VIBRATION AND WELDING CHARACTERISTICS OF A 94 kHz ULTRASONIC PLASTIC WELDING SYSTEM

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Abstract

Vibration and welding characteristics of a 94 kHz ultrasonic plastic welding system are studied. The 94 kHz ultrasonic plastic welding system consists of a 30-mm-diameter bolt-clamped Langevin type PZT longitudinal transducers with four PZT rings, a stepped horn (vibration transform ratio N=3.0) with a supporting flange at a nodal position and a catenoidal horn (N=3.13) with a 8-mm-diameter welding tip. Maximum vibration velocity of the welding is 3.2 m/s (peak-to-zero value) at loaded condition. Welding characteristics of 1.0-mm-thick polypropylene sheet specimens using the 94 kHz welding system are studied. Using the 94 kHz system, weld strength more than 370 N per one welded area was obtained at vibration velocity 2.7 m/s_{p-0}, welding time 0.8 s and static pressure 600 kPa.

1. Introduction

At high frequency, the welding characteristics of an ultrasonic welding system are improved due to the large vibration loss of plastic materials. As an example, the required vibration velocity of the 90 kHz ultrasonic plastic welding system is 1/3 that of a 27 kHz ultrasonic welding system. Moreover, the required vibration amplitude of the 90 kHz former system is about 1/10 that of the latter system[1]-[3]. Using high-frequency vibration, temperature measured at welding surfaces increases in a shorter time and reaches a value higher than when lower-vibration frequency is used. The combination of a low-frequency-vibration system (27 kHz) with large vibration amplitude and a high-frequency-vibration system (90 kHz) with small vibration amplitude is effective for welding rather large specimens because high-frequency vibration stress is transmitted throughout the specimens by large vibration displacement at low-frequency [4]-[7]. Vibration frequency of commercially available welding systems are up to 40 kHz and there is no higher frequency system such as 94 kHz.

The 94 kHz welding system consists of a bolt-clamped Langevin-type piezoelectric ceramic (PZT) transducer (BLT) of 30 mm diameter and a stepped catenoidal horn with a supporting flange at a nodal position. The welding tip vibrates at a maximum velocity of more than 3.2 m/s_{p-0} at loaded condition. The welding characteristics of 1.0-mm-thick polypropylene sheets are measured in the cases where the welding tip vibration velocity, welding time and static pressure are altered. The required vibration velocity of the 94 kHz welding system decreases compared with that of lower frequency welding system such as 27 kHz to 67 kHz system. The welding characteristics of rather thin specimens using the ultrasonic plastic welding system are improved significantly by using higher frequency. Almost all welding specimens are usually thin as 1 to 2 mm in thickness.

But for large specimens, it is effective to combine high frequency vibration with large velocity and low frequency vibrations with large vibration amplitudes [1]-[7].

2. Configurations of the vibration systems and welding specimen

Configurations of the 94 kHz ultrasonic plastic welding systems are shown in Fig.1. The 27 kHz vibration system used consists of a bolt-camped Langevin type piezoelectric ceramic (PZT) transducer (BLT) of 30 mm diameter that has four PZT disks of 5 mm thickness and 30 mm outer diameter, a stepped horn (vibration velocity transform ratio N = 3.0) and a catenoidal horn (N = 3.13), which has a welding tip of 8 mm diameter and a flange at a nodal position. The PZT position of the BLT

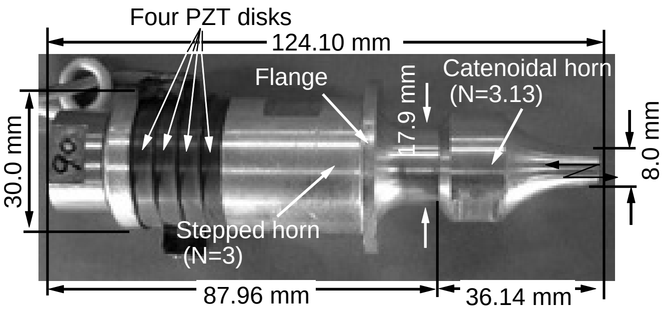

Figure 1: Configurations of a 30-mm-diameter 94 kHz longitudinal vibration systems with four PZT rings using a stepped horn and a catenoidal horn with a 8-mm-diameter welding tip for ultrasonic plastic welding.

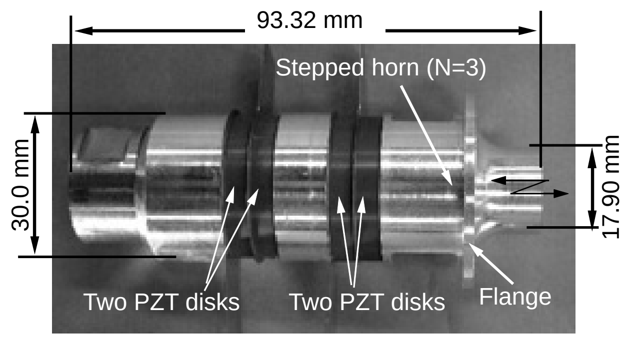

Figure 2: Configuration of a 30-mm-diameter 94 kHz longitudinal vibration system that two PZT ring pairs are installed separately with half-wavelength distance to decrease heating of the vibration system.

transducer is designed as positioned at longitudinal node. Figure 2 shows a configuration of a 30-mm-diameter 94 kHz longitudinal vibration system that two PZT ring pairs are installed separately with half-wavelength distance to decrease heating of the vibration system. Two BLT transducer parts has two 5 mm thick and 30-mm-diameter PZT rings and an aluminum alloy vibration rod is inserted between the BLT transducers. The two BLT transducer parts are driven in parallel connection.

The BLT transducer part has aluminum alloy vibration rods (0.56 longitudinal wavelength) and one or two BLT transducer with four PZT disks of 30 mm diameter (0.94 longitudinal wavelength). The conventional design criteria length is under 0.25 longitudinal wavelength in diameter.

To increase available vibration velocity, the two vibration systems are made of high-strength aluminum alloy (super aluminum alloy, JISA7075B). The welding tip of 94 kHz system vibrates at more than 3.2 $m/s_{p\text{-}0}$ at loaded condition. The total length of the 94 kHz system is about 124 mm (3.5 longitudinal wavelength).

The 30-mm-diameter longitudinal vibration systems are driven at fundamental frequency using a 500 W wide-band static induction transistor power amplifier (7—300 kHz).

Welding tip vibration velocity at a fundamental resonance frequency is measured using a ring-type magnetic vibration detector that is installed in a loop position of the vibration system. The vibration detector is calibrated at the welding tip by a laser Doppler vibrometer in the case where the vibration system is clamped at the node-supporting flange. The detector has band-pass-filter characteristics and the center frequency is adjusted at the fundamental resonance frequency.

The welding specimens used are two-lapped 1.0-mm-thick polypropylene sheets that have smooth surfaces. The weld strength of the polypropylene sheet specimen is the tensile force required for breaking the welded specimens.

3. Vibration characteristics of the 94 kHz system

Free admittance loop of the 94 kHz longitudinal vibration system measured at no load condition is shown in Fig.3. Quality factor and motional admittance |Ymo| of the system are 1562 and 30 mS.

Figure 4 shows radial vibration distribution along the 94 kHz vibration system. Driving frequency is 93.83 kHz and driving voltage is kept 50 Vrms constant. Maximum vibration position of radial vibrations are corresponding to longitudinal nodal positions. It is shown that the PZT driving part and the flange of the stepped horn are position at longitudinal vibration nodal positions. The vibration system vibrates in 2.5 wavelength longitudinal vibration mode with five nodal positions.

Figure 5 shows the relationship between driving voltage and longitudinal vibration velocity of the welding tip without power factor compensating inductance and at no load condition. Driving frequency is 93.83 kHz. Welding tip vibration velocity is 2.5 $m/s_{p\text{-}0}$ at driving voltage of 80 Vrms. Using the power factor compensating inductance, maximum welding tip vibration amplitude of 3.2 $m/s_{p\text{-}0}$ is obtained under driving voltage of 200 Vrms at loaded condition of 1.0-mm-thick polypropylene plate welding specimens. Radial vibration velocity distribution measured along the circumference of

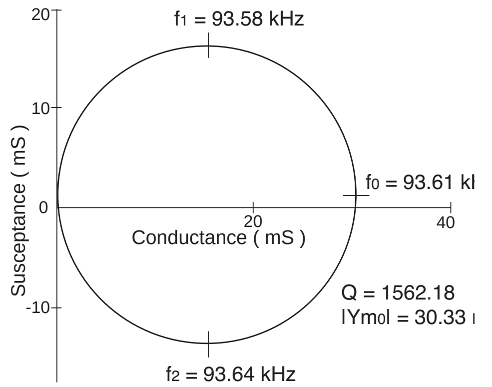

Figure 3: Free admittance loop of the 94 kHz longitudinal vibration systems at fundamental resonance frequency under no load condition.

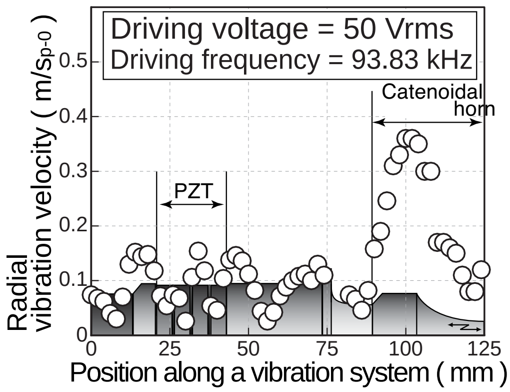

Figure 4: Radial Vibration distribution along the 94 kHz vibration system. Driving frequency: 93.83 kHz. Driving voltage: 50 Vrms.

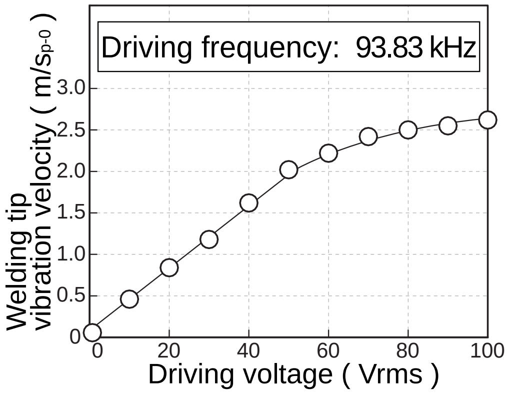

Figure 5: Relationship between driving voltage and longitudinal vibration velocity of the welding tip. Driving frequency: 93.83 kHz.

the welding tip under driving voltage of 10 Vrms is shown in Fig.6. Radial vibration distribution is about circular. Radial vibration amplitude is one fifty compared with longitudinal vibration amplitude normal to the welding tip surface and negligibly small compared with longitudinal vibration.

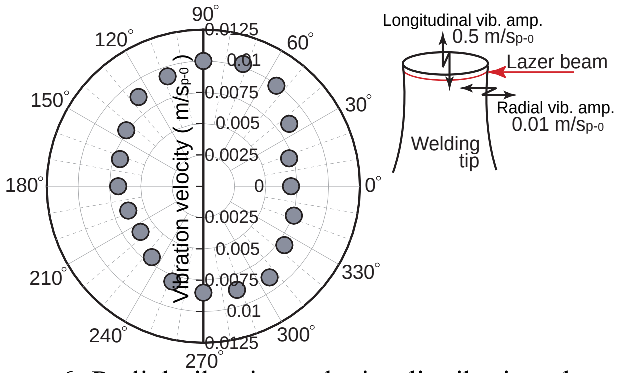

Figure 6: Radial vibration velocity distribution along the circumference of the welding tip under driving voltage of 10 Vrms.

4. Welding characteristics of the 94 kHz welding system

Figure 7 shows the relationships between welding tip longitudinal vibration velocity, welded area, weld strength and weld strength/ unit area of two lapped 1.0-mm-thick polypropylene sheet specimens welded using the 94 kHz welding system. Welding tip static clamping pressure is 600 kPa and welding time is kept 0.8 s constant. Welded area, weld strength and weld strength per unit area increase as welding tip vibration velocity increases up to 2.75 m/s_{p-0}, and welded area increases and weld strength saturate at over 2.75 m/s_{p-0}. Weld strength per unit area decreases at over 2.75 m/s_{p-0} welding tip velocity amplitude due to fatigue by vibration. Maximum weld strength per unit area is about 350 MPa.

Figure 8 shows the relationships between welding time, input power, welded area, weld strength and weld strength per unit area of two lapped 1.0-mm-thick polypropylene sheet specimens welded using the 94 kHz welding system. Static clamping pressure is 600 kPa and driving voltage of the system is kept 200 Vrms constant. Weld strength, welded area and weld strength per unit area increase as welding time becomes longer up to 1.0 s, but welded area and weld strength per unit area somewhat saturate at longer welding time. Input power to the welding system is about 75 W.

The relationships between static clamping pressure, input power, welded area, weld strength and weld strength/ unit area of two lapped 1.0-mm-thick polypropylene sheet specimens welded using the 94 kHz welding system is shown in Fig.9. Welding time and driving voltage are kept 0.8 s and 200 Vrms constant. Welded area and weld strength increase as static pressure increases, but weld strength per unit area saturates at 350 MPa beyond 400 kPa static clamping pressure.

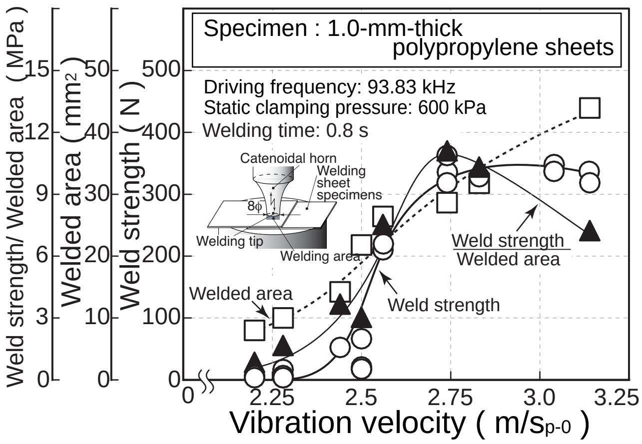

Figure 7: Relationships between welding tip longitudinal vibration velocity, welded area, weld strength and weld strength/ unit area of two lapped 1.0-mm-thick polypropylene sheet specimens welded using the 94 kHz welding system. Static pressure: 600 kPa. Welding time: 0.8 s.

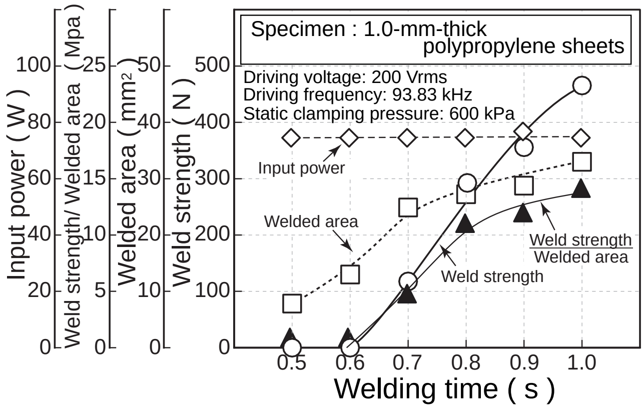

Figure 8: Relationships between welding time, input power, welded area, weld strength and weld strength/ unit area of two lapped 1.0-mm-thick polypropylene sheet specimens welded using the 94 kHz welding system. Static pressure: 600 kPa. Driving voltage: 200 Vrms.

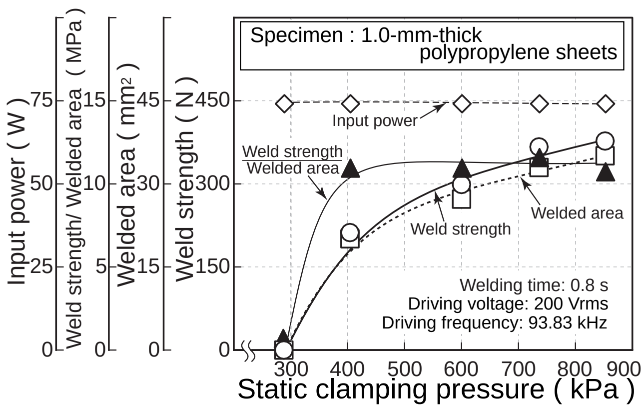

Figure 9: Relationships between static clamping pressure, input power, welded area, weld strength and weld strength/ unit area of two lapped 1.0-mm-thick polypropylene sheet specimens welded at different welding times using the 94 kHz welding system. Driving voltage: 200 Vrms.

5. Welded Conditions of polypropylene sheet specimens

Figure 10 shows cross sections of 1.0-mm-thick polypropylene sheet specimens welded at different vibration velocity using the 94 kHz welding system. Static pressure is 600 kPa and welding time and driving voltage are kept 0.8 s and 200 Vrms constant. With excessive vibration velocity, welded part is partially push out to between plate specimens and gap between specimens is produced at adjacent of welded area.

Welded conditions of 1.0-mm-thick polypropylene sheet specimens after tensile test that are welded using the 94 kHz welding system are shown in Fig.11. Welded areas are pealed off at welding time under 0.7 s and are

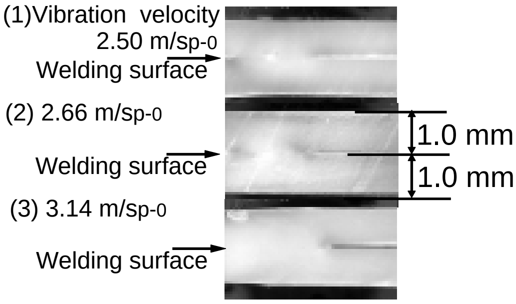

Figure 10: Cross sections of 1.0-mm-thick polypropylene sheet specimens welded at different vibration velocity using the 94 kHz welding system. Static pressure: 600 kPa. Welding time: 0.8 s. Driving voltage: 200 Vrms.

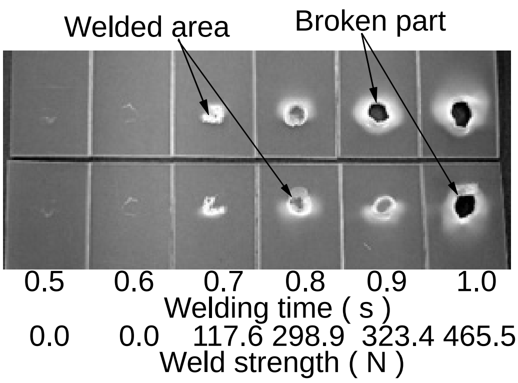

Figure 11: Welded conditions of 1.0-mm-thick polypropylene sheet specimens welded using the 94 kHz welding system.

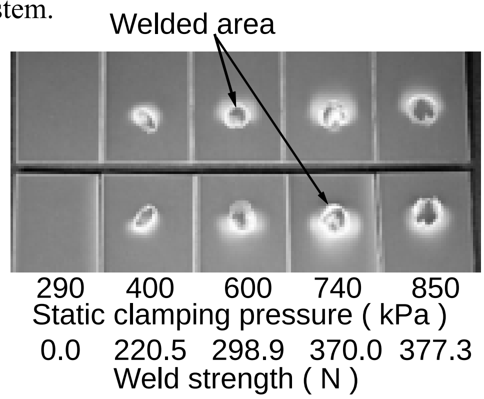

Figure 12: Welded conditions of 1.0-mm-thick polypropylene sheet specimens welded at different static pressures using the 94 kHz welding system.

broken at welding time over 0.8 s under tensile strength tests. These welded areas were transparent after welding and become opaque and changes to milky at broken area due to elongation after tensile tests.

Figure 12 shows welded conditions of 1.0-mm-thick polypropylene sheet specimens welded at different static pressures using the 94 kHz welding system. Welding time and driving voltage are kept 0.8 s and 200 Vrms constant. Welded areas over static pressure of 400 kPa are broken at tensile tests.

6. Conclusions

(1) The 30-mm-diameter 94 kHz longitudinal vibration systems with four PZT rings using a stepped horn and a catenoidal horn with a 8-mm-diameter welding tip for ultrasonic plastic welding was designed and the vibration characteristics were studied. Maximum welding vibration velocity 3.2 m/s$_{p-0}$ was obtained at welding condition of polypropylene sheets.

(2) For decreasing heating of the vibration system, it was effective to install two PZT ring pairs with half or one wavelength distance by inserting metal block between them.

(3) Welding characteristics of 1.0-mm-thick polypropylene sheet specimens were studied using the 94 kHz welding system. Maximum weld strength obtained was 370 N per one weld area using an 8-mm-diamaeter welding tip. Maximum weld strength per unit area 11 MPa was obtained at 2.75 m/s$_{p-0}$ and welding time 0.8 s.

(4) In the cases where welding specimens are rather thin such as 1 to 2 mm thickness, the 94 kHz system was more effective than lower frequency 27 kHz to 67 kHz systems due to higher vibration loss of the plastic welding specimens at higher frequency [5][6][7].

(5) As a result, the effectiveness of higher frequency for ultrasonic welding of plastic materials was reconfirmed. This system may be useful for various applications that require frequency-dependent characteristics.

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