3P2-1

Laser ultrasonic technique to detect cracks on directed energy deposition (DED) process

レーザー超音波法による指向性エネルギー堆積加工でのクラック検出

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1. Introduction

The required specifications of mechanical parts for engines, transmissions, robot joint drive shafts, machine tool spindles, positioning stages, etc. are becoming more accurate year by year, and the delivery time is getting shorter. Many high-precision parts in those products are manufactured by grinding, and the finished precision of those parts is determined by the performance of the jig used at this time, so it is required to make the jig fast and accurately. Therefore, we are developing a technique to form a hard layer on the jig by directed energy deposition (DED) process. DED is one of additive manufacturing (AM) methods (3D printing). The hard layers made by DED might contain defects. The laser ultrasonic technique (LU) can apply to inspect samples with curved surface, so it is considered that LU is useful for the inspection. In this study, the authors made an AM object by DED, and detected defects in it by LU.

2. Experimental sample and setup

Equipment of DED was ALPION (MURATANI MACHINE MANUFACTURE Co., Ltd.), and the powder was Ni-based self-fluxing alloy powder (Höganäs 1660-22). The substrate was SUS304 whose thickness was 2 mm. The wavelength of direct diode laser for process was 975 nm, its power was 120 W in a continuous wave, the feed speed was 20 mm/s, the supply amount of the powder was about 20 mg/s, the spot diameter of the laser beam was 0.3 mm, and the thickness of the layer was 0.1mm. The cross section of the AM object was a rectangle of $0.4 \times 0.6 mm^2$.

Fig. 1 shows the experimental setup. To generate ultrasonic, a solid state laser was used. The wave length was 523 nm, the pulse width was 5 ns, and the focused spot diameter was about 0.1 mm. The frequency of excitation was 4 kHz, and the energy was 8 μJ. The laser beam was scanned by a Galvano scanner. The scanning distance was about 1.5 mm. To detect the ultrasonic, a laser Doppler interferometer was used. The laser beam (probe) of the interferometer was fixed at one point on the sample.[1] The output of 65536 readings of the interferometer was averaged with a digital oscilloscope and then output to a PC. The laser beam irradiation positions were 51 in this experiment, and the experimental time was about 34 minutes.

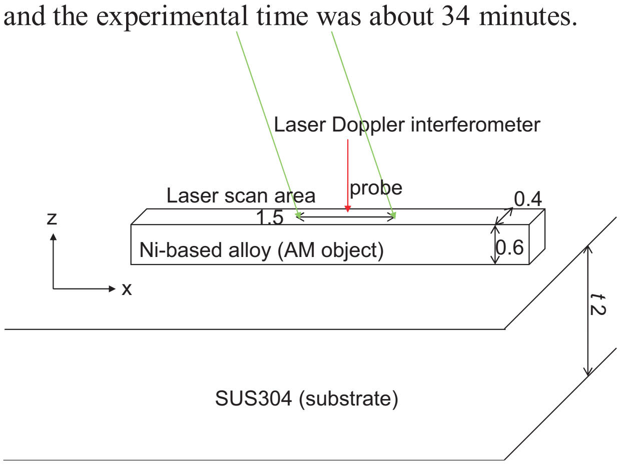

Fig. 1 Experimental setup

3. Experimental results

Fig.2 shows displacements at 7 positions at which the laser beam irradiated. The origin (0 μs) of the time was determined same as the peak time of the laser pulse. The origin (0 mm) of the x-position (laser beam irradiation position) was determined same as the position considered the probe. The displacements at $x = 0.002$ mm and $t \sim 0.23$ μs seems to be affected by the overlap between the probe and the laser beam. The complex multiresolution analysis using RI-Spline[2] of the displacements was done, and it appeared that the effect of the overlap existed under 10 MHz in the frequency domain. It is considered that the peaks at $x = -0.422$ mm and $t \sim 1.5$ μs and $x = -0.635$ mm and $t \sim 2.2$ μs were an acoustic wave. The propagation velocity was about 300 m/s, so it seems that they were the acoustic wave which propagated in the air. The frequency range of the acoustic wave which propagated in the air was

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0.32 − 2.6 MHz by the complex multiresolution analysis using RI-Spline of the displacements at $x = -0.422$ mm. The main frequency range of the acoustic waves which propagated in the sample was 5.1 − 20 MHz by the same analysis. **Fig. 3** shows the wavelet transformation of displacements at $x = -0.422$ mm. The mother wavelet was Gabor function. It appears that the acoustic wave near 0.3 µs had frequency component from 8 to 20 MHz, and its propagation velocity did not depend on the frequency. Since it is considered that the sample was made of the Ni-alloy, it can be considered that the sound velocity of longitudinal wave is about 6000 m/s and the wavelength at 10 MHz is about 0.6 mm. If this estimation is true, the acoustic wave was to propagated as the guided wave. However, this experiment did in the near field condition, so it is thought that dispersions were not clear. Here, the upper limit of the frequency of the interferometer is 20 MHz, so we can say that our experimental setup of LU was enough for the interferometer.

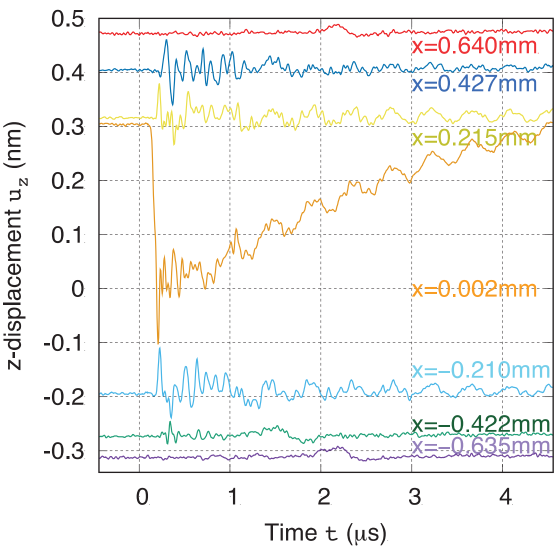

Fig. 2 Displacements

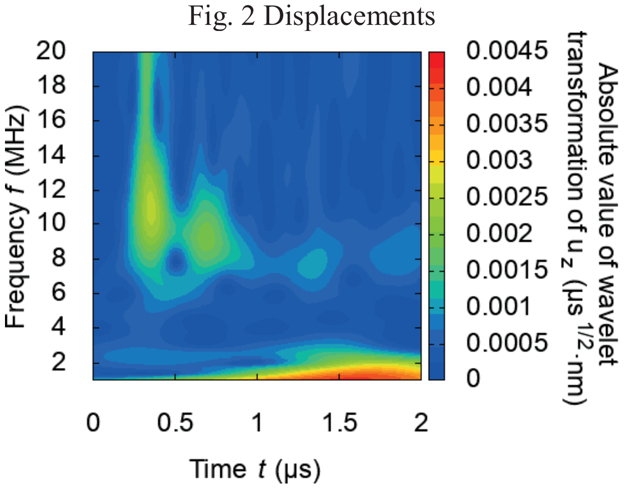

Fig. 3 Wavelet transformation of displacements at $x = -0.422$ mm

To erase acoustic wave which propagated in the air and the effect of the overlap between the probe and the laser beam and to show only acoustic waves which propagated in the sample, **Fig. 4** shows displacements whose frequency-range is from 10 to 20 MHz. These data were obtained by the complex multiresolution analysis using RI-Spline. It appears that acoustic waves propagated to both $+x$ and $-x$ directions. They were reflected at $x = -0.44$ mm and $x = 0.59$ mm, and this distance is 1.03 mm.

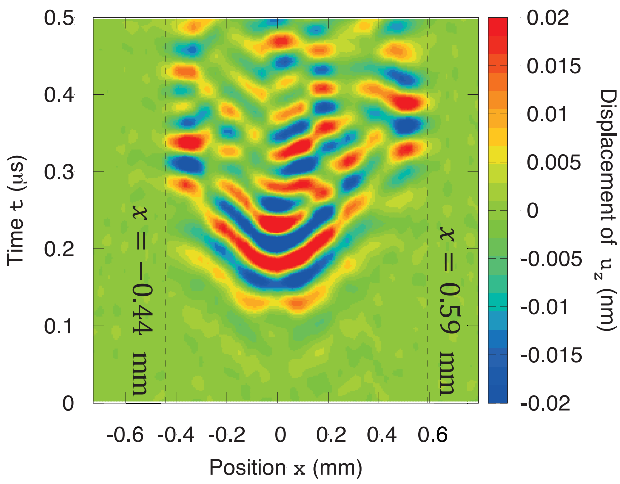

Fig. 4 Image of displacements for laser position

Fig. 5 shows the optical image of the sample. It seems that the surface of the AM object is very rough, so cracks are difficult to find. However, there are two cracks caused by the residual stress. The distance between cracks is about 1.06 mm. This value is similar to the estimated value (1.03 mm). Therefore, we can conclude that cracks in AM sample were detected by LU. **Fig. 5** is the optical image taken after the experiment, and there are no ablation marks. Then we can also say that the thermo-elastic mode was used.

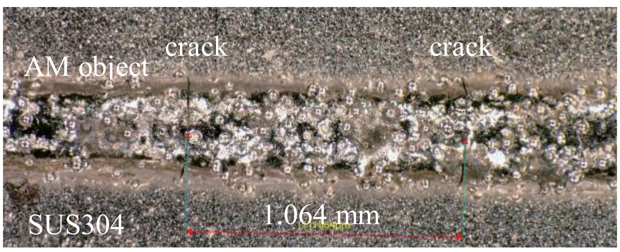

Fig. 5 Optical image of sample

Acknowledgment

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References

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