WELDING CHARACTERISTICS OF COATED COPPER WIRE SPECIMENS USING 40 KHZ, 60 KHZ AND 100 KHZ ULTRASONIC COMPLEX VIBRATION WELDING EQUIPMENTS

Jiromaru Tsujino, Shigeru Ihara, Yoshiki Harada, Kohei Kasahara and Yoshihide Sakamaki
Faculty of Engineering, Kanagawa University, Japan
tsujino@cc.kanagawa-u.ac.jp

Abstract

Welding characteristic of thin coated copper wires were studied using 40 kHz, 60 kHz, 100 kHz ultrasonic complex vibration welding equipments with elliptical to circular vibration locus. The complex vibration systems consisted of a longitudinal-torsional vibration converter and a driving longitudinal vibration system. Polyurethane coated copper wires of 0.036 mm outer diameter and copper plates of 0.3 mm thickness and the other wires were used as welding specimens. The copper wire part is completely welded on the copper substrate and the insulated coating material is driven from welded area to outsides of the wire specimens by high frequency complex vibration.

Introduction

High-frequency ultrasonic complex vibrations are effective for various high power ultrasonic applications including direct welding in microelectronics [1]-[5]. Insulated thin wires with various plastic coatings are used for various applications in electronics and furthermore microelectronics. If ultrasonic welding of the insulated wires becomes possible, as an example, direct joining without solder, of course lead free, antenna wires installed in various wireless IC cards may be applicable. Coated wires are impossible to weld using a conventional welding equipment with linear vibration locus. Welding characteristic of thin coated copper wires were studied using the 40 kHz, 60 kHz, 100 kHz and higher frequency ultrasonic complex vibration welding equipments with elliptical to circular vibration locus. Polyurethane coated copper wires of 0.036 mm outer diameter and copper plates of 0.3 mm thickness were used as welding specimens. Required vibration amplitudes of 40 kHz, 60 kHz and 100 kHz welding equipments are more than 4 μm, 2 μm and 1 μm (peak-to-zero value). The welded specimens were inspected using a tensile strength tester, a digital height gage, SEM and a laser microscope. It is revealed that the copper wire part is completely welded on the copper substrate and the insulated coating material is driven from welded area to outsides of the wire specimens by high frequency complex vibration. Weld strengths obtained were almost the copper wire strength. Deformation of the welded part is smaller as vibration frequency becomes higher.

Configurations of 40 kHz, 60 kHz and 100 kHz Complex Vibration System and Welding Specimen

Figure 1, 2 and 3 shows the 40 kHz, 60 kHz and 100 kHz vibration system using a complex vibration converter with diagonal slits installed in a welding frame. The 40 kHz, 60 kHz and 100 kHz vibration systems have similar configurations. These complex vibration systems consist of a longitudinal-torsional vibration converter with diagonal slits which has welding tips at the free edge, a stepped horn for amplifying vibration velocity (transform ratio N = 4) with a supporting flange, a bolt-clamped Langevin type PZT longitudinal vibration transducer (BLT) (diameter: 30 mm) for driving the complex vibration converter and a ring-type magnetic vibration

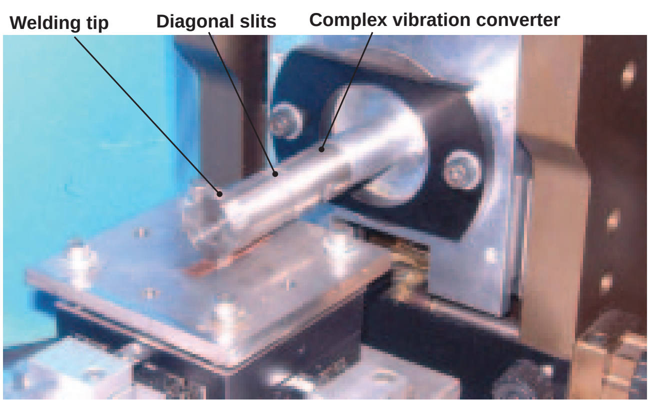

Figure 1: Configuration of a 40 kHz ultrasonic welding system using a longitudinal-torsional vibration converter.

velocity detector. Four welding tips are installed in a free edge of the complex vibration converter. Welding tip vibrates in elliptical to circular locus in the case where longitudinal and torsional resonance frequencies of the converter are adjacent and the vibration difference of these vibrations is near to 90º [2]-[5].

Figure 4 shows a cross section of a 0.036-mm-outer-diameter polyurethane coated copper wire. Copper wire is 0.030 mm in diameter. Thickness of the coated polyurethane layer varies from 0.02 mm to 0.04 mm according to the wire position. Tensile strength of the wire specimen is about 0.4 N.

Vibration characteristics of the complex vibration systems

Free admittance loops of the 40 kHz and 100 kHz complex vibration systems are shown in Fig.5. Quality factor of the 40 kHz complex vibration system is 1144 at loaded condition. Quality factor and motional admittance |Ymo| of the 40 kHz are 1144 and 15.4 mS. Quality factor and |Ymo| of the 100 kHz complex vibration system at loaded condition and also with power factor compensation inductance is so large as 364 and 16.3 mS. These large values ensure good operations of the vibration systems.

Figure 6 shows a radial vibration distribution along the 100 kHz vibration systems. It is shown that the PZT rings and the supporting flange locate in longitudinal vibration nodal positions.

Torsional vibration velocity and phase difference distributions along the 100kHz complex vibration converter are shown in Fig.7. Vibration nodal position exists within

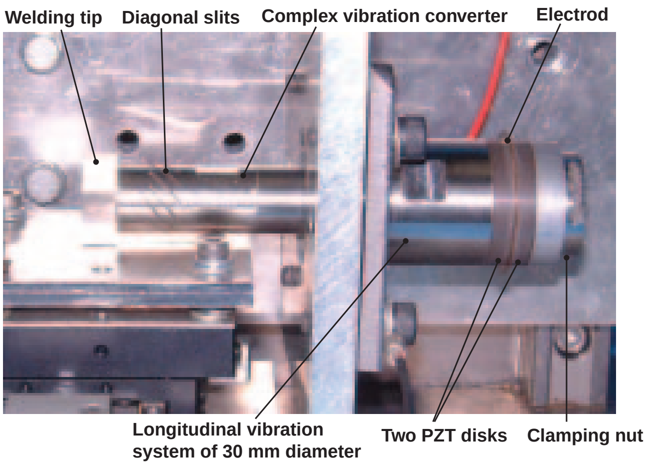

Figure 2: Configuration of a 60 kHz ultrasonic welding system using a longitudinal-torsional vibration converter.

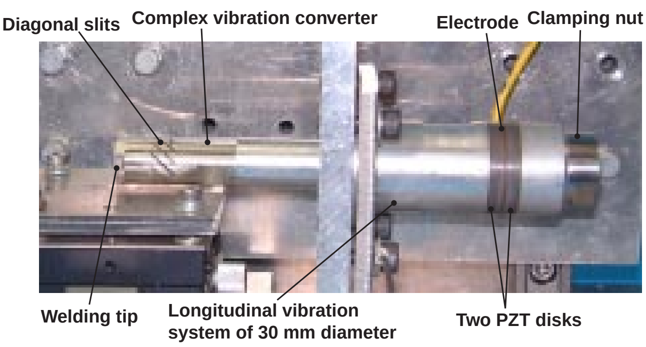

Figure 3: Configuration of a 60 kHz ultrasonic welding system using a longitudinal-torsional vibration converter.

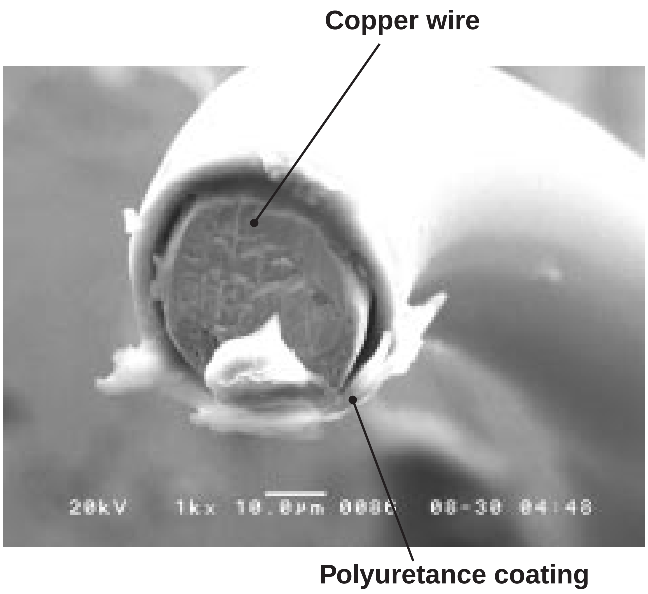

Figure 4. Cross section of 0.036-mm-diameter polyurethane coated copper wire specimen.

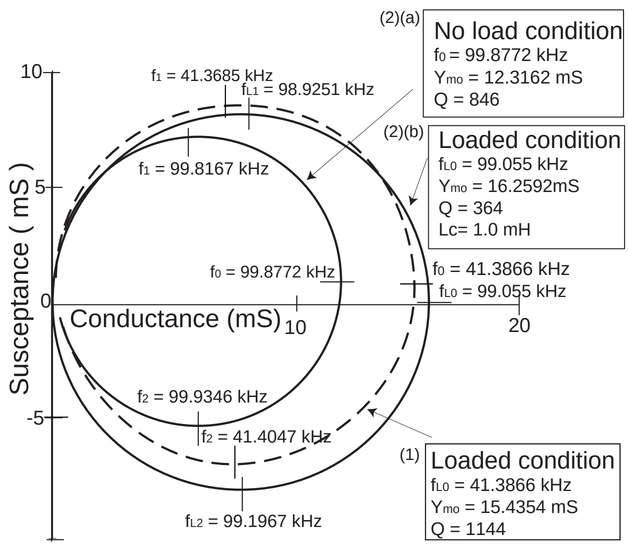

Figure 5: Free admittance loops of (1) a 40 kHz complex vibration system at loaded condition, (2) a 100 kHz complex vibration welding system at (a) no load condition and (b) loaded condition with a power factor compensating inductance.

Vibration nodal position exists within the slitted part and vibration velocity at the welding tip part has maximum value.

Vibration loci of the 40 kHz and 60 kHz welding tips are shown in Fig.6. The loci are elliptical but sufficiently effective for ultrasonic welding.

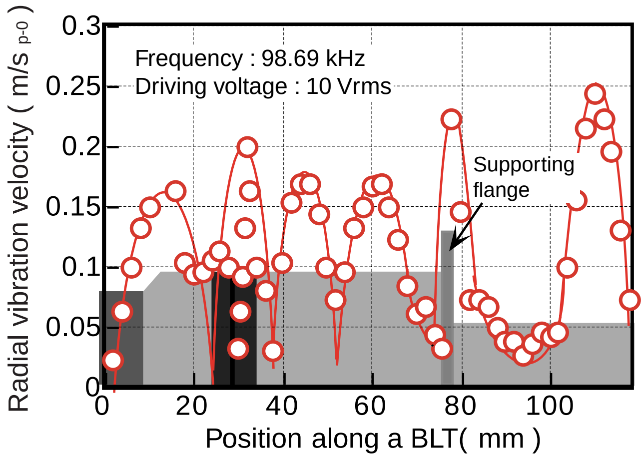

Figure 6: Radial vibration velocity distribution along a 100 kHz longitudinal vibration system of 30 mm diameter with a stepped horn. Driving voltage: 10 Vrms.

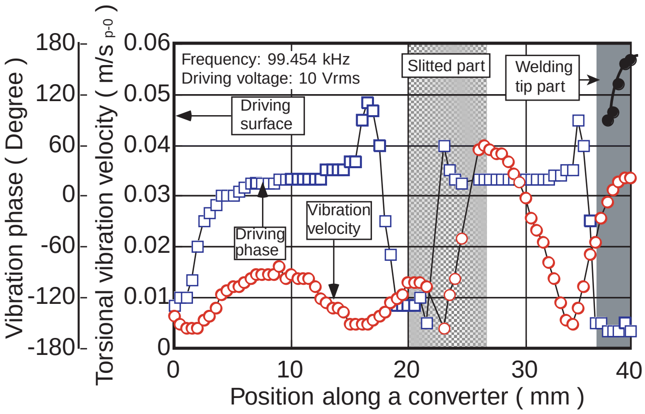

Figure 7: Torsional vibration velocity and vibration phase distributions along a 100 kHz complex vibration converter with a slitted part of 2.0 mm depth. Driving voltage: 10 Vrms.

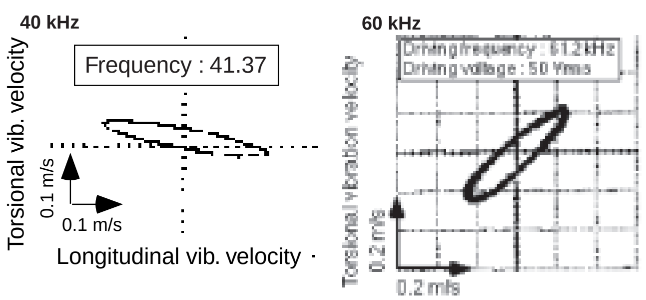

Figure 8: Vibration loci of 40 kHz and 60 kHz complex vibration welding tips at the free edge of the converter. Driving voltage: 50 Vrms.

Welding characteristics of the coated wire specimen

The relationships between vibration amplitudes of welding tips and weld strength of 0.036-mm-diameter polyurethane coated copper wire specimens welded using the 40 kHz, 60 kHz and 100 kHz complex vibration systems are shown in Fig.9. Required vibration amplitude for obtaining weld strength near to the wire strength is more than 4 mm using the 40 kHz complex vibration system. Required vibration amplitudes of the 60 kHz and 100 kHz welding equipments are more than 2 mm and 1 mm. As the vibration frequency of the welding systems becomes higher, the required vibration amplitude decreases [1]. High frequency complex vibration system is effective for welding of various materials.

Welded conditions of the coated wire specimens

Figure 10 shows scanning electron microscope photographs of the conditions of the 0.036-mm-diameter polyurethane coated copper wire specimens welded using the 40 kHz, 60 kHz and 100 kHz complex vibration welding systems. The copper wire part is completely welded on the copper substrate and the insulated coating material was driven from welded area to outsides of the wire specimens by high frequency complex vibration. Figures 11 and 12 show the welded conditions of 0.2-mm-thick, 1.0-mm-wide polyester coated flat copper wire and 0.5-mm-thick, 1.5-mm-wide polyester-polyimide coated flat copper wire to nickel plated phosphor bronze terminals.

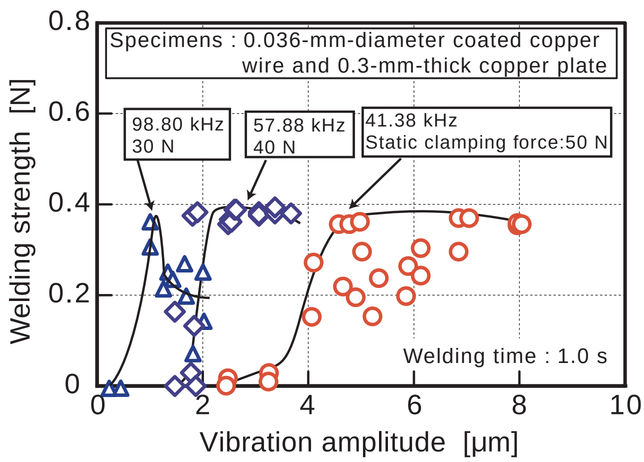

Figure 9: Relationships between vibration amplitude and weld strength of 0.036-mm-diameter coated copper wire specimens using the 40 kHz, 60 kHz and 100 kHz ultrasonic complex vibration welding equipments.

Conclusions

Welding characteristic of resin coated insulated copper wires were studied using 40 kHz, 60 kHz, 100 kHz high frequency ultrasonic complex vibration welding equipments with elliptical to circular vibration locus.

Polyurethane and polyester-polyimide coated copper wires and copper plates and nickel-plated phosphor bronze terminals were welded directly using the 40 kHz, 60 kHz and 100 kHz complex vibration welding systems at room temperature.

Required vibration amplitudes of the 40 kHz, 60 kHz and 100 kHz welding equipments were more than 4 μm, 2 μm and 1 μm (peak-to-zero value).

The copper wire part is completely welded on the copper substrate and the insulated coating material was driven from welded area to outsides of the wire specimens by high frequency complex vibration.

Weld strengths obtained were almost the copper wire strength. Deformation of the welded part is smaller as vibration frequency becomes higher. Furthermore, fluctuations of obtained weld strength become smaller as higher vibration frequency is used.

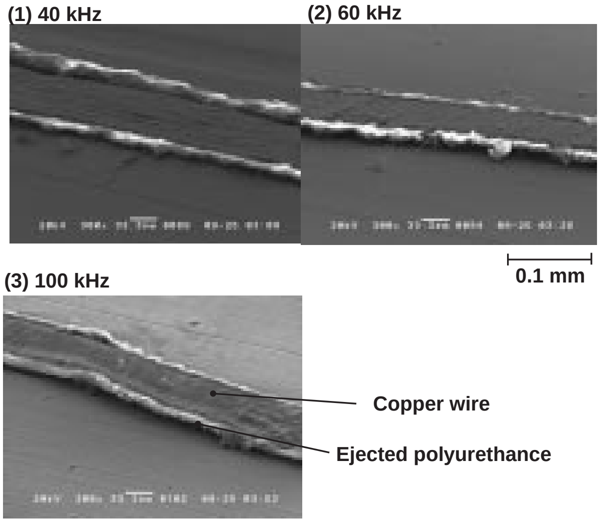

Figure 10: Welded conditions of 0.036-mm-diameter polyurethane coated copper wire specimens joined using by the (1) 40 kHz, (2) 60 kHz and (3) 100 kHz complex vibration welding tip.

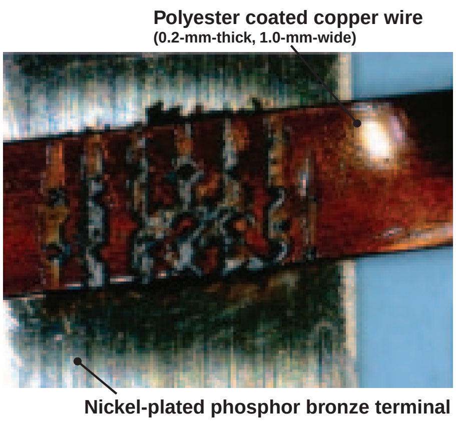

Figure 11: Welded condition of a 0.2-mm-thick, 1.0-mm-wide polyester coated flat copper wire and a nickel plated phosphor bronze terminal.

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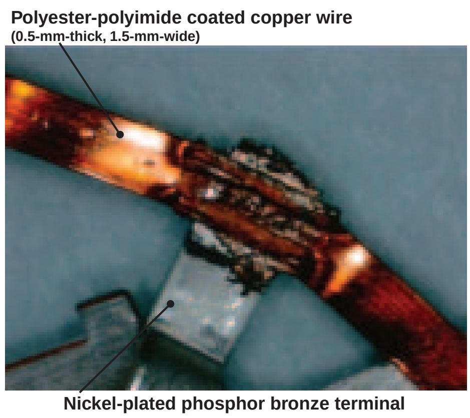

Figure 12: Welded condition of a 0.5-mm-thick, 1.5-mm-wide polyester-polyimide coated flat copper wire and a nickel plated phosphor bronze terminal.