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Imaging of laser excited surface acoustic wave for in-process evaluation of 3D additive manufacturing (AM) process

3D 積層造形のレーザー励起弾性表面波映像化によるインプロセス評価

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1. Introduction

Additive manufacturing (AM) significantly attracts attention from worldwide manufacturing industries. Especially recent progress of the metal-based AM technologies exemplified by powder bed fusion (PBF) method promotes that the usages of the AM shift from fabrication of prototypes to manufacturing of industrial products. This trend simultaneously draws manufacturer's attention to the reliability of AM products. To ensure the strength and lifetime performance of AM products is therefore one of the most crucial issues.

Our previous study showed that the velocity of the longitudinal wave decreased on the defective specimen fabricated by PBF method. [1] However, longitudinal wave is not sensitive to layer defects near the surface, frequently observed in AM products. Moreover, imaging is crucial for evaluating where and how large the defects are. In these respects, surface acoustic wave (SAW) is more advantageous than longitudinal waves.

Thus, we develop a method for evaluating AM products using imaging of laser excited SAW. The performance of the method is discussed as the in-process monitoring for AM.

2. Concept of in-process evaluation system

The final goal of this study is to develop in-process monitoring technology using laser ultrasonic methods for the PBF equipment. **Figure 1** shows our concept. PBF method uses galvanometer scanners for scanning a processing laser beam. This composition is well compatible with the laser ultrasonic method because the acoustic- excitation laser can be applied with the shared optical path.

The laser beam is 2-dimensionally scanned to excite SAW, the surface vibration is detected by the laser interferometer, and the 2-dimensional field of surface vibration is obtained.

The acoustic field propagating from the detection point as the point sound source is imaged by mapping the instantaneous signal of the 2-dimensional field, based on the reciprocity $\mathbf{u}(\mathbf{r}_E; \mathbf{r}_D, t) = \mathbf{u}(\mathbf{r}_D; \mathbf{r}_E, t)$ of sound wave excitation and detection, where $\mathbf{u}(\mathbf{r}_E; \mathbf{r}_D, t)$ is displacement waveform excited at $\mathbf{r}_E$ and detected at $\mathbf{r}_D$ [2)]

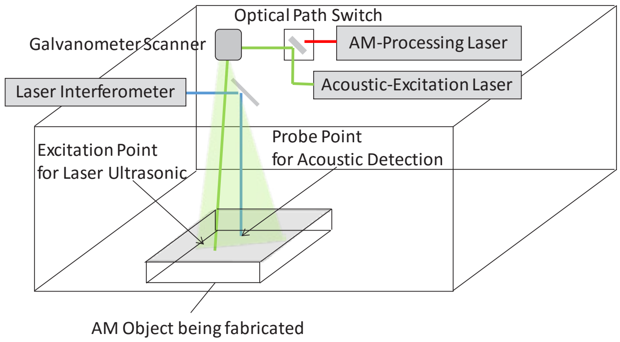

Fig.1 Concept of in-process evaluation system combined into PBF equipment.

3. Experimental setup

Figure 2 shows the experimental setup to verify the concept. The second harmonic wave of a Nd:YAG pulse laser (λ:532nm) was used to generate acoustic waves. The pulse width was 4-6 ns, and the energy of one pulse was about 1 mJ. The laser beam was focused by a convex lens so that the spot diameter was less than 1mm on the sample. The laser beam was 2-dimensionally scanned by the mirror driven by 2 mechanical 2-axies rotary stage. The acoustic wave was detected by a laser Doppler interferometer at a fixed position on the sample.

Two samples fabricated with different PBF-process conditions were prepared, hereafter called sample A and sample B. The scanned area on the samples was 2.3×1.9 mm^2, and the number

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of excitation points was 11×11.

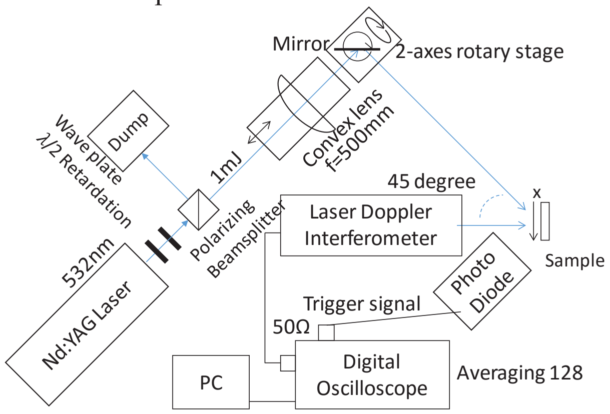

Fig. 2 Evaluation system setup for AM samples using laser ultrasonic method.

4. Experimental Results and discussions

Figure 3 shows sample of detected waveforms of imaging area on samples A and B. It was found that SAW on sample B had lower velocity and lower frequency than that on sample A. Then, complex discrete wavelet transform and the inversed transform were applied to the waveform of each point, and the monochromatic waves of 4MHz and 8MHz were extracted.

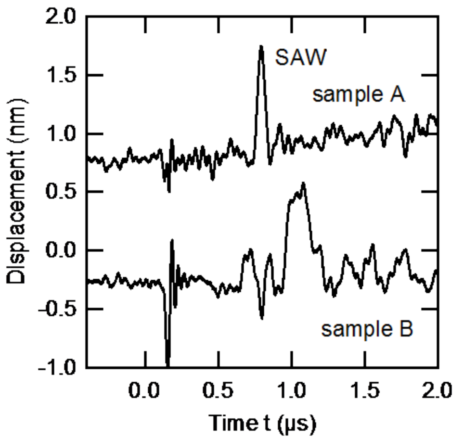

Fig. 3 Samples of waveforms detected at the center of images in Fig. 4.

In **Fig. 4.**, the waves were imaged at time $t = 0.8\,\mu s$ as a sound field generated from the detection point near the top left corner, showing the arc-shape wave fronts. Clear differences were found in the wave fronts on the sample A (Figs. 4(a) and 4(c)) and sample B (Figs. 4(b) and 4(d)). The wave front on sample A was relatively smooth and show continuous curves as compared with those on sample B. These characteristics were more noticeable at 8MHz than at 4MHz. This result shows that the sample B has more scattering sites than the sample A, suggesting that the sample B is more defective than sample A.

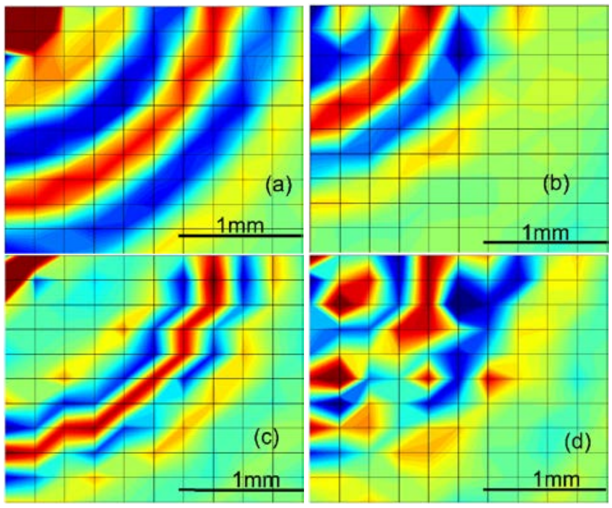

Fig. 4 Images of displacement at 0.8 μs: (a) Sample A at 4 MHz, (b) sample B at 4 MHz, (c) sample A at 8 MHz, and (d) sample B at 8 MHz.

To examine the relation between internal structure and the propagation of SAW, cross sectional images of samples A and B were observed (**Fig. 5**). Sample A was dense and homogeneous, in contrast sample B contained the delaminations and powders remaining with insufficient melting. This defective structure of sample B well explains the disturbances of wave propagations in Fig. 4(d).

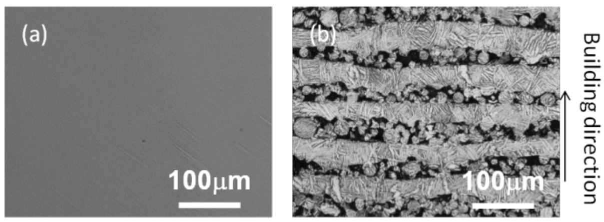

Fig. 5 Cross sectional images of samples A and B.

5. Conclusions

The imaging of SAW field of AM samples using laser ultrasonic method was conducted for developing in-process monitoring techniques for PBF equipment. The imaging and wavelet transform analysis revealed that the disturbance and lower velocity of the SAW propagation were caused by the delaminations in AM samples.

Acknowledgment

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References

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