Chapter 27
Acoustic Emission System for Monitoring Mechanical Behavior During Ultrasonic Metal Welding

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Introduction

Ultrasonic metal welding (USMW) gained notable attention as a solid-state joining process. USMW is extensively used in the electrical, electronics and automobile sector due to its advantage over other conventional joining methods. Another advantage of the process has capability to join dissimilar, multiple, and thin layers of metals at low temperatures [1, 2]. USMW is solid-state welding process therefore no consumable materials are required and maximum process temperature is only 40% of the absolute melting temperature of the substrate materials. The quality issues are rising such as porosity, heat-affected zone or burn-through during the conventional fusion welding processes while USMW has no as such issues during the welding [3, 4]. Literature reports that using UMW technique, soft metals such as aluminum (Al), nickel (Ni), copper (Cu), gold (Au) and silver (Ag) can also be welded. UMW is not suitable for hard ferrous alloy and thickness greater than 3 mm is also constraint for this process [5, 6]. Interlayer technique in ultrasonic welding can be useful to weld Molybdenum material [7].

Zhao et al. [2] proposed a new technology that could monitor in situ transient temperature. They found that weld temperature increased with amplitude.

Liu et al. [8] investigated microstructure and mechanical properties of Al/Cu ultrasonically welded joints. They found weld time is an important parameter for weld strength. The recrystallization was observed at the weld interface for maximum weld temperature, i.e., 360°.

Balle et al. [9] performed experimental study to identify process parameters to weld metal to composite material. The weld temperature for metal/carbon fiber textile

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S. Kumar and K. P. Rajurkar (eds.), *Advances in Manufacturing Systems*,
Lecture Notes in Mechanical Engineering,
https://doi.org/10.1007/978-981-33-4466-2_27

joints was found within the range of 350–400 °C and from the SEM micrograph, it was found intensive bonding connection at the interface.

Cao et al. [10] developed FEM model to study resistance heat produce during the ultrasonic welding. They measured temperature using thermocouples. They performed experimental validation in terms of interface temperature, horn displacement and cross-section pattern. They found good agreement between experimentation and FEM model.

Lionetto et al. [11] performed experimental investigation on ultrasonic welding of carbon fiber-reinforced composite to aluminum metal. They observed high weld temperature and plastic deformation due to high force and high frequency shear oscillations during welding. They found force is significant for the higher lap shear strength.

Watanabe et al. [12] performed experiments with combinations of dissimilar metals are aluminum–copper and aluminum–austenitic stainless steel (SUS304) to identify the effect of the material hardness, thermal properties, and surface roughness on ultrasonically welded joint. From their study, they concluded that process parameters like weld time, clamping pressure affect the weld strength of Aluminum–Copper joint.

Haddadi and Tsivoulas [13] welded Al 6111-T4 material using USMW. They studied mechanical performance and thermal behavior of the weld joint. They reported that temperature increase with weld time and the highest value was 440 °C at maximum weld time.

Elangovan et al. [14] have used response surface methodology (RSM) with genetic algorithm (GA) to obtain optimum process parameter for maximum weld strength. They observed that as pressure increases weld strength decreases because relative motion between weld surfaces reduces. On the other hand, increasing amplitude causes more area for rubbing leading to higher weld strength.

Thus, from the literature review, it is observed that weld pressure, amplitude and weld time are the governing parameters for weld strength and quality of the weld. In this study, UMSW of pure copper specimen has been done to investigate the lap shear and T-Peel test with different combinations of input parameters. During the process, in situ temperature measurement has been performed during the process. Also, in situ quality measurement has been performed using piezoceramic acoustic emission sensor.

Experimental Study

Experimental Setup

Ultrasonic welding was carried out using Ultrasonic M-4000 Metal Welding press (3000 W, 20 kHz), which is shown in Fig. 27.2 with microprocessor system MPS-4 and generator. The sonotrode used along with M-4000 is made of hardened steel.

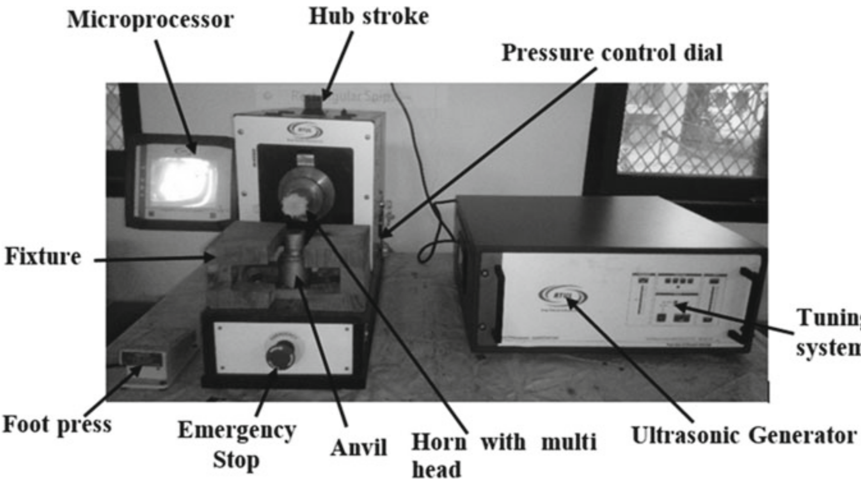


Fig. 27.1 Ultrasonic Metal welding setup

Anvil block has knurling impressions to provide grip to the specimen placed on it and it is made up of steel. The parameters that can be varied on this machine tool setup are amplitude and weld time. Figure 27.1 shows the ultrasonic welding setup. The placement of the sensor on machine tool is a crucial aspect to collect accurate data. For the temperature measurement, k-type thermocouple was used that was place closest to the weld zone to get capture weld zone temperature during the process. Kistler makes Piezoceramic Acoustic Emission Sensor was used to monitor in situ weld quality. The sensor was clamped through magnetic clamp on the weld specimen. The sensor and thermocouple were connected through National Instrument to make data acquisition system.

Material

In the present study, the first stage was the preparations of work specimen. All the specimens were cut from the copper sheets. The ASTM D1002-01 [15] and ASTM D1876-08 [16] standards were referred during the specimen preparation. The overlap distance during the welding was kept 25 mm. Before welding, workpieces were cleaned with acetone to remove the surface impurities as it may also affect the bond strength. Figure 27.2 shows the dimensions of the specimen prepared as per the standards.

In the present work, amplitude and weld time are considered as the controlled factors and varied at three levels as shown in Table 27.1. The pressure was kept constant 1.5 bar. In the present work, amplitude range is selected from 10 to 20 μm

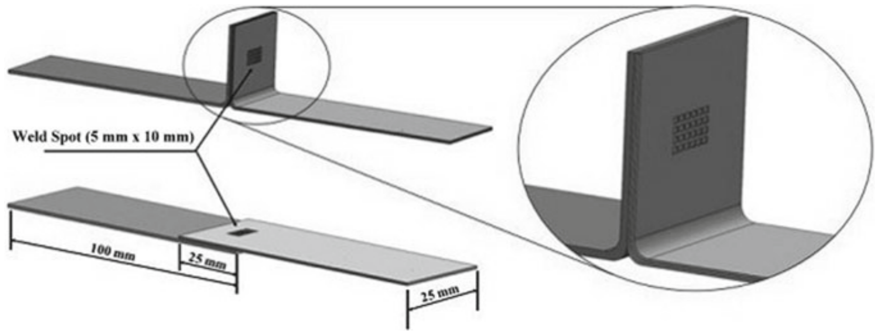


Fig. 27.2 Specimen for T-peel test and lap shear test

Table 27.1 Parameters and levels for the experiments

Parameter	Unit	Level 1	Level 2	Level 3
Weld time	S	1	1.5	2
Amplitude	µm	10	15	20

to utilize maximum capacity of machine tool. The experimental plan was designed as per L9 orthogonal array, which considers two parameters each at three levels.

Results and Discussion

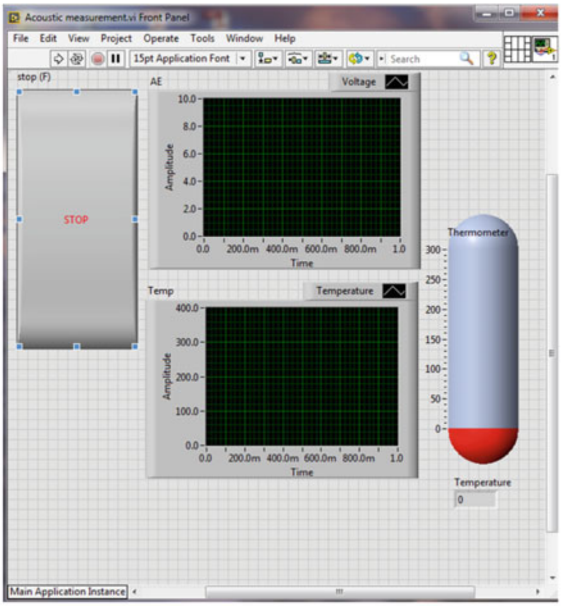
The ultrasonic welding was performed on Cu–Cu strips. During welding, weld temperature and the deformation were sensed by Acoustic Emission (AE) sensor. Figure 27.3 shows the interface of data collection using a LabVIEW software. Table 27.2 represents the data collected during the welding and postwelding.

Thermal Behavior

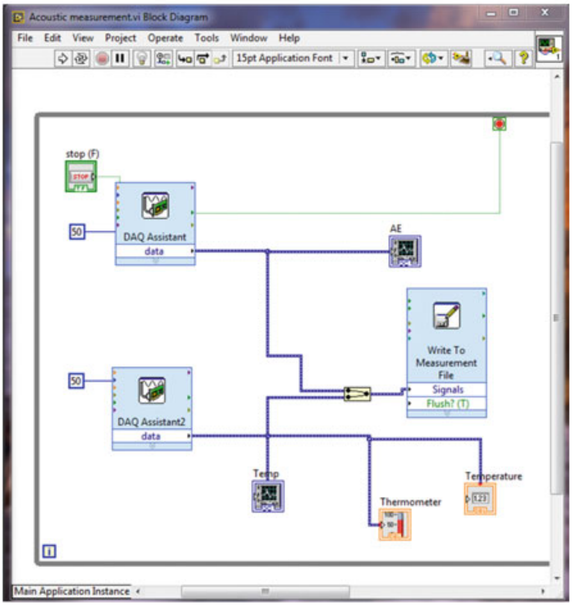
During the ultrasonic metal, welding maximum temperature was recorded with help of K-type thermocouple. The effect of weld time was studied at different weld time. Figure 27.4 shows the effect of weld time on weld interface temperature during the sample fabrication for Lap shear test and T-peel test.

From Fig. 27.4, it can be observed that the maximum weld temperature, i.e., 357.80 °C was recorded during welding of Lap shear specimen. The maximum temperature was achieved for the combination amplitude 20 µm and 1.5 s weld time. Due to the higher amplitude, rubbing action covers higher area and it produces more

Fig. 27.3 LabVIEW interface



(a) Measurement Panel



(b) Block diagram for the measurement

Table 27.2 Results obtained during USMW

S. No.	Weld time (s)	Amplitude, A (μm)	Lap shear test		T-Peel test	
			Max temperature (°C)	Load (N)	Max temperature (°C)	Load (N)
1	1	10	240.35	31.51	298.26	4.84
2	1	15	209.27	30.20	206.37	0.37
3	1	20	208.19	15.61	280.72	1.55
4	1.5	10	183.15	28.38	251.75	5.93
5	1.5	15	235.43	28.52	405.88	3.02
6	1.5	20	357.80	32.28	397.48	3.06
7	2	10	256.77	28.66	376.20	1.88
8	2	15	285.74	27.77	441.16	1.86
9	2	20	353.56	30.67	463.68	1.78

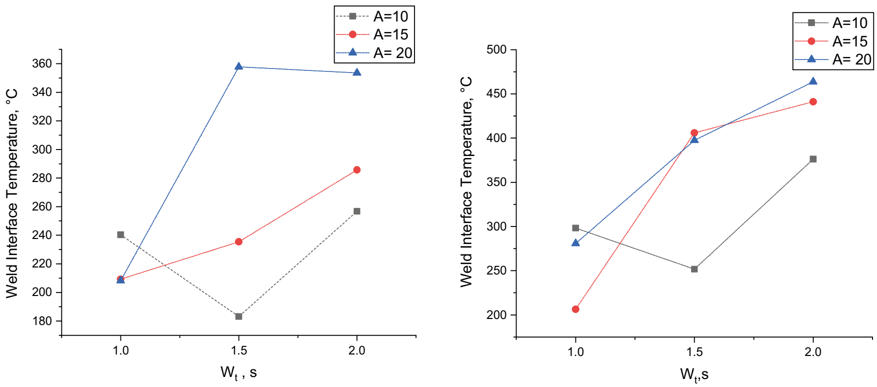


Fig. 27.4 Effect of weld time on weld interface temperature

frictional heat between the interfaces that are under modest pressure. Similarly, the highest temperature was recorded 463.68 °C for maximum amplitude and weld time.

Mechanical Behavior

The ultrasonically welded specimens were tested for Lap shear test and T-Peel test. Figure 27.5 shows the effect of weld time on Lap shear strength and T-Peel strength. Both mechanical strengths were measured using Kudale make tensometer.

It can be seen that maximum lap shear strength was obtained for higher amplitude and moderated weld time. It is also observed that as the weld time increases weld

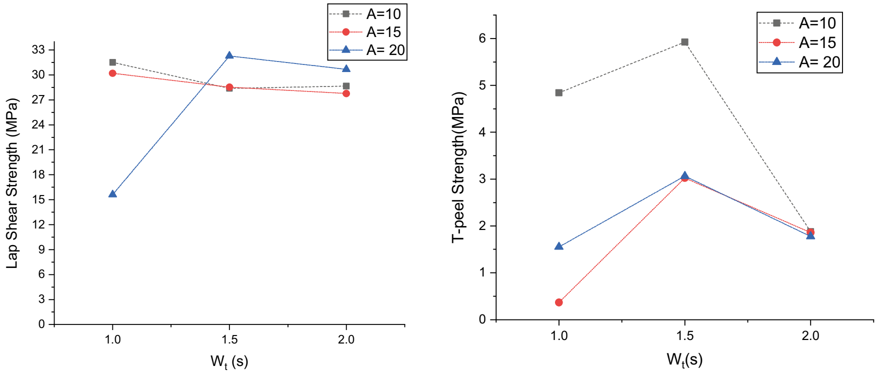
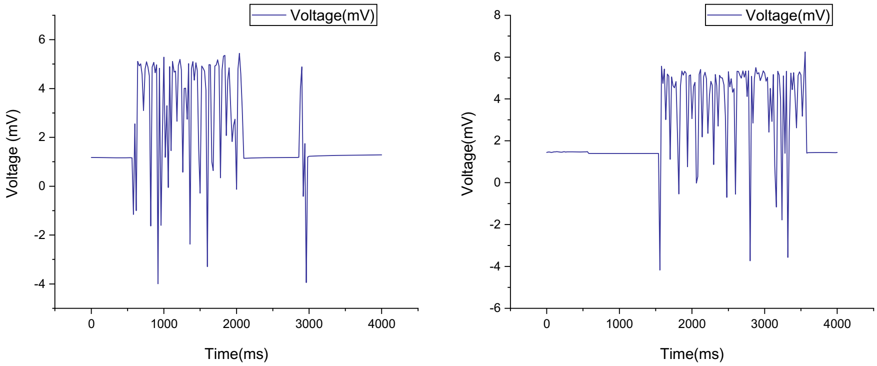


Fig. 27.5 Effect of weld time on lap shear and T-Peel strength

strength also increases up to moderated weld time. As the more weld time given to weld interface, more plastic deformation occurs and it produces strong bond at interface under the constant modest pressure. The continuous increase in weld time produces adverse effects on weld strength. It produces the over weld of specimen and it damages the bond due to excess vibrational energy. The over welded specimen consists of weak bonding mechanism that leads to lower lap shear strength as well as T-Peel strength. It was also observed that amplitude stepping affects the weld strength of the ultrasonically welded joints.

Weld Quality Monitoring

Piezoceramic acoustic emission sensor was used to monitor in situ weld quality during the ultrasonic welding process. Acoustic emission (AE) involves a sensor that converts process sounds into electrical output to a measurable variable. Air-borne emission has the human audible ranges between 20 and 20 kHz. The typical sensor for this emission is a microphone placed nearby the weld zone. Figure 27.6 shows the AE signal waveform during the welding. The AE data are converted into mV it ranges −10 V to 10 V. Figure 27.6a shows AE data collected for the maximum lap shear testing at weld time 1.5 and amplitude 20 μm. It can be observed that maximum amplitude can produce higher friction heat between the weld interfaces that lead to maximum lap shear strength, i.e., 32.28 MPa. It is also observed that for this combination of parameters, maximum weld interface temperature, i.e., 357.80 °C was achieved among all combinations. Figure 27.6b shows the AE data collected during T-peel testing. The maximum interface temperature was observed for 2 s weld time and 20 μm amplitude. Figure 27.6 shows the Maximum deformation was observed at same time when maximum weld time was observed during the process.



(a) For W_t =1.5s and A = 20µm (b) For W_t=2s and A = 20µm

Fig. 27.6 AE signal waveform during welding

Conclusions

In the present work, Cu–Cu specimens were ultrasonically welded to study the effect of weld time and amplitude on Lap shear strength and T-Peel strength. During the ultrasonic welding process, in situ temperature and quality were measured using thermocouple and AE sensor, respectively. From the above study, flowing conclusions can be drawn:

1. In situ temperature and quality measurement were successfully carried out using K-type thermocouple and piezoceramic acoustic emission sensor.
2. Longer weld time results into higher weld strength because a higher welding time facilitates in providing prolonged application of vibrational energy, thereby resulting into better weldment.
3. The amplitude stepping shows better weld strength for lap shear and T-Peel testing.
4. As the amplitude and weld time increase the weld interface temperature also rises for both cases.
5. AE results and weld interface temperature show the good agreement during the welding process.

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