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Ultrasonic imaging of molten pool configuration using sound velocity compensation

音速補正を用いた溶融池形状の超音波映像化

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1. Introduction

Welding process have a risk of defect generation, like cracks and blow holes. We have developed defect monitoring system under welding in-process condition and improved welding process efficiency.[1] It is also required to improve quality of welding by controling welding parameters such as input power, position of torch and so on. In order to put it into practice, it is necessary to clarify welding mechanism and correlation between welding parameters and quality. One of the method for elucidating the nature of welding mechanism is imaging of molten pool configuration during welding. Measurement method of the molten pool depth using phased array system with heat resisting wedge is already known.[2] It is also reported non-contact measurement system using laser ultrasonic, and molten pool configration was measured using propagation time of molten pool surface echo.[3]

In this work, we show the laser ultrasonic imaging system of molten pool configration using echo of molten pool solid-liquid interface. In order to obtain more precise image, we apply our synthetic aperture focusing technique (SAFT) [1] combined with newly developed compensation method for 2D temperature distribution in a specimen.

2. Principle

2.1 Molten pool measurement

Figure 1 shows a schematic of molten pool measurement. Generation and detection lasers are irradiated on the opposite side of melting side. Ultrasonic wave is generated by a generation laser and propagates into the base metal. This wave reflects at the interface of solid base metal and liquid molten pool due to the difference in acoustic impedance. Signal intensity from solid-liquid interface is so weak that we use SAFT and obtain molten pool images.

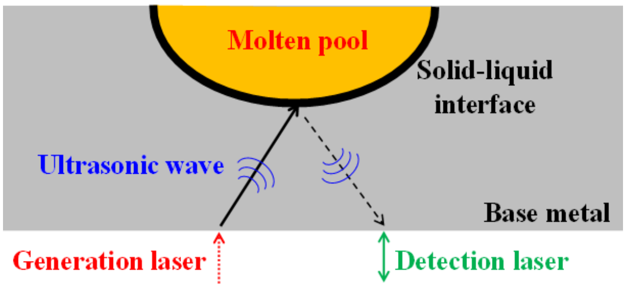

Fig. 1 Principle of molten pool measurement.

2.2 Velocity compensation

In the SAFT processing, sound velocity is important to identify the location of the solid-liquid interface. However, sound velocity of the specimen is not constant during welding since specimen has a temperature distribution from room temperature to melting point by welding heat.[4]

Figure 2 shows coordinate of imaging area. Here, color of each grid shows difference of sound velocity. Sound velocity at each grid $V_L(r_n,\theta)$ is extracted along the O'A following to r_n given by

$$r_n = r_{n-1} + \Delta r \qquad (0 < \Delta r \le r)$$

where Δr is calculation pitch. Then, propagation time $t(X,Z)$ from O' to A is obtained as below.

$$t(X,Z) = \frac{\Delta r}{V_L(r_1,\theta)} + \frac{\Delta r}{V_L(r_2,\theta)} + \cdots + \frac{r-(n-1)\Delta r}{V_L(r_n,\theta)}$$

Repeating above calculation at each propagation path, propagation time table reflected velocity distribution in a specimen is obtained.

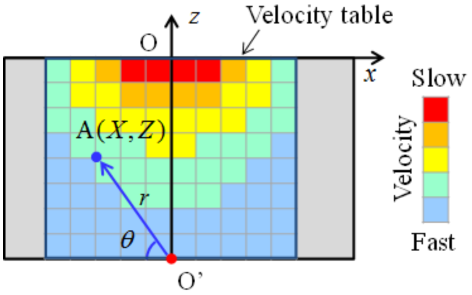

Fig. 2 Coordinate of imaging area.

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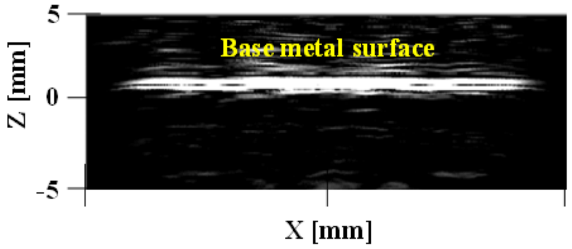
3. Experimental setup

We used Q-switched pulsed Nd:YAG laser(1064 nm) for generation, CW Nd:YAG laser (532 nm) for detection. Detection laser was scanned X= -7 mm ~ 7 mm (7 mm step, 3 points) using linear stage, and generation laser was scanned X= -20 mm ~ 20 mm (0.1 mm step, 401 points) using galvanometer scanner at each detection point.

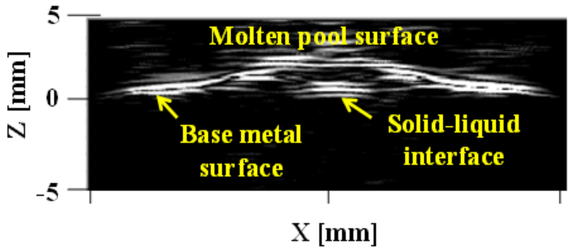
We used SUS304 for the base metal (10 mm thickness). Molten pool was formed by TIG welding, and welding torch was fixed for 3 min with welding current 100 A.

4. Experimental result

Figure 3 shows SAFT images of before and after welding. Before welding, flat base metal surface was observed (Fig. 3(a)). As welding proceeds, after 3min welding, surface near the center area changed its shape since molten pool was formed here and sound velocity became lower than that in base metal by welding heat. Moreover, another echo appeared below the molten pool surface echo (Fig. 3(b)). This echo is solid-liquid interface of molten pool. However, solid-liquid interface was imaged at almost the same depth as base metal surface. This was caused by using constant sound velocity. Effect of temperature distribution in a specimen should be taken into account to obtain correct SAFT image.



(a) Before welding



(b) 3 min welding

Fig. 3 SAFT images: (a) before welding (b) 3min welding.

We applied sound velocity compensation to the 3 min welding result as shown in **Fig. 4**. Solid-liquid interface lowered compared to no compensation result (Fig. 3(b)), and image was close to real shape confirmed by cross-section photo (**Fig. 5**).

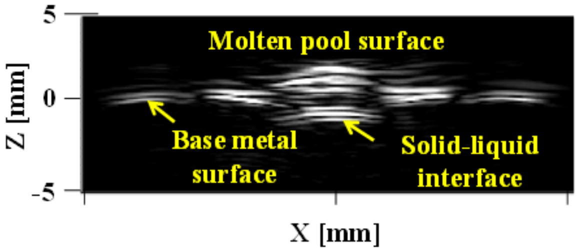


Fig. 4 SAFT image with sound velocity compensation (3 min welding).

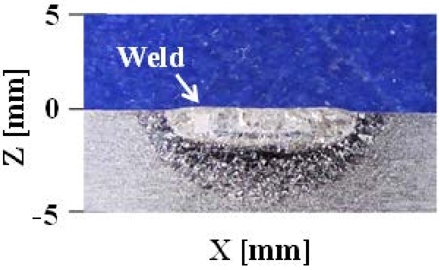


Fig. 5 Cross-section photo of after 3 min welding.

5. Conclusion

We developed molten pool imaging system, including 2D sound velocity distribution compensation SAFT. In the experimental results, capability of 2D sound velocity compensation was verified. Moreover, solid-liquid interface was clearly imaged. In the future, using this system, clarification of welding phenomenon and establishment of high quality welding process are expected.

References

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