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Laser ultrasonic characterization of additive manufacturing objects fabricated by powder bed fusion

パウダーベッド法で作成した3D積層造形物のレーザ超音波による特性評価

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1. Introduction

Additive manufacturing (AM), also referred to as a 3D printing or Rapid Prototyping etc, has a characteristics of directly fabricating three dimensional (3D) products by adding layer upon layer of resin or metal, and it is distinguished from conventional process techniques. Therefore AM is used for the production of single product for one design to use for test production or in the human body. It is also used for the production of the shape that cannot be fabricated by the conventional processing techniques. When AM objects are single products for one design, the nondestructive inspection is essential. Riederi *et al.* inspected AM objects by an ultrasonic transducer.[1)] However, in the method using the transuducers, there is a problem of the limited band width due to resonant frequency of the transducers.

We have developed an AM equipment by powder bed fusion in collaboration with Aspect, inc., and are making the products of AM objects. Depending on the process condition, layer-type defects may be generated inside an AM object. Therefore, we examined the changes in the acoustic properties of the AM objects with and without defects by laser ultrasonics.

2. Experimental Results and discussion

Figure 1 shows conceptual design of the AM equipment (Aspect inc. RaFaEl 150V). Material powder is layered by the re-coater, and the layered powder is fused by a laser beam, and the fused powder is moved down by the elevator, and this procedure is repeated. Thus, an AM object of any shape can be created.

Table 1 shows samples used in our experiment; one bulk material of Ti-6Al-4V and three AM objects. The material powder was Osaka Titanium technologies Co., Ltd. TILOP (Gas-atomized titanium powder, Ti-6Al-4V).

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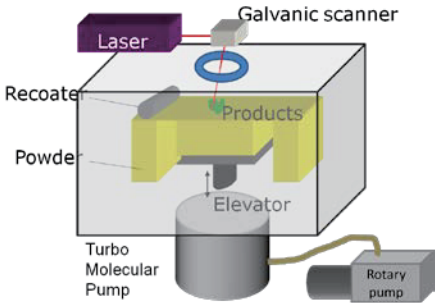

Fig. 1 Conceptual design of developed machine (Aspect, inc.).

Table I Samples and experimental results

	Bulk materials	AM objects		
Sample name	Bulk plate	AM plate	Lamellar sample	Porous sample
Thickness (mm)	3.14	2.265	7.3	7
Sound velocity (m/s)	6400	6300	3000	1300

"AM plate" with the shape of plate is the successfully fabricated sample. "Lamellar sample" is the sample containing layer-type defects. "Porous sample" has numerous pores, which had been fabricated on purpose. **Figure 2** show cross sectional images of Lamellar sample and Porous sample. Layered structure and defects between the layers are observed in Lamellar sample. The gap in Porous sample was larger than Lamellar sample.

Figure 3 shows the experimental setup. A second harmonic wave of a Nd:YAG laser was used as a laser beam to generate the ultrasonic wave. The pulse width was 4-6 ns, and the power was about 1.5-2.5 mJ. The laser beam was focused by a convex lens so that the spot diameter was less than 1mm on the sample. After the experiment, a trace of the ablation was observed on the sample. Ultrasonic wave generated by Nd:YAG laser was detected on the opposite surface by a laser Doppler interferometer.

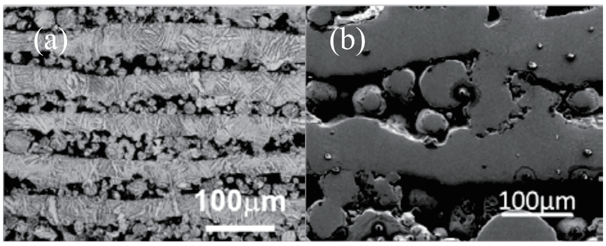

Fig. 2 Cross sectional images of samples.
(a) Lamellar sample (Optical image). (b) Porous sample (SEM image).

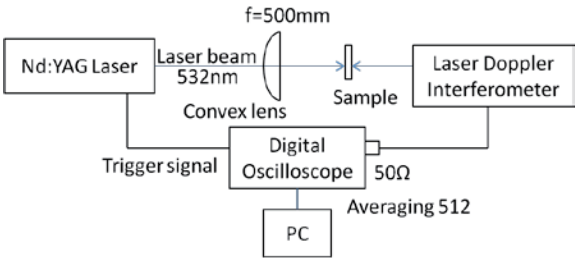

Fig.3 Experimental setup.

Figure 4 shows an experimental result of waveform in the AM plate and its wavelet transform at 12 MHz. Transmitted longitudinal wave and multiple reflection waves are observed. Sound velocities in Table 1 were calculated by the thickness of the sample and the propagation time difference between transmitted wave and a multiple reflection wave. Sound velocities of the Bulk plate and AM plate were approximately equal, and sound velocity of Lamellar sample was slower, and sound velocity of Porous sample was the slowest.

Because the sound velocities of AM plate and Bulk plate were approximately equal, it is considered that AM plate is as dense as the Bulk material. On the other hand, the sound velocities of Lamellar sample and Porous sample were slower than Bulk material. It is considered that it is because the effective elastic modulus became smaller due to the lamellar defects or pores.

Figures 5 and 6 show wavelet transforms of displacement waveforms in AM plate (Fig.4) and Lamellar sample, respectively. Longitudinal wave with frequencies higher than 5 MHz was observed in Fig.5, but it was attenuated in Fig.6.

The reason of the attenuation of the higher frequency component of ultrasonic wave in Fig. 6 is probably because it was scattered by the lamellar defects and did not reach the opposite surface.

3. Conclusions

We measured the acoustic properties of the AM objects by laser ultrasonics. It is confirmed that sound velocity and frequency characteristics were changed by the inner defects. Thus, it is considered that the evaluation of layer-type defects or porosity of AM objects will be possible by measuring the sound velocity or frequency characteristics.

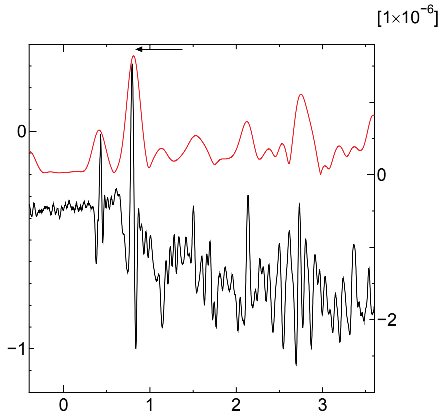

Fig.4 Displacement waveform in AM plate.

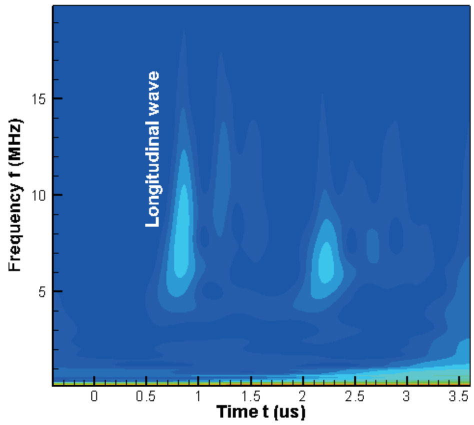

Fig. 5 Wavelet transform of displacement waveform in AM plate.

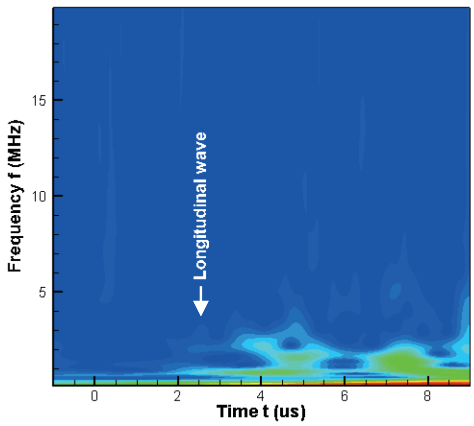

Fig. 6 Wavelet transform of displacement waveform in Lamellar sample.

Acknowledgment

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References

1. H. Riederi *et al.*: QNDE 2014 p.184.