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Nondestructive inspection based on laser ultrasonics for the cracks inside the WC-based hard alloy formed by additive manufacturing (AM)

積層造形(AM)で形成した WC 超硬合金内部のき裂のレーザー超音波法による非破壊検査

Harumichi Sato[1†], Hisato Ogiso[1], Yorihiro Yamashita[2], and Yoshinori Funada[2] ([1]AIST; [2]IRII)

佐藤治道 [1†]，小木曽久人 [1]，山下順広 [2]，舟田義則 [2] ([1] 産総研, [2] 石川県工業試験場)

1. Introduction

Bearing rollers indispensable for automobiles and robots are smaller in diameter now, and in order to make them precision jigs required for polishing such rollers must be thinner. However, the conventional brazing method to deposit a sintered cemented carbide to a jig surface to prevent abrasion has a high failure rate due to cracking or peeling of this surface caused by thermal strain. Therefore, a 3D printing method (additive manufacturing, AM) called direct energy deposition (DED) is being developed to deposit cemented carbide directly on a thin jig substrate without defects. Last year the authors reported that a Ni-based self-fluxing alloy powder was deposited by DED, deposited layers whose cross section was 0.4×0.6 mm^2, and cracks were successfully detected by Laser ultrasonics (LU).[1] In this paper, the authors reported the cemented carbide (WC-based hard alloy) deposited layer, which is thinner than the wavelength, was fabricated and the defects were detected by LU.

2. Experiment

Experimental sample (specimen) was fabricated by DED. WC-12wt.%Co (WC-Co) powder was deposited on a 1-mm-thick steel substrate (JIS:S45C) via DED ALPION (MURATANI MACHINE MANUFACTURE Co., Ltd.). In DED, the wavelength of the direct diode laser was 975 nm, its power was 120 W in a continuous wave, its feed speed was 10 mm/s, feed rate of the powder was about 20 mg/s, and the thickness of deposited layer was 0.06 mm. Its cross-sectional area was 0.2×0.06 mm^2.

To generate an acoustic wave, a solid-state laser was used whose wavelength was 523 nm and pulse width was 5 ns. The laser beam was focused to a spot diameter of about 0.1 mm. The frequency of excitation was 4 kHz, and the energy was 8 μJ. To detect the acoustic waves, a laser Doppler vibrometer was used (Polytec GmbH OFV-3001 with OFV-303 and OVD-030). The laser beam of the vibrometer (probe) was fixed at one point on the specimen, and laser beam to generate acoustic wave (laser beam) scanned on the specimen surface by using a Galvanometer scanner (**Fig. 1**). The scanning step was about 34 μm. The output of 65536 readings of the vibrometer was averaged using a digital oscilloscope and then output to a PC.

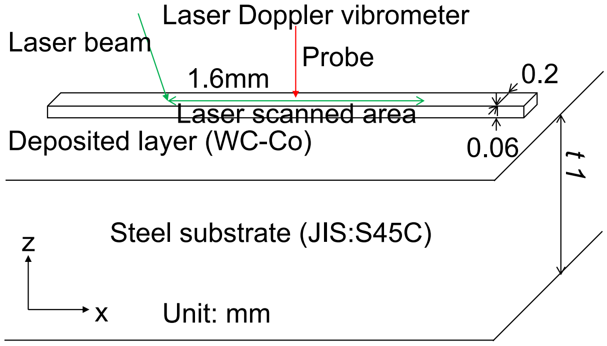

Fig. 1 Experimental setup

2. Experimental results and discussion

Fig. 2 shows displacements (u_z) at 7 positions at which the laser beam irradiated the specimen surface. At $x = 0$ mm acoustic waves were present at $t \cong 0.25$ μs (V_1) and $t \cong 0.45$ μs (V_2). The frequency of V_1 is higher than the frequency of V_2. As the absolute value of x increased, the time at which V_1 and V_2 were observed became later and later, it is confirmed that V_1 and V_2 were acoustic waves generated by laser beam. Since the propagation velocity of V_2 is close to the sound velocity of the air, V_2 is considered to be acoustic wave which propagates in the air, and V_1 is considered to be acoustic wave which propagates in the specimen. **Fig. 3** shows displacements whose frequency range was 10 to 20 MHz obtained by complex discrete wavelet transform using $m = 4, 3$ RI-Spline[2]. Displacements are indicated by color, with the horizontal axis representing the position where the laser beam irradiated and the vertical axis

h.sato@aist.go.jp

representing time. Due to reciprocity, the acoustic wave (V_1) appears to propagate form the probe ($x \cong -0.05$ mm) to the laser beam irradiated position ($x < -0.05$ mm and $x > -0.05$ mm).[3] It was observed that the acoustic wave generated at $x \cong -0.05$ mm was reflected at $x \cong -0.35$ mm, and was reflected and transmitted at $x \cong 0.5$ mm.

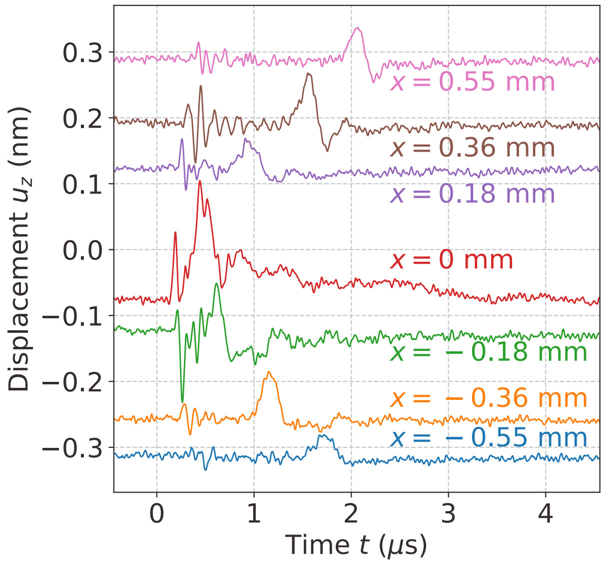

Fig. 2 Displacement on deposited layer

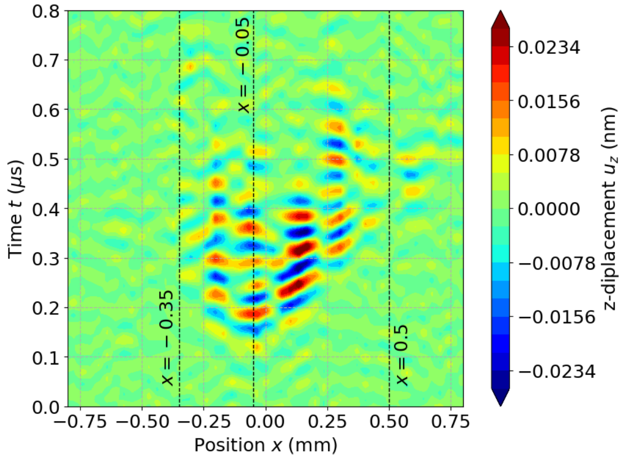

Fig. 3 Image of z-displacement

Fig. 4 shows an optical image of specimen after the experiment. Since there are no ablation marks, it considered that acoustic waves were generated by thermoelastic stress. In addition, a crack existed at $x \cong -0.35$ mm. Since the cross-sectional area of the cemented carbide deposited layer is estimated to be about 0.01 mm^2, it can be said that the crack with a maximum cross-sectional area of 0.01 mm^2 was successfully detected. If we consider the sound velocity of the surface wave of WC-Co to be about 3500 m/s, the wavelength at 10 MHz is about 0.35 mm. The thickness of the cemented carbide deposited layer is 0.06 mm, which means that we detected defects at about 17% of the wavelength. On the other hand, no cracks were found around $x = 0.5$ mm, suggesting the existence of sub-surface defects.

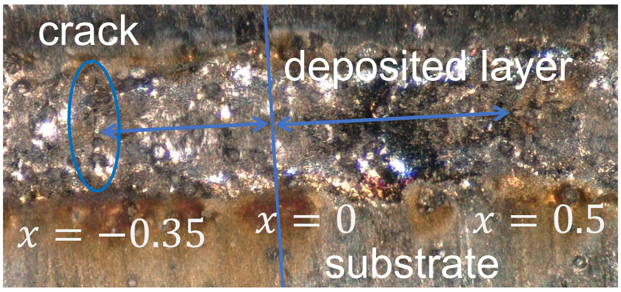

Fig. 4 Image of specimen

3. Conclusions

The cemented carbide deposited layer was fabricated by DED, and the laser ultrasonics were used for non-contact and non-destructive inspection. As the result, we successfully detected cracks whose depths were shallower than the wavelength. The results should lead to the inspection of the precision jigs.

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References

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