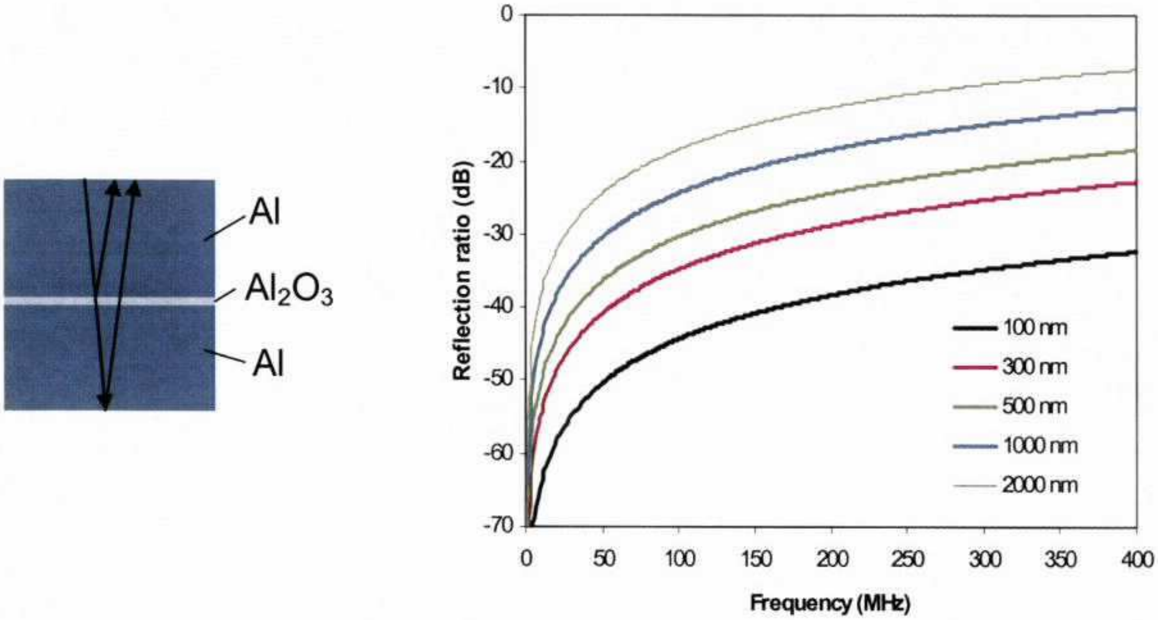

FIGURE 8. Theoretical reflection coefficient as a function of frequency for an aluminum oxide layer of different thicknesses.

CONCLUSION

The detection of a kissing bond interface in the longitudinal seam of aluminum extrusion has been done with high frequency and high sensitivity laser-ultrasonics. A simple pulse-echo configuration has been used with good results for both generation in ablation regime and thermoelastic regime.

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