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Ultrasonic metal welding by complex vibration source using planar vibration locus
面状振動軌跡を用いた複合振動源による超音波金属接合

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1. Introduction

Electric vehicles use large - capacity lithium ion batteries that contain an aluminum positive electrode and copper negative electrode. To increase the battery capacity, the positive and negative electrodes are connected alternately in series, which requires a technique for welding dissimilar metals. Ultrasonic welding does not use heat, making it suitable for welding metals with different melting points. The method uses a vibration locus capable of applying two-dimensional stress[1]. We have proposed ultrasonic welding with a planar vibration locus composed of longitudinal-torsional vibration to which two-dimensional stress can be applied[2]. In this work, we investigated ultrasonic metal welding of aluminum and copper plates using a complex vibration source capable of individually controlling longitudinal and torsional vibration.

2. Complex vibration source

Figure 1 shows the complex vibration source, which consists of a 27 kHz bolt-clamped Langevin-type longitudinal vibration transducer (D4427PC, NGK Spark Plugs) and a 19 kHz bolt-clamped Langevin-type torsional vibration transducer (DAN4419, NGK Spark Plugs) connected to either end of a cylindrical dumbbell-shaped stepped horn (A2017) with a diameter ratio of 1.5. At the center of the horn, a knurled welding tip for applying the vibration is attached to the object to be welded. By varying the magnitude of the input signal to each transducer, the complex vibration source can control each vibration displacement amplitude at the welding tip portion. In addition, the wavelength of each vibration was matched by using a longitudinal vibration transducer and a torsional vibration transducer having different resonance frequencies. The complex vibration source can add longitudinal vibration and torsional vibration to the welding target at the maximum position of the displacement amplitude by matching the wavelengths of the vibrations. **Figure 2** shows the welding tip. The tip of the welding tip is knurled so as to make it easier to apply vibration to the welding target.

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3. Vibration characteristics

To clarify the resonance characteristics of the complex vibration source, the admittances were measured (**Fig. 3**). The drive voltage was set to 20 V_{rms} for each transducer, and the drive frequency was

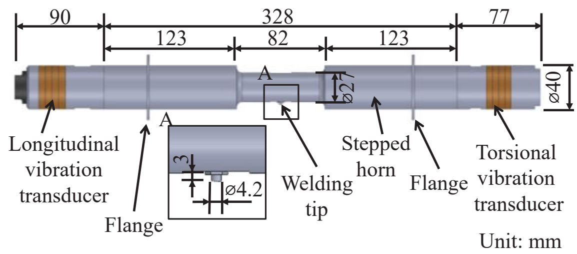

Fig. 1　Ultrasonic complex vibration source.

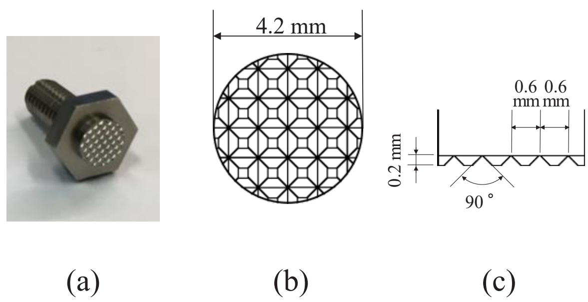

Fig. 2　Welding tip.

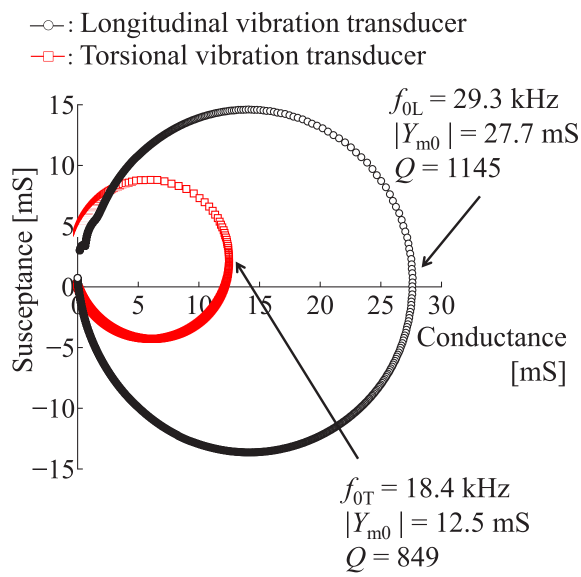

Fig. 3　Free admittance loops.

set to 29–30 kHz for the longitudinal vibration transducer, and to 18–19 kHz for the torsional vibration transducer. The resonance frequency of the longitudinal vibration was 29.3 kHz and that of the torsional vibration was 18.4 kHz. For the longitudinal and torsional vibration sources, the conductances were 12.9 and 18.7 mS and The Q values were 1145 and 849, respectively.

To investigate the vibration locus obtained from the complex vibration source, the vibration locus at the welding tip was measured with two laser Doppler vibrometers at the resonance frequency obtained in Fig. 3. The driving voltage was 31 V_{rms} for the longitudinal vibration transducer and 8 V_{rms} for the torsional vibration transducer. **Figure 4** shows the result. Straight linear vibration loci were produced by the longitudinal and torsional vibration transducers alone. A nearly square planar vibration locus was obtained by driving both transducers individually to combine linear loci.

4. Ultrasonic metal welding of aluminum and copper plates

We investigated the weld strength of an aluminum plate (A1050, length 40 mm, width 20 mm, thickness 0.5 mm) and a copper plate (C1100, length 40 mm, width 20 mm, thickness 2.0 mm) at each vibration locus. Welding was performed at weld times of 0.2–3 s, at a pressure of 500 N, a vibration displacement amplitude of 10.0 $\mu m_{p\text{-}p}$, and using the vibration loci shown in Fig. 4. Welding was performed 10 times under each set of conditions. After welding, the weld strength was measured by a tensile shear test with a tensile compression tester (SDT-503NB, Imada Seisakujyo) compliant with Japanese Industrial Standard Z 3136.

Figure 5 shows the average weld strength as a function of weld time. The error bars in the figure indicates the deviation (± 1σ). The torsional vibration locus did not weld the samples for weld times of 0.2 and 0.4 s. Only 3 of the 10 welds were successful for a weld time of 0.6 s, while 8 of 10 welds were successful for a weld time of 0.8 s. Therefore, in these cases, the average value and deviation were calculated using the only welded samples. The weld strength was in the order planar vibration locus > longitudinal vibration locus > torsional vibration locus for all weld times. Welding using the planar vibration locus reached the maximum weld strength for weld times of 0.6 s or longer, and reached a high strength in shorter times than the longitudinal and torsional vibration loci. At weld times of 0.2 and 0.4 s, the weld strength could be improved by making it a planar vibration locus combined with the longitudinal vibration locus, even though welding was not achieved using the torsional vibration locus alone.

5. Conclusions

In this work, we investigated ultrasonic metal welding of aluminum and copper plates with a complex vibration source. The weld strength produced by the planar vibration locus was higher than that produced by each linear vibration locus, allowing a strong weld to be performed in a shorter time.

Acknowledgment

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References

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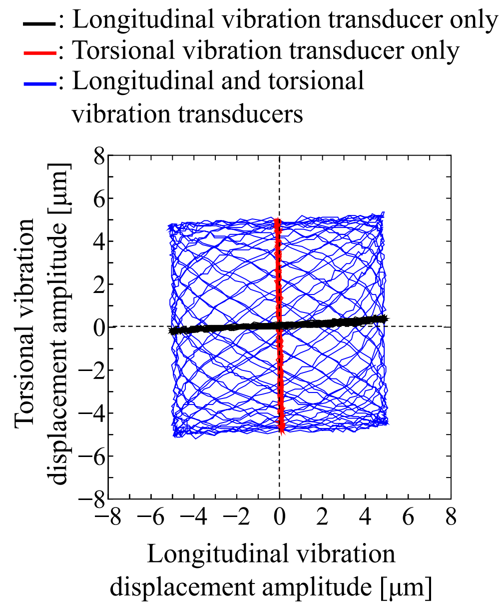

Fig. 4 Vibration loci.

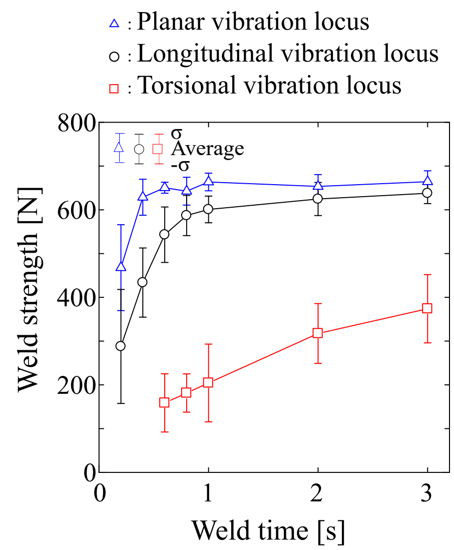

Fig. 5 Weld strength as a function of time.