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Optimization of Ultrasonic Metal Welding Parameters for Copper Sheet to Copper Wire Joints and Numerical Analysis of Ultrasonic Wire Bonding

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Abstract: One of the major manufacturing processes used to assemble automobile structures is material joint. In this material joint ultrasonic welding is one of the advanced technologies in joining of non-ferrous metals. The study is carried out to understand the mechanism of ultrasonic metal welding and to optimize the process parameters such as amplitude, clamping pressure and weld time for Cu-Cu joint by design of experiments (DOE). The finite element model (FEM) and mathematical modeling are developed to predict the temperature distribution and deformation between the weld specimens during welding. From the results obtained from experimental work, finite element analysis and mathematical models are compared and validated. Experiments are conducted with 0.2 mm thick copper specimen and 0.9 mm thick copper wire. The results are discussed in detail.

Key words: Ultrasonic Metal Welding · Design of Experiment · Ansys

INTRODUCTION

Solid state welding is the one of the advanced technologies in ultrasonic welding (USW). As per American Welding Society (AWS), welding is defined as the localized coalescence of metallic member by heating the member to a temperature called welding temperature by the application of heat and with or without the application of pressure and filler material. It's basically a joining process. Solid state welding are a group of welding processes which produces coalescence at temperatures essentially below the melting point of the base materials being joined without including brazing filler metal. Pressure is used if required. These processes are sometimes erroneously termed as solid state bonding processes. The various types of welding processes included are diffusion welding, cold welding and explosion welding, friction welding, forge welding, hot pressure welding, roll welding and ultrasonic welding. The sound waves whose frequency lie above the audible frequency of 20000 Hz are called ultrasonic waves. The working principle of ultrasonic metal welding is shown in Figure 1. Their wavelengths are small and hence exhibit some unique phenomena in addition to the properties of audible sound waves. The sound waves whose frequency lies below the audible limit are called infrasonic waves and the sound waves whose frequency is higher than the audible limit are called supersonic waves.

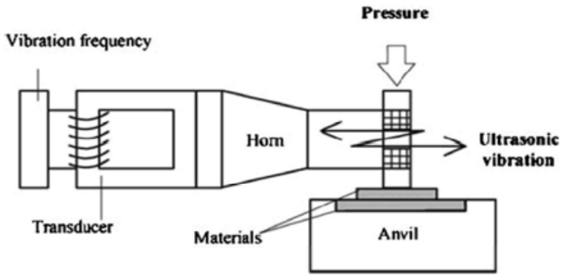

Fig. 1: Working principle of USMW

Yong Ding et [1] presented the numerical analysis of ultrasonic wire bonding. The 2-D and 3-D finite element method is used to analyze the deformation that takes place in ultrasonic wire bonding. A special focus has been placed on how the important wire bonding parameters, such as bond force and power affects the contact pressure along the wire-bond pad interface and the real contact area was calculated. The stress distribution in both 2-D and 3-D models were analyzed.

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Paul G Mathews [2] has explained the concept of design of experiments (DOE). Design that can deliver quadratic terms of their design variables are called response surface design. Response surface design is capable of solving curvature in the response associated with each design variable. Types of design are 2k design with centers, 3k Factorial design and Box-Behnken design. Response surface design problems are solved using Minitab software. Creation of response-surface design and Analysis of response-surface design are the two steps in solving problems using Minitab.

Elangovan et [3] has dealt with dominant problem faced by industry dealing with ultrasonic metal welding process, which is the poor weld quality and strength of the weld due to improper selection of weld parameters. In their work, welding parameters such as welding pressure, amplitude of the vibration and weld time are considered while producing ultrasonically welded joints of copper whose thickness is 0.2 mm. A suitable experimental design based on Taguchi's robust design methodology was designed and executed for conducting trial.

Shin-ichi *et al* [4] discussed about experimental study of the ultrasonic welding of ceramics and metals using inserts. There are two methods in joining ceramic and metal, first one is binder-based technique which involves vacuum depositing of metal onto the surface of the ceramic, putting the metal on this surface and applying pressure to the metal by using ultrasonic vibration. While another technique involves the joining of metal and ceramic with low-melting-point metal as insert material. Their results have revealed that by using an activated metal or low-melting-point metal as an insert material or by metalizing (vacuum-deposition) the contact surface, it is possible to obtain good bonding effects. It also indicated that these encourage joining with Cu, which has been difficult to join.

Elangovan *et al* [5] discussed about the temperature distribution at weld interface, sonotrode and anvil during ultrasonic welding of aluminium alloy using FEM. From this study it is observed that as the weld time increases the temperature at the weld interface also increases and clamping force increases leads to decreasing temperature and more deformation at the weld interface.

Soundararajan *et al* [6] develops a thermo-mechanical model to predict the transient temperature field, active stresses and forces at the interface of the workpiece and backing plate in FSW. In this study the contours were adaptively modified after each load step as the tool moves over the workpiece. Comparison of the temperature profile developed using adaptive and uniform contact conductance with the experimental results showed the possibility of more accurate determination using the present model.

Sunar *et al* [7] discussed about the temperature and stress analysis during welding. In this study a control volume approach is introduced for the numerical solution of heat transfer equations. The finite element is adopted for stress field predictions. The longitudinal tensile stress component is higher in the regions close to the top and bottom surfaces of the workpiece and its magnitude decreases as the heating period progresses.

Yanhong Tian *et al* [8] has presented an experiment study on investigation of ultrasonic copper wire wedge bonding on Au plated Cu substrates at ambient temperature. Based on the obtained results copper wire bonding on Au/Ni plated Cu substrate at ambient temperature was achieved and the bonding parameters for both first bond and second bond were optimized by design of experiment. To get strong pull force of the wedge bond, higher power and force were required for the second both that for the first bond.

Ward S M *et al* [9] has presented the finite element analysis of thin aluminium alloy. A methodology for determining the fracture parameters associated with pull-out of spot welds is presented. Fracture parameters associated with ductile fracture in thin aluminum alloy was determined by comparing experimental observations to numerical parameters. Previous studies are strength based approach. In this paper strength based and energy based approach to determine strength of the spot weld is presented. All analysis done using commercial finite element code ABAQUS.

Bappa A *et al* [10] has presented the prediction of weld quality in laser transmission welding of thermoplastics using artificial neural network. This paper establishes a correlation between the laser transmission welding parameters and output variables though a nonlinear model, developed by applying artificial neural network (ANN). Input parameters are power, welding speed, standoff distance, clamp pressure. Output parameters are average lap shear strength, average weld seam width. The aim of this paper is to show the possibility of the use of neural networks for the determination of the weld dimensions for laser transmission welded thermoplastic sheets.

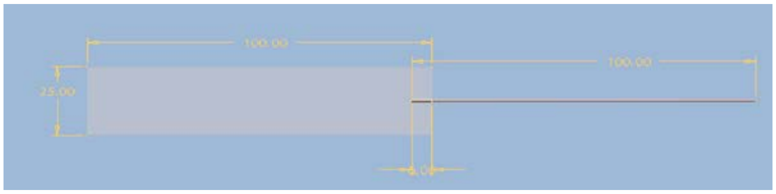

Fig. 2.1: Standard Specimen

Fig. 2.2: Ultrasonic metal welding setup

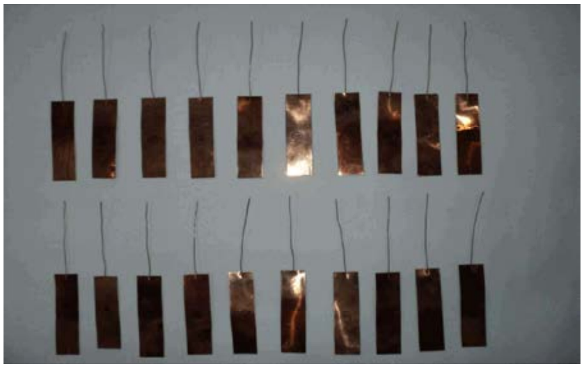

Fig. 2.3: Material After Welding

Table 2.1: Central Composite design for 3 factors

X1	X2	X3	RUNS
±1	±1	±1	8
0	0	0	6
±1	0	0	2
0	±1	0	2
0	0	±1	2
Total Runs			20

Table 2.2: Experimental parameters and their levels

		Levels		
Variable name	Parameter	-1	0	+1
X1	Pressure(bar)	2.5	3	3.5
X2	Weld time(sec)	2	2.5	3
X3	Amplitude(αm)	28	42.5	57

Experimental Setup: The specimen was prepared for Standard test methods for Tension Testing of Metallic Materials as shown in Figure 2.1. The samples were cleaned with cotton soaked in acetone to remove the impurities on the surface of the specimens.

And the experimental setup for the Ultrasonic metal welding is shown in Figure 2.2 with data acquisition system (DAQ).

A Box-Wilson Central Composite Design, commonly called as central composite design contains an fractional factorial design with center points that is augmented with a group of star points that allows estimation of curvature. If the distance from the center of design space to a factorial point is ±1 unit for each factor then the distance from the center of the design space to a star point is $\pm \alpha$, where $|\alpha|> 1$. The precise value of α depends on certain design properties and on the number of factors involved. In spherical central composite design the star points are the same distance from the center as the corner points. In rotatable central composite design the star points are shifted or placed so that the variances of the predicted values of the responses are all equal for x's which are an equal distance from the center. The spherical central composite design method is used here. The central composite design for three factors is shown in Table 2.1 where X1, X2 and X3 are the 3 variables. The central composite design has 2^x star points on the axial lines outside of the box defined by the corner points.

Minitab is a statistical analysis software. It is also used to learn about statistics and statistical research. The advantages of statistical analysis computer applications are accuracy and reliability over computing statistics and drawing graphs by hand. Minitab is relatively easy to use once we get to know its fundamentals. By using different parameters on these vaiables at variable levels the values tabulated in Table 2.2. Based on these values the materials are welded and is shown in Figure 2.3.

RESULTS AND DISCUSSION

Thus, optimize the process parameters for joining copper specimens wire (0.9mm) and sheet (0.2mm) thickness is adopted systematically. By calculating the values from trail 1 and 2 the average welding strength for various levels of selected parameters are shown in Table 3.1. The data observed from Table 3.1 is that when the pressure is at level 2.5 bar, amplitude of vibration is 57.0 (αm) and weld time is 2.0 sec gives average joint strength value is much greater than the other levels welding parameter. The structural deformed shape of welded specimen at various pressures such as 2.5, 3, 3.5 bar are shown in Figure 3.1, Figure 3.2 and Figure 3.3. The maximum deformation takes place at 3.5 bar.

Table 3.1: Weld strength obtained in Experiment

				Weld strength (Experimental) (N/mm^2)		
Ex.No	Clamping Pressure(bar)	Amplitude Of Vibration(μm)	Weld Time(sec)	Trail 1	Trail 2	Average
1	3.0	42.5	2.5	19.556	17.121	18.3385
2	3.0	42.5	2.5	16.423	14.884	15.6535
3	3.5	57.0	3.0	15.780	16.423	16.1015
4	3.5	28.0	3.0	15.071	15.780	15.4255
5	2.5	57.0	3.0	24.324	20.179	22.2515
6	3.0	42.5	2.5	17.333	19.111	18.2220
7	3.5	42.5	2.5	10.284	11.428	10.8560
8	2.5	42.5	2.5	25.000	24.333	24.6665
9	3.0	57.0	2.5	19.444	17.121	18.2825
10	3.0	42.5	2.5	14.881	15.777	15.3290
11	3.0	42.5	2.5	15.111	16.144	15.6275
12	3.0	28.0	2.5	22.222	21.777	21.9995
13	2.5	28.0	3.0	20.721	20.176	20.4485
14	3.5	28.0	2.0	18.262	18.080	18.1710
15	3.0	42.5	2.5	15.870	15.000	15.4350
16	2.5	57.0	2.0	26.577	25.627	26.1020
17	3.0	42.5	3.0	23.810	23.188	23.4990
18	3.0	42.5	2.0	18.849	17.944	18.3965
19	3.5	57.0	2.0	16.312	18.322	17.3170
20	2.5	28.0	2.0	20.437	19.334	19.8855

Copper wire - 0.9mm
Copper sheet - 0.20mm
Total height - 1.10mm(Before welding,)

Height of the welded specimen(After welding)

1. 2.5bar - 1.05mm
2. 3.0bar - 1.01mm
3. 3.5bar - 0.93mm

Deformation of the welding specimen = total height of the welding specimen - height of the welded specimen

Pressure Result
1. 2.5 bar - 1.10 - 1.05 = 0.05mm
2. 3.0 bar - 1.10 - 1.01 = 0.09mm
3. 3.5 bar - 1.10 - 0.93 = 0.17mm

Structural deformed shape of welded specimen at various pressures by using Ansys.

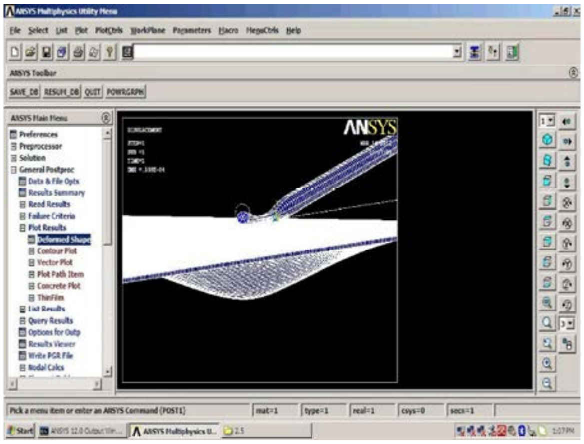

Fig. 3.1: Deformed shape at 2.5KN pressure

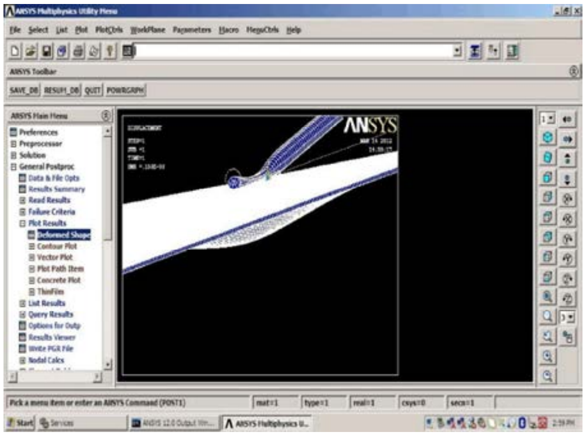

Fig. 3.2: Deformed shape at 3.0KN pressure

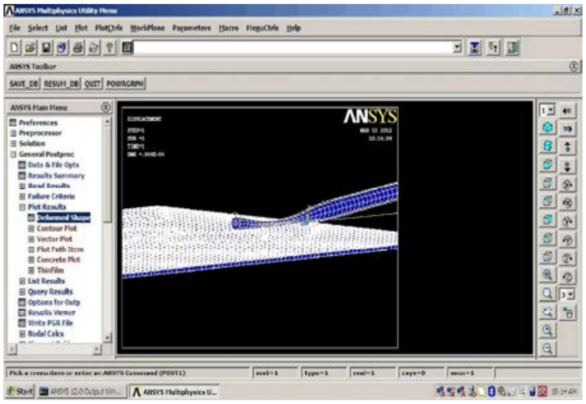

Fig. 3.3: Deformed shape at 3.5KN pressure

Temperature distribution on the welding specimen and the correlation between thermo couple and FEA model.

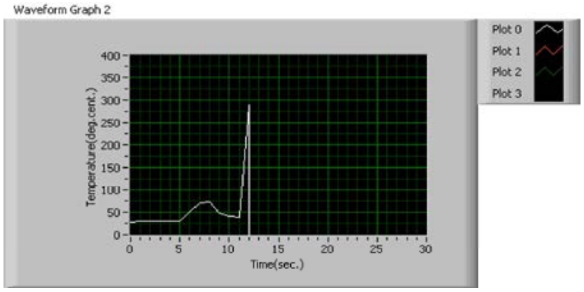

Fig. 3.4: Thermo couple result

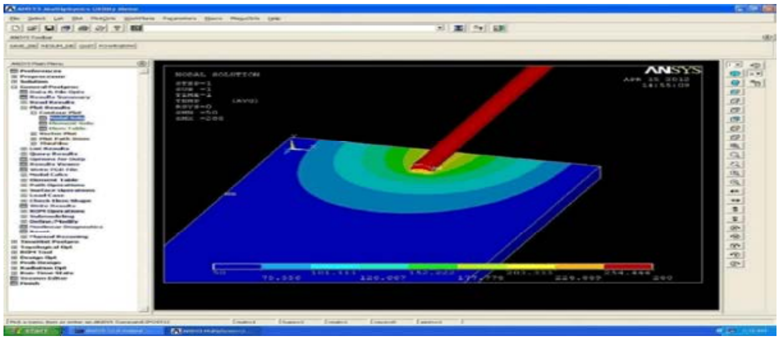

Fig. 3.5: Temperature distribution Ansys result

Figure 3.4 shows the temperature at the weld interface for welded copper sheet with copper wire using lab view. In lab view the output is in the form of a wave indicating the temperature rise from the ambient room temperature to the maximum temperature attained at the weld interface. The maximum interface temperature observed on lab view is 290° C. The temperature distribution throughout the component by means of ansys is shown in Figure 3.5.

CONCLUSION

- The Process of ultrasonic metal welding and the mechanism of bond formation during welding are studied. Ultrasonic welding of copper sheet to copper wire joints are performed successfully and the parameters affecting Ultrasonic metal welding are studied.
- Maximum interface temperature developed for copper sheet with copper wire welded specimen during Ultrasonic welding was 290°C which is measured using thermocouple.
- A finite element model of copper sheet to copper wire joint was generated successfully. Finite Element Analysis (FEA) is carried out to this model to predict the deformation shape along the copper sheet and copper wire.
- Based on the design matrix developed using response surface methodology (RSM) the optimum combination of weld parameters for copper sheet to copper wire joint was identified.

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