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OPTIMIZATION OF PROCESS PARAMETERS OF ULTRASONIC WELDING ON DISSIMILAR METAL JOINTS

Nowadays the automotive industry mostly prefers innovative solid-state welding technologies that would enable to welding of lightweight and high-performance materials. In this work, 3105-H18 Aluminium alloy (Al) and pure Copper (Cu) specimens with 0.5 mm thickness have been ultrasonically welded in a dissimilar (Al-Cu) manner. Optimization of process parameters of ultrasonic welding has been carried out through full factorial method, three levels of variables considered for this experimental studies namely, weld pressure, amplitude, and time, also each variable interaction with welding strength has been studied. Additionally, micro-hardness and microstructure investigation in welded joints has been studied. The result shows that the weld strength greatly influenced weld amplitude at a medium and higher level of weld pressure. The interface micro-hardness of the welded joint has lower compared to the base metal.

Keyword: 3105-H18 aluminium alloy, pure copper, ultrasonic welding, optimization, micro-hardness

1. Introduction

Ultrasonic welding process is one of faster welding process, compared to laser and friction stir welding [1,2] material loss is very minimum and also it needs minimum energy compare to resistance spot welding [3,4]. Owing to the many advantages of ultrasonic welding, it becomes more appropriate for dissimilar metal joints especially aluminium and copper, which are applicable to aerospace industries. High-power ultrasonic welding have highly preferable for dissimilar metals, due its ability to weld thicker metals. However, intermediate compound layer found during welding process at the aluminium and copper interface, it reduces welding quality and mechanical properties. Recent researchers found that the Al and Zn interlayer improved ultrasonic welding quality of Al-Cu [5].

The applications of 3105-H18 aluminium alloys are automotive parts, household applications etc. Salifu et al. analyzed the hybrid material (3105-H18 aluminium and carbon-epoxy) used in automotive component [6]. Few researches has carried out on welding of dissimilar metals due to their application in various fields namely, automotive, electric power industry, aerospace industry etc., [7,8]. In previous researches, friction stir welding mostly used for aluminium based metals while difficult to weld in conventional welding process. Fusion welding used for welding dissimilar metals is difficult due to their difference of mechanical and physical properties [9]. Due to specific advantages of ultrasonic welding, it has used for welding dissimilar metals especially aluminium based metals. Ultrasonic welding is one of solid state welding process, in which similar or dissimilar metals can be weld by applying vibration and pressure shown in Fig. 1. The major advantages of ultrasonic welding are temperature developed during welding and time taken to finish joining process are very minimum without effecting properties of the materials [10].

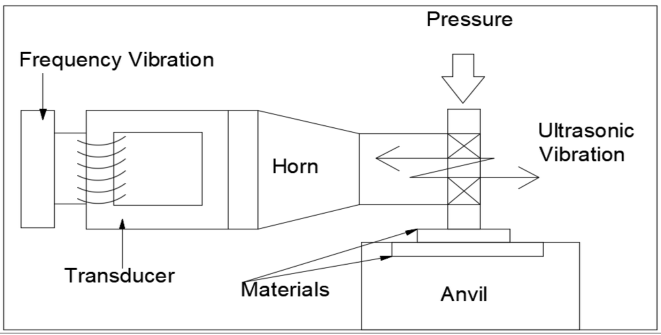

Fig. 1. Basic principal of ultrasonic metal welding

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Satpathy et al. [11] investigated optimization of process parameters of ultrasonic welding during welding of aluminium and brass with 0.3mm thick. They used input parameters namely, vibration amplitude, weld pressure and weld time, output parameters namely, Tensile shear stress, T-peel stress and weld area. They have used full factorial method and two optimization methods namely, Genetic algorithm and fuzzy logic. It has found that the optimized parameters obtained from fuzzy logic was better than Genetic algorithm. Few researchers has been carried out research work on the parameter optimization of ultrasonic welding, however, no research work has been found in ultrasonic welding using dissimilar metals namely, 3105-H18 Aluminium alloys and copper with specimen thickness 0.5 mm.

In this work, dissimilar (Al-Cu) metals has weld by using ultrasonic welding machine, full factorial design has been used and 27 experiments has conducted for each category. Control process parameter selected for the study namely, welding pressure, amplitude and weld time with three levels each. Output parameter namely, weld strength, objective of this study is to maximize the welding strength.

2. Materials and methods

2.1. Experimental setup

The welding process has been carried out using ultrasonic welding machine shown in Fig. 2, output power 2 kW, voltage 230 V, Frequency 20 kHz, PLC controlled, Pneumatic powered machine shown in Fig. 2. Components of ultrasonic welding machine namely, generator, converter, booster, horn, holding fixture, pneumatic assembly, and start switches.

Fig. 2. Ultrasonic welding machine

Tensometer is used for measuring material response under the load applied. Horizontal microcontroller based tensometer has used for experiments. The load cell varies from 200 N to 20 kN, AC servo motor with drive, the load accuracy is 0.5%, it has electronic overload stopper for load cells. Vickers micro hardness tester has used to found hardness of the test specimen. The machine modal is HVS-1000 B, digital display, test force varies from 10 to 1000 kgf, and magnification ranges from 100× to 400×, maximum height of the specimen can be test is 75 mm and power supply is 220 V and 50 Hz. The microscopic model AEI/BMM/55 type of machine has used for experiment, the ranges from 50× to 450× with illumination by Halogen lamp with power 20W-6V, inclined 45° and 360° rotatable.

2.2. Specimen composition

The specimen composition (Aluminium Alloy 3105 – H18) is shown in Table 1. The Manganese (Mn) content as higher than other alloying elements and it will induce the hardness and corrosion resistance but Magnesium (Mg) presents in higher alloy quantity next to Mn and it will induce the toughness and ductility. As presents of Silicon content deoxidising effect have increased. Pure copper specimen contains minimum 99.9% copper, 0.05% oxygen and rest contains metal impurities.

2.3. Process parameter selection

In this study process parameters selected namely, weld pressure, amplitude and weld time with 3 level as to carry out the interaction of each parameter on response variable as taken as tensile strength. To optimize these welding parameters and its levels the full factorial design of experiments methodology was included to obtain the maximize weld strength on Al-Cu joint. The welding parameters has selected as per trial and error method as shown in the following Table 2.

2.4. Specimen preparation

The specimens were prepared as per the standard of ASTM D1002 [12]. Both of material specimens has cut into the specified dimension (65 mm × 15 mm × 0.5 mm) with overlap distance of 15 mm. The schematic diagram of the specimen as shown in Fig. 3. A Tensometer has used to determine the weld strengths,

TABLE 1

Composition of Aluminium alloy 3105 – H18

Material	Mg %	Mn %	Fe %	Si %	Cu %	Zn %	Ti %	Cr %	Al %
Aluminium Alloy 3105 – H18	0.2-0.8	0.3-0.8	0.7	0.6	0.3	0.25	0.1	0.1	Remaining

TABLE 2

Welding process parameters & its range

Specimen	Weld pressure (bar)			Amplitude (μm)			Weld time (sec)		
Al-Cu	6.5	6.75	7	54	56	58	2.5	2.75	3

which has coupled with the computerized data storage system. The specimens has fixed by the fixture to avoid slippage due high frequency shearing forces.

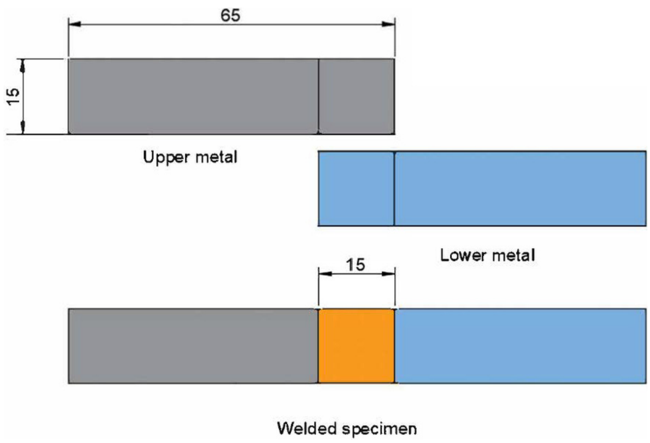

Fig. 3. Schematic diagram of specimen

2.5. Taguchi method

Taguchi method is one of statistical tool, which have use to designing high quality system. To find the deviation of experimental and desired values, a loss function has characterized. Three process characteristic has been used to analyze signal to noise (S/N) ratio namely, lower-the-better, nominal-the-better and higher-the-better Eq. (1).

$$\text{Higher}-\text{the}-\text{better} = -10\log\left(\frac{1}{n}\sum_{i=1}^{n}\frac{1}{y_t^2}\right) \quad (1)$$

Here, n – Number of replication, y_t – Tensile strength for i^{th} trial.

The highest S/N ratio gives optimum process parameters and lesser variation in tensile strength, hence the predicted values near to the preferred target. The mean S/N ratio found average of each level [13]. Three process parameters of ultrasonic welding has been considered as input parameters namely, welding pressure, amplitude and weld time with three levels each. L27 orthogonal array has found to be appropriate for this study.

3. Result and discussion

3.1. Effect of welding process parameters on tensile strength

Table 3 shows the effect of 6.5 bar pressure on welding strength is various from 22.3 MPa and to 39.6 Mpa. At 6.5 bar pressure the welding strength is decreases with increase of amplitude initially due to rubbing action between the two metals. Further increase of amplitude and welding time leads to increase of welding strength upto 39.6 Mpa due to dispersion of molecules. The same trend has been followed at 6.75 bar and 7 bar welding pressures. At 6.75 bar welding pressure, the welding strength is decreases initially and then increases upto 46.6 Mpa due to rubbing action of metal and dispersion of molecules during welding respectively. The welding strength increases upto 46.6 Mpa due to increases of welding amplitude and welding pressure initially, the Vander-wall forces develops between the metals may be the reason for increasing of tensile strength. The welding time increases with increase of tensile strength initially and then dropped due to dispersion of molecules optimum upto 2.75 s, further increases of welding time leads to decrease of weld strength.

TABLE 3

Tensile strength of the specimen

S. No	Welding Pressure (bar)	Amplitude (μm)	Weld time (sec)	Tensile strength (MPa)
1	6.5	54	2.5	30
2	6.5	54	2.75	32.3
3	6.5	54	3	30
4	6.5	56	2.5	27
5	6.5	56	2.75	29.3
6	6.5	56	3	22.3
7	6.5	58	2.5	29.3
8	6.5	58	2.75	39.6
9	6.5	58	3	32.6
10	6.75	54	2.5	21.6
11	6.75	54	2.75	32.6
12	6.75	54	3	33.3
13	6.75	56	2.5	46.6
14	6.75	56	2.75	30
15	6.75	56	3	32
16	6.75	58	2.5	34.6
17	6.75	58	2.75	27.6
18	7	58	3	22.5
19	7	54	2.5	23.2
20	7	54	2.75	43.3
21	7	54	3	27.6
22	7	56	2.5	32
23	7	56	2.75	32
24	7	56	3	37.3
25	7	58	2.5	45.3
26	7	58	2.75	25.3
27	7	58	3	42

The optimized weld strength has been obtained and tabulated as shown in Table 3. From all combinations of welded joint parameters shown in Table 3, parameters of weld pressure 6.75 bar, amplitude 56 μm, weld time 2.5 sec gives the maximum weld strength of 46.6 MPa. The ultrasonically welded specimen is shown in the Fig. 4.

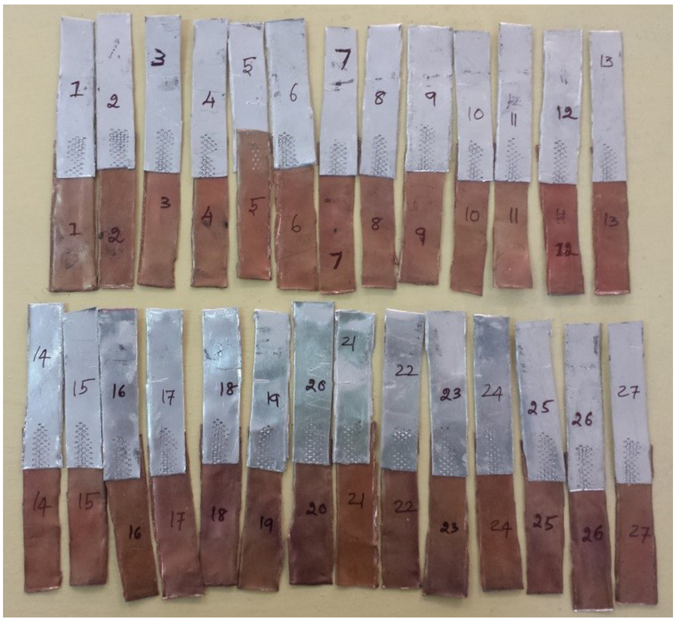

Fig. 4. Al-Cu Welded samples

The tensile tested specimen has shown in the Fig. 5. Using the Minitab software the results were analysed, the interaction of each welding parameters on weld strength has been investigated.

Fig. 5. Tensile strength tested specimen

Fig. 6. shows S/N ratio for tensile strength and it showed that weld strength has increased with increase in pressure and amplitude. The tensile strength rises with increase of welding pressure, Vander-wall forces develops between the metals may be the reason for increase bonding between the weld metals [14]. Tensile strength increases with increase of amplitude due to increase area for rubbing action between the two metals. The weld strength was initially increased then dropped with increased in weld time as shown in Fig. 6. strength increases due to the molecular attraction between the metals, further increase of weld time leads to dispersion of molecules may be the reason for reducing strength [14].

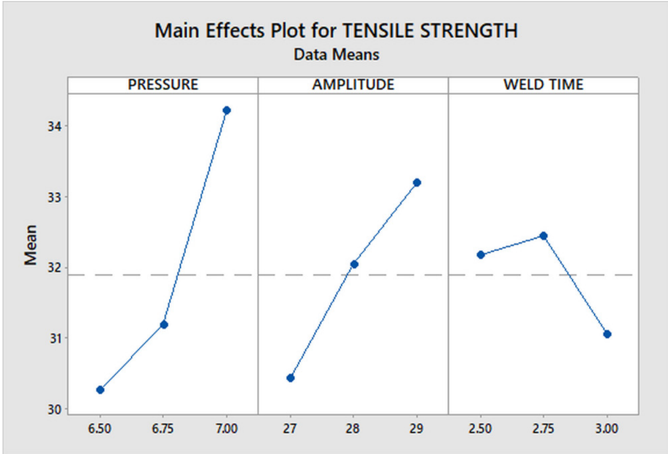

Fig. 6. S/N ratio for process parameters

3.2. Effect of interaction of welding process parameters on tensile strength

Fig. 7. depicted that interaction of welding variables on weld strength. From this graph at 6.5 bar of pressure and constant increase of welding amplitude the following observation has been described, the weld strength has dropped initially, reached upto 24 Mpa and then increased upto 34 Mpa but at 6.75 bar raised initially upto 37 Mpa and then dropped to 32 Mpa. At 7 bar welding pressure, the tensile strength has increased slightly with increase of amplitude and weld time because of high pressure permits Vander-wall forces between the plates during welding. At welding pressure of 6.75 bar the tensile strength has dropped gradually with increase of weld time, in contrary, at 7 bar welding pressure, the welding strength gradually increases with increase of molecular dispersion and further increase of weld time may be the reason for increasing of tensile strength.

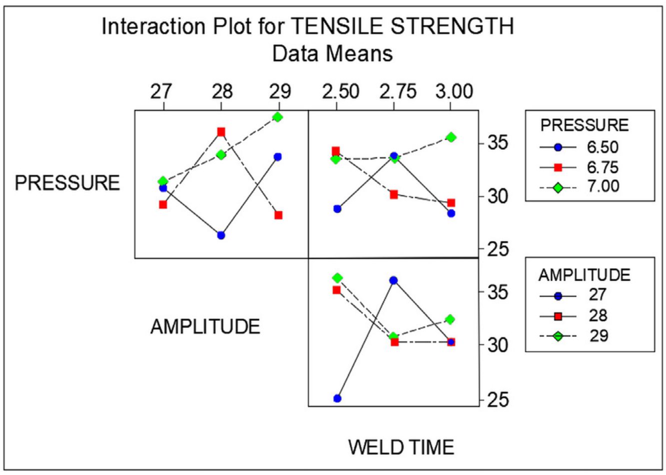

Fig. 7. Interaction plot for Tensile strength

Due to the welding amplitude of 27 µm the tensile strength has raised initially with weld time and then dropped to 30 Mpa, in contrary at amplitude of 29 µm dropped initially and then increased due to rubbing action of two metals. At 28 µm welding amplitude, the tensile strength has decreased with increase of weld time, due to the variation of area for rubbing action of two metals.

3.3. Micro-hardness Test

The micro-hardness test has carried out for the specimen having optimum parameters namely, weld pressure 6.75 bar, amplitude 56 µm, weld time 2.5 sec using Vickers micro-hardness tester and the results are shown in Table 4. The load and dwell time used for hardness test are 200 kgf and 15 s respectively. Here the base metal section having the higher hardness value than intermetallic section. The results were analyzed which arise during micro-hardness test through the Minitab software as following. Here the hardness values has taken from intermediate section and at 2 points from intermediate to base material direction, which has the average interval of 0.15 mm.

TABLE 4

Al-Cu hardness

Interface	Left side	Right side
HV-27.5	HV-30.4	HV-63.5

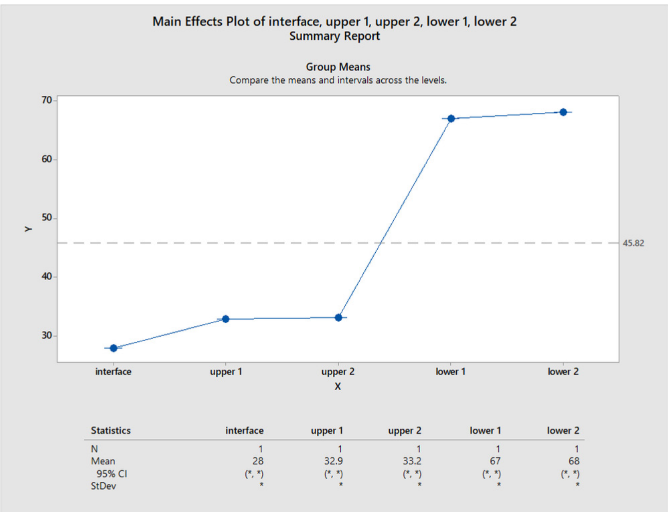

Fig. 8. Effects of different sections in welded specimen

- Through this analyses by Minitab software the hardness values increased with increase in distance from intermediate section shown in Fig. 8, which implies the hardnes s value has obtained higher in base metal section than intermediate section.
- Also the hardness was higher in upper weldment than lower weldment shown in Fig. 9.

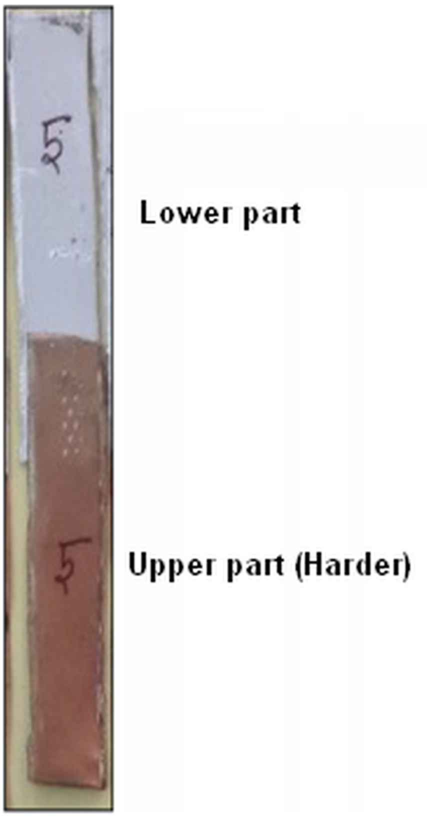

Fig. 9. Upper and Lower weldment

3.4. Microscopic examination

The microstructural investigation has been carried out for specimen having optimized process parameters as shown in Fig. 10.

- The intermetallic diffusion occurred from both sides as shown in Fig. 10, it implies strong bonding has been obtained at optimized parameters of ultrasonic welding.
- The diffusion width is narrow in middle section and rise in sideward direction because of plastic flow has occurred due to higher pressure.
- The joint having more plastic flow on aluminium side compare to copper due to its excess vacancy concentration accelerates inter-diffusion between the metals [15].

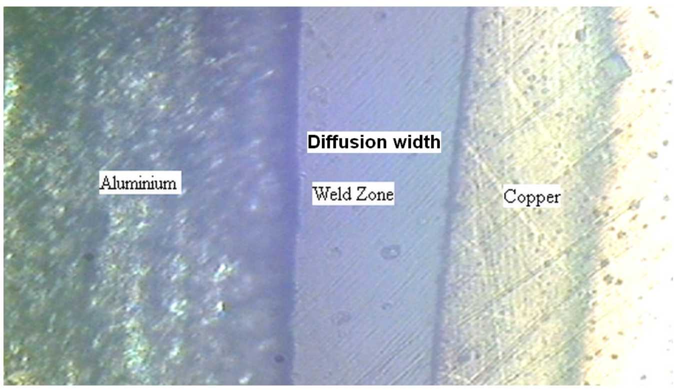

Fig. 10. Microstructure of Al-Cu Joint

4. Conclusion

In this work, parametric optimization of ultrasonic metal welding on Al-Cu joint has been studied. For this purpose full factorial design of experiments methodology was developed. The tensile strength as taken as response variable with consideration factors as welding pressure, amplitude, and weld time. Moreover, main effect and interaction plots has used for detailed explanation of analysis of results. The obtained results are,

- The optimum weld parameters for Al-Cu joint are weld time of 2.5 s, amplitude of 56 µm and pressure of 6.75 bar, which increases weld strength to maximum of 46.6 MPa.
- When weld pressure and weld time increases leads to increase of weld strength, Vander-wall forces between the plates, and molecular attraction between the materials may be the reason for tensile strength increase. The weld strength is good in medium and lower level of weld amplitude due to increase of contact area and rubbing action between the plates. At higher amplitude level the crack will propagate with increase in pressure and welding time.
- The interface section has lower hardness value than the base metal section.
- The hardness of the upper weld plate was higher than the lower weld plate. This is because of large amount strain caused by the horn in the upper part compared to lower one.
- Intermetallic diffusion of welded specimen was higher at optimized process parameters.

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