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EFFECT OF PARAMETERS ON WELD STRENGTH DURING ULTRASONIC WELDING OF AL-AL STRIP

Himanshu V. Patel[1], Harshit K. Dave[2]*

[1]Research Scholar, [2]Assistant Professor Department of Mechanical Engineering, SVNIT, Surat 395 007

ABSTRACT

This paper describes an experimental study on ultrasonic welding of Aluminium. Ultrasonic Welding (USW) is an upcoming joining process which is expected to replace old techniques due to its speed and Weldablity. Weld strength is an effective attribute to identify the quality of ultrasonically welded joints. In this study the relation between Weld strength and other welding parameters has been studied. Taguchi's L27 orthogonal array has been used for the experimentation. Using Signal to Noise (S/N) ratios optimal combination of input parameters have been identified. Further to identify the level of significance of process parameters, ANOVA has been carried out on S/N ratios. It has been concluded that pressure is the most significant factor for USW of Aluminium.

Key words: *Ultrasonic, USW, Weld strength, Thickness ratio*

1. Introduction

Nowadays Ultrasonic welding is receiving significant attention over other solid state welding processes such as friction stir welding due to its relative easiness in its use and its low energy requirements [1]. Ultrasonic welding (USW) process is widely used for rapidly joining a wide range of similar and dissimilar combination of metals in very short cycle times and without melting the materials being joined. The process is performed under the application of a static clamping pressure which acts to maintain part contact. The weld interface experiences maximum temperature rises that are only 35-50% of the melting point of the material [2]. For these capabilities, the use of USW has been expediting within the electronics and electric motor industries for wire and sheet welding. Aluminium is the most widely used material in these industries due to its favourable properties. So if a joining method which is fast and has better weld strength is investigated with aluminium it will bring new benefits to the industries.

A proper set of critical variables and their values needs to be determined in order to achieve a weld bond with maximum weld strength. Some research has been carried out to weld aluminium using ultrasonic vibration and selection of these variables. Noticeably, the work done by Elangovan et al. on ultrasonic welding of copper to optimize of the process parameters using Taguchi method in which it was shown that pressure, amplitude and time are the important welding parameters [3]. Watanabe et al. studied the effect of welding conditions on the interface microstructure of the welded joint while joining mild steel sheet to aluminium alloy sheet containing magnesium and concluded that the excessive clamping force reduced the frictional action at the interface [4]. Macwan et al. have performed experiments using a dual-reed ultrasonic welding system to join Al/Mg/Al tri-layered clad sheets [5]. Bakavos and Prangnell analyzed the microstructure of weld formation mechanism of Aluminium alloys by the USW process [6]. Prasath and Rose studied mechanical and metallurgical properties of welds created by solid state welding process [7] Tsujino et al. have proposed three configurations of complex vibration systems with more than one frequency. Better weld strength is obtained using longitudinal and torsional vibration system [8]. Zhou et al. proposed measureable physical attributes that may affect the weld performance [9].

Matsuoka and Imai did and experimental study ultrasonic welding of aluminium and copper alloy and suggested that welding pressure is an important parameter to keep check on the energy requirements of a weld [10].Some research has also been carried out to quantify the bond quality of ultrasonically welded joints [11]. Baboi and Grewell have performed a series of experiments using stepped amplitude and a constant amplitude for comparing corresponding weld strengths and weld quality [12]. Hiraishi and Watanabe studied the change in weldability of Al-mg alloys by preheating and alcohol adhesion on the faying surface [13].

**Corresponding Author - E- mail: harshitkumar@yahoo.com*

Thus, from the literature review it is observed that weld pressure, amplitude and weld time are critical parameters in deciding the weld strength and quality of the weld. In this study, USW of pure Aluminium specimen has been done to investigate the Weld strength trends with different combinations of input parameters. After a series of experiments analysis is performed to identify the optimal combination of input parameters and also find the most significant parameter Weld strength.

2. Experimental Plan and Procedure

2.1 Work piece and Horn Material

Present study deals with parametric effects on weld strength during Ultrasonic welding process. This study was divided in two parts (1) Work piece Preparation and (2) Welding and Weld strength testing. Work piece materials as strips were cut from Pure Aluminium sheet. Work piece with 0.4 mm and 0.56 mm thickness were prepared according to the ASTM standard (D 1002 - 01).This generates thickness ratio combinations T_1 = 0.7, T_2= 1 and T_3= 1.4.Standard specimen size is shown in the Fig. 1. Before welding, Work pieces were cleaned with acetone to remove the surface impurities as it may affect the bond strength.

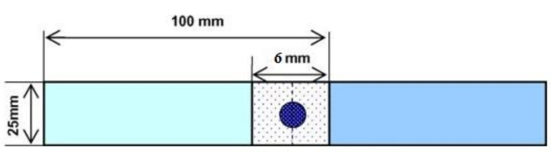

Fig. 1 ASTM standards (D 1002 – 01) [14] for weld specimen (all dimensions are in mm)

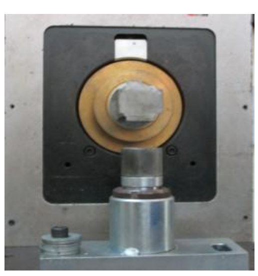

Fig. 2 Horn in USW machine

In this work horn made of hardened steel with diamond knurl pattern and anvil made of steel with serrations on top surface were used as shown in Fig. 2. During the process work pieces were held between horn and anvil under modest clamping pressure of horn. The horn has a cross section of 10 mm×6 mm.

1.2 Input and Output parameters

In present study, four parameters are selected as the input machining parameters: Amplitude (μm), Pressure (bar), Weld time (s) and thickness ratio. Three levels for each input parameters has been decided. It is desirable to have three minimum levels of process parameters, as shown in table 1, to reflect the true behaviour of the output parameters to study. Experimentation has been carried out using Taguchi's L_{27} orthogonal array. In this study weld strength was Output Parameter (Response) which was obtained by tensometer.

Table 1. Input parameters and their levels

Parameter	Symbol	Unit	L_1	L_2	L_3
Amplitude	*Ø*	μm	16	18	20
Pressure	*P*	bar	1	2	3
Weld time	*t*	s	0.5	0.75	1
Thickness ratio	*T*	-	0.7	1	1.4

2.3 Signal to Noise (S/N) ratio *η*

Signal to Noise ratio was calculated for the response parameters i.e. weld strength. As weld strength is a desirable response characteristic which is preferred to be maximum, expression for larger the better type has been used [15]. Expression used is given below:

$$\eta_s = -10\log\left[\frac{1}{10}\left(\frac{1}{y_1^2}+\frac{1}{y_2^2}+...+\frac{1}{y_n^2}\right)\right] \qquad (1)$$

Where η_s is signal to noise ratio, and y_1, y_2, y_3 ...y_n are the response of the testing characteristics carried out which were repeated *n* times.

1.3 Experimental Setup

The experiments have been carried out on RTUL M-4000 USW machine as shown in Fig 3. Machine has microcontroller based control as shown in.

Fig. 3 USW Machine

Table 2. S/N ratios for Weld strength in USW of Aluminium

Exp. No.	Parameters				Weld strength		S/N ratios
	Amplitude (µm)	Pressure (bar)	Weld time (s)	Thickness ratio	Trial 1	Trial 2	
1	16	1	0.5	0.7	25	47	29.887
2	16	1	0.75	1	38	26	29.642
3	16	1	1	1.4	45	48	33.335
4	16	2	0.5	1	103	80	39.022
5	16	2	0.75	1.4	137	129	42.465
6	16	2	1	0.7	59	72	36.196
7	16	3	0.5	1.4	108	204	42.606
8	16	3	0.5	0.7	127	124	41.971
9	16	3	0.75	1	134	127	42.302
10	18	1	1	1	120	103	40.870
11	18	1	0.5	1.4	40	118	34.579
12	18	1	0.75	0.7	71	126	38.838
13	18	2	1	1.4	145	152	43.427
14	18	2	0.5	0.7	135	114	41.810
15	18	2	0.75	1	40	84	34.164
16	18	3	1	0.7	188	148	44.321
17	18	3	0.5	1	109	90	39.837
18	18	3	0.75	1.4	171	114	42.551
19	20	1	0.5	1.4	22	24	27.210
20	20	1	0.75	0.7	133	150	42.968
21	20	1	1	1	70	62	36.343
22	20	2	0.5	0.7	124	95	40.559
23	20	2	0.75	1	38	65	33.329
24	20	2	1	1.4	82	63	36.982
25	20	3	0.5	1	83	127	39.847
26	20	3	0.75	1.4	136	111	41.700
27	20	3	1	0.7	235	228	47.288

Fig. 4 for setting welding parameters and displaying weld cycle summary at the end of the process Weld Cycle summary

Experiments were performed according to the L_{27} orthogonal array on Aluminium material. Each experiment was performed twice to get more accurate results. The weld strength was measured by tensometer. Results for weld strength and corresponding signal to noise ratio calculated are shown in table 2.

3. Results and Discussion

Main effect plots have been plotted using mean of the S/N ratio for each parameter at all levels. Analysis of variance (ANOVA) is performed and signal-to-noise (S/N) ratio is determined to know the level of significance of the process parameters. In ANOVA, the P-values test the statistical significance of each of the parameters. Percentage contribution (%P) is calculated which indicates the relative power of a factor to reduce variation. For a factor with a higher percentage contribution, a small variation will have a great influence on the performance. The procedure for ANOVA followed in present study has been laid down by Phadke, M.S. [16].

Fig. 5 shows the main effective plots for signal to noise ratio calculated for Weld strength obtained during USW of Aluminium. Further, the optimum parameter combination can be identified from the main effect plots by selecting the levels at which the signal to noise ratio is highest. The optimal combination of input parameter levels for obtaining maximum weld strength for USW of Aluminium has been identified as amplitude level 2(18 µm), pressure level 3(3 bar), weld time level 3 (1 s), thickness ratio level 1(T=0.7).

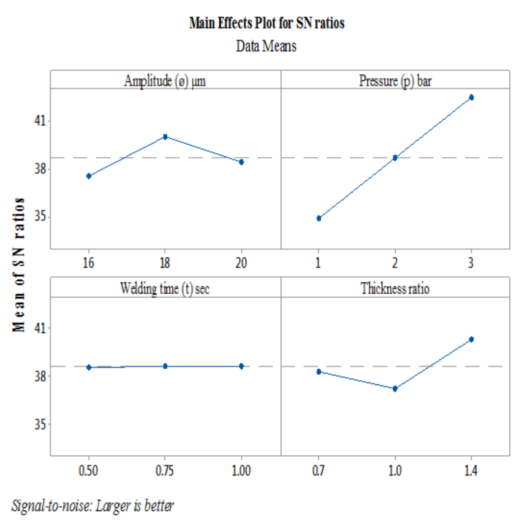

Fig. 5 Main Effect Plots for Weld strength

In order to identify the significant factors that affect weld strength, analysis of variance (ANOVA) has been carried out. Table 3 shows the results for the same. It can be seen from the table that p value for pressure is less than 0.05 which shows that the statistical significance at a confidence interval of 95%. This observation can further be confirmed by checking the percentage contribution of the factors as it can be seen that pressure has the highest percentage contribution among all parameters considered. Thus, it can be concluded that pressure has a significant effect of weld strength of in ultrasonic welding of aluminium.

Table 3 ANOVA for Weld strength during USW of Aluminium

Source	DOF	SS	MS	F value	P value	% cont.
Ø	2	29.85	14.92	0.88	0.433	4.63
P	2	262.60	131.30	7.33	0.004	40.71
t	2	0.017	0.009	0.00	0.999	0.0026
T	2	46.73	23.37	1.37	0.278	7.24
Error	18	305.90	16.99			47.42
Total	26	645.10				

As the applied pressure on the strips increases, the gap between the two strips reduces which allow better transfer of vibrations between the strips. Due to the better vibration transfer good quality of welding can be achieved. Thus, weld strength of the welded joint also increases. High weld strength can be achieved by using optimal combination of pressure and weld time.

Aluminium has low thermal conductivity. At lower amplitude of vibration, smaller area comes under scrubbing action which results into lesser frictional heat generation and dissipation in the welding zone. Hence, the weld formed is weak and confined to a very small area. As amplitude increases, the heat generation and dissipation region also increases and sound bond formed at 90 % (18 µm) amplitude. However, at 100 % (20 µm) amplitude, lower weld strength is observed due to over welding as well as temporary adhesion with anvil.

There was no significant effect of weld time on weld strength. However, it is worth noting that high thickness ratio results in attainment of high weld strength. This could be because of the use of relatively thicker sheet at the top portion. For higher thickness ratio the lower thickness (0.4 mm) sheet will be on upper side so it could easily transfer vibration to lower sheet which have higher thickness (0.56 mm) so better weld is produced. However, it is difficult for higher thickness (0.56 mm) on upper side to effectively transfer ultrasonic vibration to lower sheet (0.4 mm).

4. Conclusion

Effect of different input parameters on Weld strength during USW of Aluminium specimen has been carried. Following conclusions have been deduced:

1. Pressure with maximum percentage contribution has been found the most significant parameter for weld strength USW of Aluminium. When there is increase in pressure intimate contact was produced at interface zone which results better weld strength.
2. During USW process, amplitude at 90% (18 µm) maximum weld strength observed.
3. Weld strength is found to be minimum when the aluminium strips are of same thickness i.e. thickness ratio (*T*) = 1.
4. Optimal combination of input parameters for USW of Aluminium with Maximum weld strength is Amplitude 18µm, Pressure 3 bar, weld time 1 second and thickness ratio 0.7.

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Nomenclatures

Symbol	***Meaning***	***Unit***
Ø	*Amplitude*	*µm*
P	*Pressure*	*bar*
t	*Weld time*	*s*
T	*Thickness ratio*	-
SS	*Sum of Square*	-
MS	*Mean Sum of Square*	-

