International Journal of Technical Research and Applications e-ISSN: 2320-8163,
www.ijtra.com Special Issue 12 (Jan-Feb 2015), PP. 35-38

OPTIMIZATION OF PROCESS PARAMETERS: TOOL PIN PROFILE, ROTATIONAL SPEED AND WELDING SPEED FOR SUBMERGED FRICTION STIR WELDING OF AA6063 ALLOY

R. Lokesh, V.S. Senthil Kumar, C. Rathinasuriyan, R. Sankar,
[1]PG Student, [2]Associate Professor, [3, 4]Research Scholar,
Department of Mechanical Engineering College of Engineering,
Guindy Campus, Anna University,
Chennai – 25, TamilNadu, India.

Abstract - **In this paper, AA 6063 alloy was friction stir welded under the submerged condition to obtain the optimum welding condition for maximum hardness. Rotational speed, welding speed and tool pin profiles (cylindrical, threaded and tapered) were taken as process parameters. An L9 orthogonal array with three levels and three factors was designed and executed for conducting trials. The analysis of variance (ANOVA) and signal to noise ratio analyses are employed to investigate the influence of different welding parameters on the hardness and to obtain the optimum parameters. The results indicated that a maximum hardness of 60 Hv can be achieved through underwater FSW at the nugget zone.**

***Index Terms*—submerged friction stir welding, Taguchi, ANOVA.**

I. INTRODUCTION

Friction stir welding (FSW) is widely utilized to weld heat treatable aluminum alloys that are difficult to fusion weld. However, a soften region composed of the weld nugget zone(WNZ), the thermal mechanically affected zone (TMAZ) and the heat affected zone (HAZ) is created due to the deterioration (coarsening or dissolution) of strengthening precipitates caused by FSW thermal cycles[1–4]. This leads to the deduction in the tensile strength compared to the base metal. In order to improve the joint performances by controlling the temperature level, external liquid cooling has been applied during FSW. Benavides et al. [5] Conducted FSW experiment with 2024 Aluminium alloy using liquid nitrogen cooling to decrease the starting temperature of plates to be welded from 30ºC to -30ºC. The hardness in the TMAZ and HAZ was improved compared to the normal joint. Fratini et al. [6] considered in-process heat treatment with water flowing on the upper surface of the samples during FSW. The hardness of the joint was found to be improved by the cooling action. Afshin Emamikhah et al. [7] conducted FSW with various tool pin profiles and achieved the hardness higher than that of the base metal in the stir zone due to grain refinement. FSW of Ti-6Al-4V was carried out with various rotational speed and higher hardness was obtained for lower rotational speed [8]. Puviyarasan et al. [9] Optimize the process parameters for FSP using the Taguchi technique in order to get maximum tensile strength. Huijie Zhang et al. [10] developed a mathematical relationship between tensile strength and welding parameters of submerged friction stir welded AA 2219-T6 and found the optimum process parameters for higher tensile strength.

Previous investigations have highlighted the advantages of submerged friction stir welding for strength improvement of normal FSW joints. From the viewpoint of application, it would be more significant to optimize the submerged FSW for maximum mechanical properties of the joints. However, there is a limited work on this area and the optimization of tool pin profiles for submerged FSW has not been conducted till date. Hence, AA 6063 alloy was underwater friction stir welded with various tool pin profiles in the present study.

II. EXPERIMENTAL PROCEDURE

The base metal (BM) used for the experiment was a commercially available AA6063 alloy which is 150 mm in length, 75mm in width and 6 mm in thickness. The chemical compositions and mechanical properties are listed in Table 1 and 2.

TABLE I. CHEMICAL COMPOSITION OF AA6063 (IN WEIGHT %)

Si	Pb	Fe	Cu	Ni	Mn	Zn	Mg	Al
.48	.17	.35	.75	.72	.63	.14	.69	Bl

TABLE 2. MECHANICAL PROPERTIES OF AA6063

UTS	YS	Elongation	Hardness
N/mm²	***N/mm²***	***%***	***Hv***
123	85	39.720	48

Butt welds were made under water using an FSW machine along the longitudinal direction of the welding samples. Fig. 1shows the setup for submerged FSW. The fixture is placed in the akrylik tank and is clamped to the FSW machine bed. The work piece is placed over the fixture and it is clamped properly to avoid distortion during welding. Water is poured until the water level reaches 50 mm and it remains constant. Fig. 2 shows the welded sample.

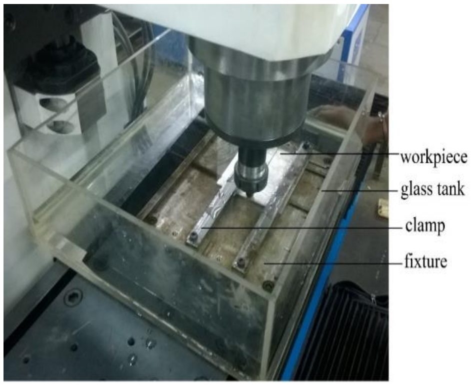

Fig.1. Submerged FSW setup

Fig.2 welded sample

The rotation speed, welding speed and tool pin profile were considered to be variables for the optimization of submerged FSW process. The parameters and its levels are shown in Table 3.

TABLE III. PROCESS PARAMETERS RANGE AND THEIR LEVELS

Factor	Process Parameter	Level		
		1	2	3
A	Tool pin profile	Cylindrical	Threaded	Tapered
B	Tool rotational speed (rpm)	800	1000	1200
C	Welding speed (mm/min)	60	120	180

The different tools including a simple cylindrical, a threaded pin with 1 mm pitch and a tapered pin with 5 mm major diameter and 2 mm minor diameter were made of H13 tool steel and were hardened up to 60 HRC. The dimensions of the tools are summarized and illustrated in Table 4.

A Vickers hardness measurement is carried out across the entire region of FSW joint with a spacing of 1 mm using a Vickers indenter with a load of 9.8 N and a dwell time of 15 s [11].

A large number of experiments have to be carried out when the number of the process parameters increases. To solve this problem, the Taguchi method uses a special design of orthogonal arrays to study the entire parameter space with a small number of experiments only An L9 orthogonal array with three levels and three factors was designed and executed for conducting trials.

TABLE IV. THE DETAILS AND DIMENSIONS OF THE DESIGNED PINS

S. No	Description of the pin	Big diameter of the pin (mm)	Small diameter of the pin (mm)	Pitch of the pin (mm)	Pin length (mm)	Shoulder diameter (mm)
1	Simple cylindrical 	5	5	None	5	15
2	Threaded 	5	5	1	5	15
3	Tapered 	5	2	None	5	15

III. RESULTS AND DISCUSSION

3.1. Signal to noise(S/N) ratio

In Taguchi method, the term “signal” indicates the desirable value for the output characteristics and the “noise” indicates the undesirable value for the output characteristics. The objective of the signal-to-noise ratio is to develop processes that are insensitive to noise. Process parameter setting with highest S/N ratio always yields the optimum quality with minimum variance. In general, signal-to-noise ratio signifies the ratio of mean to the standard deviation [12]. The quality of the welded joints is investigated by considering hardness as the main characteristic feature. In order to find the influence of process parameters on the response, the Signal to Noise ratio and means for each process parameter were calculated.

In this current work, the S/N ratio was chosen according to the principle of ‘the larger-the better’ characteristics, which is shown below.

$$(S/N)_{HB} = -10\log_{10}\left(\frac{1}{n}\sum_{i=1}^{n}\frac{1}{H_i^2}\right) \quad (1)$$

Where n is the number of the repetitions and H_i is the value of the hardness of the test on that trail. The process parameters, experimental hardness and signal-to-noise (S/N) ratio are given in Table 5.

TABLE V. L9 ORTHOGONAL ARRAY WITH RESPONSE

S. No	Input Parameters			Hardness (Response)	S/N ratio
	A	B	C		
	Pin profile	***rpm***	***mm/min***	***Hv***	***Db***
1	Cylindrical	800	60	49.30	33.85
2	Cylindrical	1000	120	50.73	34.10
3	Cylindrical	1200	180	51.32	34.20
4	Threaded	800	120	55.20	34.83
5	Threaded	1000	180	48.08	33.63
6	Threaded	1200	60	52.53	34.40
7	Tapered	800	180	52.04	34.32
8	Tapered	1000	60	53.35	34.54
9	Tapered	1200	120	61.54	35.58

The mean response of S/N ratio and experimental data for each level of the process parameter are given in Table 6 and 7.

TABLE VI. AVERAGE RESPONSE TABLE FOR MEAN

Levels	Mean		
	Tool pin profile	**Rotational speed**	**Welding speed**
		(rpm)	***(mm/min)***
1	50.45	52.35	51.89
2	51.94	50.89	55.36
3	55.51	54.66	50.65
Max-min	5.06	3.78	4.71
Rank	1	3	2

TABLE VII. AVERAGE RESPONSE TABLE FOR S/N RATIO

Levels	S/N ratio		
	Tool pin profile	**Rotational speed**	**Welding speed**
		(rpm)	***(mm/min)***
1	34.06	34.37	34.30
2	34.30	34.12	34.84
3	34.87	34.73	34.08
Max-min	0.82	0.61	0.76
Rank	1	3	2

3.2. Analysis Of Variance

Analysis of variance (ANOVA) test was performed to identify the statistically significant process parameters [13]. This analysis was carried out for a level of significance of 5 %, i.e. for 95% confidence level. The ANOVA results of S/N ratio and means for hardness are given in Table 8 and Table 9 respectively. Statistically, there is a tool called an F test named after Fisher [14] to find which design parameters have a significant effect on the quality characteristic.

TABLE VIII. ANOVA OF MEANS FOR HARDNESS

Factor	**Process Parameters**	**Sum of squares**	**Degrees of freedom**	**Mean sum of squares**	**F-test**
A	Tool pin profile	40.582	2	20.291	11.43
B	Rotational speed	21.762	2	10.881	6.13
C	Welding speed	35.733	2	17.866	10.06
Error		3.552	2	1.776	
Total		101.629	8		

TABLE IX. ANOVA OF S/N RATIO FOR HARDNESS

Factor	**Process Parameters**	**Sum of squares**	**Degrees of freedom**	**Mean sum of squares**	**F-test**
A	Tool pin profile	1.0564	2	0.52819	10.27
B	Rotational speed	0.5644	2	0.28221	5.49
C	Welding speed	0.9168	2	0.45840	8.91
Error		0.1029	2	0.05145	
Total		2.6405	8		

Usually, when F>4, it means that the change of the design parameter has a significant effect on the quality characteristic [14]. Therefore, the tool pin profile, the rotational speed and the welding speed has the significant influence on the quality characteristic. The percentage of the contribution of the tool pin profile, rotational speed and welding speed is shown in Fig. 3.

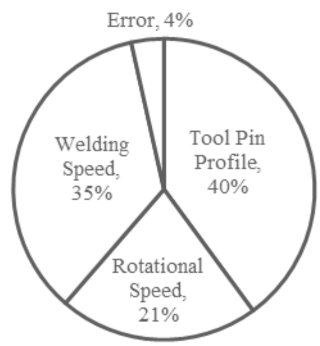

Fig.3. Percentage Contribution of Process Parameters

The most important factors that influence the Submerged FSW process was the tool pin profile with 40% contribution rate and the percentage of error is 4%

3.3. Confirmation Test

Fig 4. Shows two graphs, each of which represent main effects plot for means and S/N ratio. Based on the highest values of the S/N ratio and mean values (Fig 4), the overall optimum process parameters for hardness are A_3, B_3 and C_2.

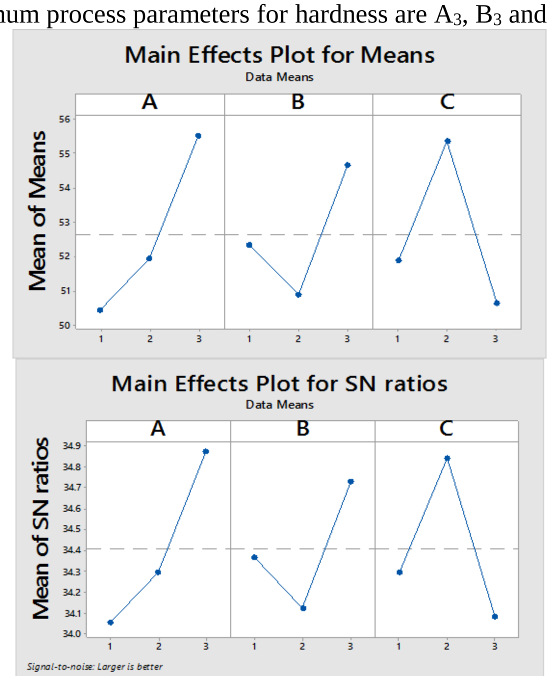

Fig.4. Main effects plot for means and S/N ratio

The theoretical hardness value for the optimum process parameters has been calculated from the following equation [9].

$$H_{predicted} = H_m + \sum_{i=1}^{n}(H_0 - H_m) \qquad (2)$$

H_m is the mean response or mean S/N ratio, H_0 is the mean response or mean S/N ratio at optimal level and n is the number of main design parameters that affect the quality characteristics. Substituting the values in Equation 2, the predicted hardness value is 60.26 Hv. The hardness value for the optimum level of process parameters was 61.54.

Vickers hardness profile of the metal welded at optimum level of process parameters under submerged condition is shown in Fig. 5. From the graph, it is evident that the hardness value of the welded metal is higher than the base metal at the stir zone.

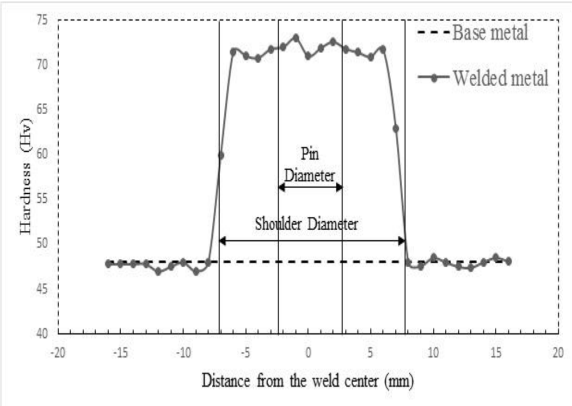

Fig. 5. Vicker's hardness profile of base metal and the welded metal at optimum condition

IV. CONCLUSION

In this investigation, AA6063 alloy was successfully welded under submerged FSW. The results can be summarized as follows:

- The parameters affecting friction stir welding while joining AA6063 alloy were studied. It is observed that tool pin profile, rotational speed and welding speed have a significant effect on the response (hardness).
- The percentage of contribution of submerged FSW process parameters was evaluated using ANOVA. It is found that the tool pin profile, rotational speed and welding speed contributes 40%, 21% and 35% respectively.
- The optimum parameter combinations such as tapered pin profile, rotational speed of 1200 rpm and welding speed of 120 mm/min provide higher hardness.
- The hardness value at the nugget zone is 20% higher than the base metal.

REFERENCES

[1] Fonda RW, Bingert JF. Microstructural evolution in the heat-affected zone of a friction stir weld. Metall Mater Trans A 2004; 35:1487–99.

[2] Mishra RS, Ma ZY. Friction stir welding and processing. Mater Sci Eng R 2005; 50:1–78.

[3] Simar A, Bréchet Y, Meester B-De, Denquin A, Pardoen T. Microstructure, local and global mechanical properties of friction stir welds in aluminium alloy 6005A-T6. Mater Sci Eng A 2008; 486:85–95.

[4] Starink MJ, Seschamps A, Wang SC. The strength of friction stir welded and friction stir processed aluminum alloys. Scripta Mater 2008; 58:377–82.

[5] Benavides S, Li Y, Murr LE, Brown D, McClure JC. Low-temperature friction-stir welding of 2024 aluminum. Scripta Mater 1999; 41:809–15.

[6] Fratini L, Buffa G, Shivpuri R. In-process heat treatments to improve FS-welded butt joints. Int J Mach Tool Manufact 2009; 43:664–70.

[7] Emamikhah, Afshin, et al. Effect of tool pin profile on friction stir butt welding of high-zinc brass (CuZn40). The International Journal of Advanced Manufacturing Technology 71.1-4 (2014): 81-90.

[8] Zhang, Yu, et al. "Microstructural characteristics and mechanical properties of Ti–6Al–4V friction stir welds." Materials Science and Engineering: A 485.1 (2008): 448-455.

[9] Puviyarasan, M., and V. S. Kumar. "Optimization of friction stir process parameters in fabricating AA6061/SiCp composites." Procedia Engineering 38 (2012): 1094-1103.

[10] Zhang, Huijie, and Huijie Liu. Mathematical model and optimization for underwater friction stir welding of a heat-treatable aluminum alloy. Materials & Design 45 (2013): 206-211.

[11] Zhang, Yu, et al. "Microstructural characteristics and mechanical properties of Ti–6Al–4V friction stir welds." Materials Science and Engineering: A 485.1 (2008): 448-455.

[12] Elangovan, Sooriyamoorthy, K. Prakasan, and V. Jaiganesh. "Optimization of ultrasonic welding parameters for copper to copper joints using design of experiments." The International Journal of Advanced Manufacturing Technology 51.1-4 (2010): 163-171.

[13] Bozkurt, Yahya. "The optimization of friction stir welding process parameters to achieve maximum tensile strength in polyethylene sheets." Materials & Design35 (2012): 440-445.

[14] Yang, W. H., and Y. S. Tarng. "Design optimization of cutting parameters for turning operations based on the Taguchi method." Journal of Materials Processing Technology 84.1 (1998): 122-129.

.