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Optimization Technique using Response Surface Method for USMW process

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Abstract

This study aims at optimizing the parameters of a manufacturing process. The process considered here is the ultrasonic metal welding of copper sheet and copper wire. The strength of the weld is maximized by optimizing the parameters like amplitude, welding pressure and weld time. Central Composite Design is adopted and the experiments are conducted based on the design matrix so obtained. A mathematical model is also developed for the same. Parametric optimization is done through Response Surface Methodology and Excel solver. The results obtained from experimental work are compared and validated through confirmatory experiments.

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Keywords: Ultrasonic metal welding; Response Surface Methodology; Central Composite Design

Nomenclature

P	Weld Pressure (bar)
WT	Weld Time (Sec)
A	Amplitude (µm)
R1	Response (N/mm2)
UTM	Universal Tensile Machine

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1. INTRODUCTION

Ultrasonic Metal Welding (USMW) finds major use in the manufacturing of accessories that are used in electrical and automotive applications. It is a solid state welding process in which high frequency vibration, in plane with the interface, is used to join similar or dissimilar metallic pieces under moderate pressure as presented in Fig. 1. Progressive shearing and localized joining of parts are achieved due to the high frequency relative motion between the copper sheet to copper wire. The temperature developed between the copper sheet to copper wire during USMW is less than the melting point of the work pieces. The process is very fast i.e. the welding is completed within few seconds and no changes are caused in the properties of the work pieces. These numerous advantages and its wide use in the industry necessitate a closer study.

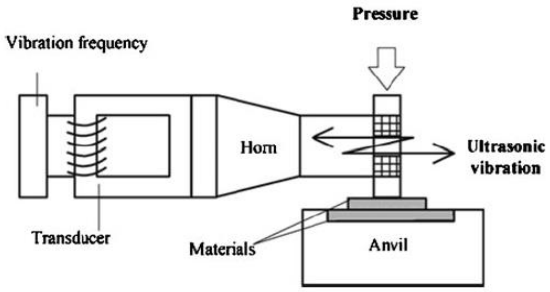

Fig. 1 Basic principle of USMW

Pressure is applied on both sides of the work while a hydraulic piston forces the welding piece against a solenoid that vibrates them at about 20,000 Hz per second. During the USMW, heat is generated due to the friction between the materials that are vibrated at high frequency and low amplitude [1].

The common problem faced in the USMW process is the production of weld of inferior quality and strength. This problem is faced during the manufacturing process due to improper selection of parameters like welding pressure, amplitude of vibration and weld time [6].

Response surface Method (RSM) delivers quadratic terms of design variables. It is capable of solving curvature in the response associated with each design variable. Types of design are 2k design with centres, 3k Factorial design, and Box-Behnken design. Response surface design problems are solved using Minitab software. Creating response-surface design and Analysis of response-surface design are the two steps in solving problems using Minitab [4].

The work presented here includes an experimental study to optimize the welding parameters with a view of maximizing the weld strength .The combination of these parameters is determined through RSM. The weld strength is an important factor that determines the weld quality. Hence, the study conducted can provide useful insight in maximizing the above mentioned response which in turn would help in improving the weld quality.
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2. EXPERIMENTAL SETUP

In this experimental work, horn made up of titanium steel with diamond knurl pattern and steel anvil with diamond knurled pattern is used to avoid slip between the work pieces. The experimental setup for the Ultrasonic metal welding is shown in Fig. 2 with data acquisition system (DAQ).

Fig. 2.Ultrasonic metal welding setup

Work pieces are prepared according to required dimensions. In this work the specimen (0.2mm copper sheet and copper wire diameter 0.9mm) was prepared based on ASTM international codes which are used for testing the joint's tensile strength by loading. Figure 3 shows the standard size of specimen from ASTM standard. The combinations of input parameters are fed into the machine as per the design matrix from RSM in which central composite design is chosen for three factors. In the current study, welding pressure and time along with vibration of amplitude of the horn were the three factors considered among the available various other factors and varied at three levels as shown in Table 1. The gap between horn and anvil is adjusted using knob screw according to the thickness of the specimens.

Table 1: Process Parameters and Experimental Levels

Variable name	Parameter	Levels		
		-1	0	+1
A	Pressure(bar)	2.5	3	3.5
B	Weld time(sec)	2	2.5	3
C	Amplitude(µm)	28	42.5	57

Specimens are placed between horn and anvil with an overlap of 6 mm. Welding was done by the ultrasonic metal welding machine for different levels of weld parameters with the data acquisition system. Weld strength for every amalgamation of weld parameters was tested and their results are tabulated in Table 2. Fig. 4 shows the actual welded samples used for joining copper sheet to copper wire. To determine the tensile strength of the A UTM was used. Some of the fractured samples are shown in Fig. 5.

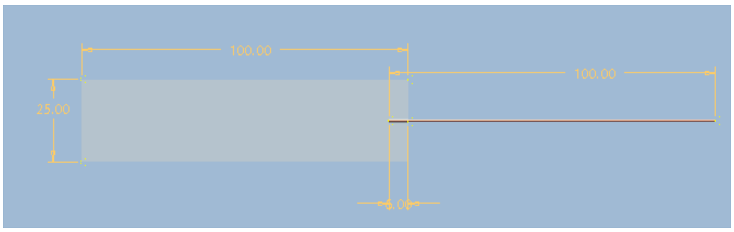

Fig 3 Standard specimen

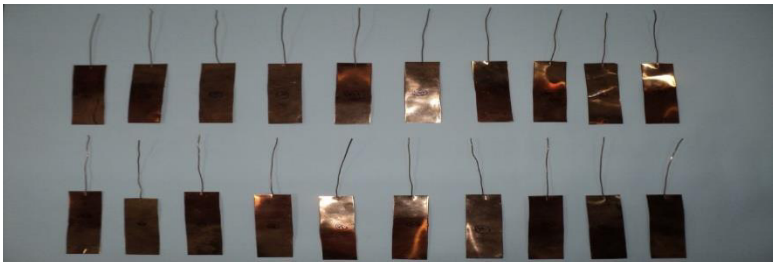

Fig. 4 Welded specimen (copper sheets 0.2mm thickness)

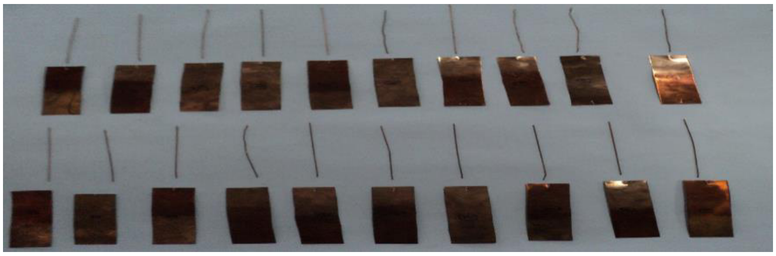

Fig 5 Tensile tested specimen (0.2 mm thickness)

Table No: 2 Experimental Results with welding and output parameters

S.No:	Pressure(bar)	Weld Time(Sec)	Amplitude(μm)	weld strength(N/mm2)
1	3.0	2.5	42.5	18.3385
2	2.5	2.0	28.0	19.8855
3	3.0	2.5	42.5	15.4350
4	2.5	2.0	57.0	26.1020
5	3.0	1.65	42.5	18.3965
6	3.5	2.0	28.0	18.1710
7	2.5	3.0	57.0	22.2515
8	3.0	2.5	42.5	18.2220
9	2.50	3.0	28.00	20.4485
10	3.50	3.0	28.00	15.4255
11	3.50	2.0	57.00	17.3170
12	3.84	2.5	42.50	15.6275
13	3.00	2.5	66.88	18.2825
14	2.15	2.5	42.50	24.6665
15	3.00	2.5	18.11	21.9995
16	3.00	3.34	42.50	23.4990
17	3.00	2.5	42.50	15.4350
18	3.50	3.0	57.00	16.1015
19	3.00	2.5	42.50	15.6535
20	3.00	2.5	42.50	15.3290

3. RESULTS AND CONCLUSION

A mathematical model is formulated based on the experimental values shown in Table.2. Weld strength is given by

Weld Strength= 87.67134-24.28873*P-23.79154 *WT+0.12364*A-0.33675*P*WT-0.14134*P*A -0.049716 *WT*A+4.28955*P2+5.42198*WT 2 + 5.09044e-003*A2 (1)

The fitness of the model is checked through Analysis of Variance. The model is found to be significant and is presented through the ANOVA table shown in Table no 3.

Table No 3: ANOVA Table for the Experiment

Source	SS	DF	MS	F Value	P Value
Model	159.28	9	17.70	3.31	0.0380
P-P	99.56	1	99.56	18.62	0.0015
WT-WT	0.13	1	0.13	0.02	0.8792
A-A	0.19	1	0.19	0.03	0.8561
P-WT	0.06	1	0.06	0.01	0.9200
P-A	8.40	1	8.40	1.57	0.2386
WT-A	1.04	1	1.04	0.19	0.6687
P2	16.57	1	16.57	3.10	0.1088
WT2	26.48	1	26.48	4.95	0.0502
A2	16.51	1	16.51	3.09	0.1094
Residual	53.47	10	5.35		

The objective of the study is to maximize the weld strength. The optimum combination of the influencing parameters for the weld strength can be found using Response Surface Method as shown in Table No 4. A list of optimal solutions is got from which the solution with the maximum desirability is chosen.

Table No 4: Desirability Table

S.No	P	WT	A	Weld Strength	Desirability
1	2.50	2.00	57.00	23.96	0.931
2	2.50	2.00	56.88	23.93	0.929
3	2.51	2.00	57.00	23.84	0.923
4	2.50	2.02	57.00	23.82	0.921
5	2.51	2.00	57.00	23.79	0.919
6	2.50	2.05	57.00	23.68	0.912
7	2.53	2.00	57.00	23.67	0.911
8	2.50	3.00	57.00	23.60	0.907
9	2.50	2.99	57.00	23.57	0.904
10	2.50	2.98	57.00	23.49	0.899

Desirability table has been plotted as graph through which desirability of the weld parameters easily identified as shown in Fig 6.

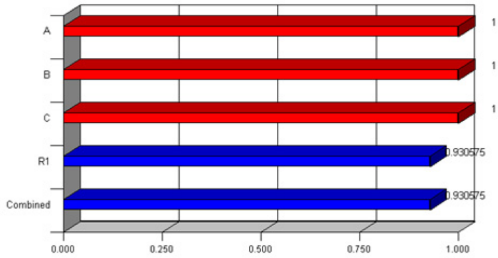

Fig 6: Desirability Graph

Optimization is also done in Excel solver by specifying the constraints. Both were found to be in close agreement with the results obtained while conducting the confirmatory experiment Optimum combination is displayed in Table No 5.

Table.5 Optimum combination

	RSM	Excel Solver	Actual
Welding Pressure	2.5	2.5	2.5
Weld time	2.0	2.0	2.0
Amplitude	57	57	57
Weld Strength	23.96	23.96	23.27

Optimization helps in the systematic control of the welding parameters to obtain a weld of good quality. RSM and Solver are found to be good prediction models.

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