Parameters Optimization for Friction Spot Welding of Aluminium 6082 by the Taguchi Method

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Abstract

Friction spot welding (FSpW) is a solid state welding process suitable for producing spot-like joints, especially in lightweight materials such as Aluminium, which is particularly interesting due to the weight saving potential. The plunging of an especially designed non-consumable and rotating tool creates a connection between the 2mm thickness overlapped sheets through frictional heat and plastic deformation. Minimum material loss is observed, and therefore a fully consolidated joint with flat surface (no keyhole) is obtained. In the current study, the effect of FSpW parameters, such as rotational speed, plunge depth and plunging time, on lap shear strength of Aluminium 6082 T6 joints was investigated. The optimization of input process parameters was carried out through Taguchi approach of DOE. Each parameter was analyzed individually by mean average and SNR (Signal to noise ratio). Level tables were developed to indicate the best levels for maximizing lap shear strength. The results show that plunging time has the higher effect on the weld strength, followed by rotational speed and plunging depth as well as the final optimized parameter for this specific weld.

Key-words: *Friction spot welding; Al 6082; Taguchi method.*

1. Introduction

Friction Spot Welding (FSpW) is a new solid-state joining process developed and patented by *GKSS Forschungszentrum GmbH* (Nowadays *HZG - Helmholz-Zentrum Geesthacht*) in Germany [1] to weld lightweight metals and thermoplastics. Originated from the process of Friction Stir Welding FSW developed by *The Welding Institute* (TWI) in England, *Friction Spot Welding* consists of joining plates through one welding point with a set of tools that generates the bonding by friction and without leaving any reminiscent keyhole at the end of the joining operation, as it’s ancestor also deriving from FSW, called *Friction Stir Spot Welding* (FSSP).

The aircraft and automotive industries are giving considerable attention to these joining processes, due to the fact that friction welding offers great appliances with Aluminium and lightweight alloys, overcoming the main disadvantages of conventional welding processes and managing the Industry to produce lighter pieces and vehicles which generates less use of energy and consequently less pollution to the environment [2]. This process increases the accuracy of the weld due to the automation in the technology, since the operator handwork isn’t requested during the bonding process. After the parameters are set on the machine and the welding button is pressed, there is no human interference until it’s finished.

FSpW also presents many advantages over conventional spot joining techniques such as high energy efficiency, surface quality (no there is no need for post processing), reduction in the number of steps to be applied during weld, process speed, reproducibility and environmental compatibility. Therefore the potential for the use of FSpW in several structural components is extremely large and the benefits of replacing mechanical fastening or fusion welding techniques are significant.

Friction Spot Welding is performed with a three pieces tool system which is shown in Figure 1, Clamping ring, Sleeve and Pin. The clamping ring is responsible for pressing the plates together and avoiding the loss of material, while the sleeve and pin are able to plunge into the plates. Every single one of them is fixed with a single actuator system being able to move in the vertical direction independently of the other but always with the same rotational speed and direction [3]. The welding can be executed with two different process variants called Sleeve-Plunge (SP) and Pin-Plunge (PP) [4]. In both processes, four different stages are recognized and explained above.

In the sleeve plunge variation (applied in this research), the sheets are overlapped and clamped, when sleeve and pin start to rotate generating then heat from friction on the upper sheet surface. While pin moves up, the sleeve plunges into the sheet until a specified plunge depth and plasticized material, due to frictional heat, is squeezed into the space left by the pin retraction. Dwell time from the pin and sleeve could also be used at this point to develop more material mixing at the lowest sleeve point, which means there is no vertical movement from any of the tools during that time.

After plunging and possible dwell time, both sleeve and pin retract back to the original position, pushing the material originally displaced, to the surface level. The process is then finished generating a completely “refilled” hole with minimal or no surface indentation, since there is almost no material loss. A schematic representation of the sleeve plunge process is showed in Figure 1 as well as tools movements and rotation.

Pin plunge variation is a similar method that instead of plunging the sleeve into the material, the pin penetrates the plates while the sleeve retracts in order to accommodate the material displaced. Pin plunge is easier to perform due to less force and torque demand from the welding machine, but it creates a smaller sized joint area, which leads to lower joint strength comparing to sleeve plunge [5].

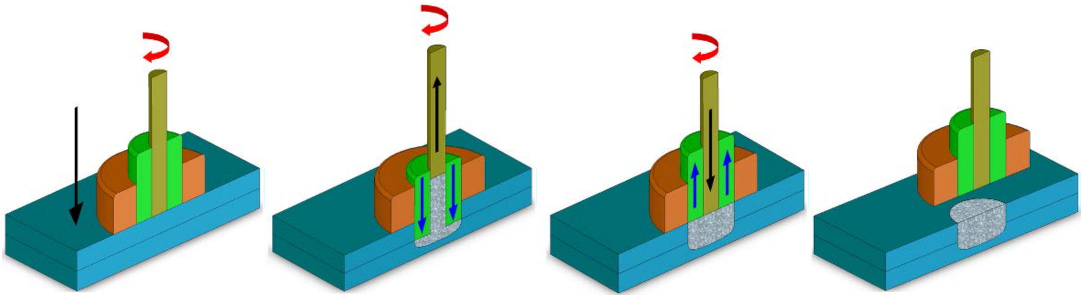

Figure 1 – Illustration of the Sleeve Plunge variation: (a) Clamping ring and tool rotation; (b) Sleeve plunge and pin retraction; (c) tools back to surface level and (d) tool removal.

2. Materials and Methods

Al 6082 T6 with 2mm thickness thick were used in the present study. Sheets were cut to 100 mm long and 25.4 mm wide coupons and according to ASTM D-1002-05 standard [6], the friction spot welded specimens were prepared in lap-shear configuration with 25.4 mm overlap. The tool system consisted of a 16mm diameter clamping ring, 9mm diameter sleeve and 6mm diameter pin. Three main process parameters have been varied in this study: plunge depth (PD), plunging time (PT) and rotational speed (RS). Before welding the samples both Al plates are cleaned with acetone to avoid any influence from dirtiness and other substances such as waste from cutting and oil. The two specimens are then placed in lap-shear configuration in a fixed specimen holder on the base plate and the parameters to be tested are typed into the control system. The equipment used for testing includes a screw-driven Zwick/Roell testing machine with a load capacity of 200 kN and TestXpert software which provides the tensile properties (maximum tensile loads are mentioned as lap shear forces) at room temperature. During the tests a speed of 2 mm/min was used and at least three replicates were produced for each joining parameter.

Preliminary experiments were performed to create working limits for the FSpW parameters. As shown in Table 1, each parameter was set by three levels. An orthogonal array was chosen by the total degrees of freedom from the experiment (DF = number of levels - 1). Since each three-level parameter has two degrees of freedom, the total DF required is six. The DF of selected orthogonal array must be greater than or at least equal to the total DF, choosing a L9 array (DF = 8) for the present experiment. LSS (Lap Shear Strength) comprehends the quality characteristics. [7]

Parameter	Symbol	Level 1	Level 2	Level 3
Plunge depth (mm)	PD	*1.9*	*2.1*	*2.3*
Plunging time (s)	PT	*1.2*	*1.8*	*2.4*
Rotational Speed (rpm)	RS	*1300*	*2000*	*2700*

Table 1 - Welding parameters and their levels.

Experiment	Parameter			Response			Mean (N)	SNR (dB)
	PD	PT	RPM	LSS 1 (N)	LSS 2 (N)	LSS 3 (N)		
Taguchi 1	1,9	1,2	1300	*6382,08*	*6592,41*	*6601,14*	6525,2	76,289
Taguchi 2	1,9	1,8	2000	*7542,43*	*7692,21*	*7759,94*	7664,9	77,688
Taguchi 3	1,9	2,4	2700	*6899,09*	*6817,36*	*7066,83*	6927,8	76,809
Taguchi 4	2,1	1,2	2000	*7948,90*	*7974,43*	*7863,87*	**7929,1**	**77,984**
Taguchi 5	2,1	1,8	2700	*6816,68*	*7025,53*	*7035,24*	6959,2	76,848
Taguchi 6	2,1	2,4	1300	*7295,66*	*6413,64*	*6471,16*	6726,8	76,512
Taguchi 7	2,3	1,2	2700	*7330,93*	*7753,57*	*7833,35*	7639,3	77,650
Taguchi 8	2,3	1,8	1300	*7278,32*	*6690,66*	*6985,85*	6984,9	76,868
Taguchi 9	2,3	2,4	2000	*6292,00*	*6064,20*	*5700,36*	6018,9	75,569

Table 2 - L9 Orthogonal array with response, mean and S/N ratio.

Level	Mean (N)			S/N ratio (dB)		
	PD	PT	RS	PD	PT	RS
1	*7039,28*	*7364,52*	*6745,66*	*76,93*	*77,31*	*76,56*
2	*7205,01*	*7202,98*	*7204,26*	*77,11*	*77,13*	*77,08*
3	*6881,03*	*6557,81*	*7175,40*	*76,70*	*76,30*	*77,10*
Δ	323,99	806,71	429,74	0,42	1,01	0,55
Rank	**3**	**1**	**2**	**3**	**1**	**2**

Table 3 - Main effects of LSS (mean and S/N ratio).

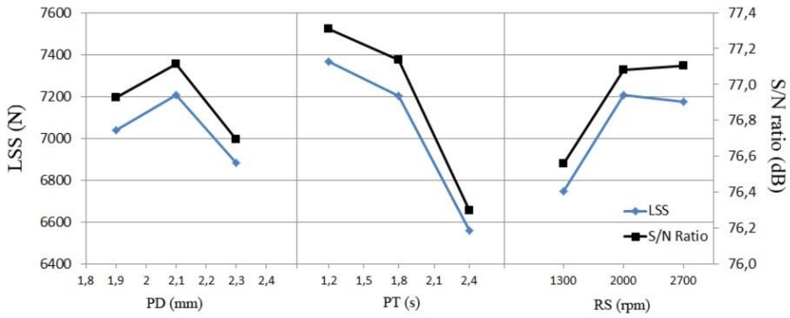

Figure 2 - Main effects for mean and S/N ratio.

3. Results and Discussion

Table 2 presents LSS experimental values along with calculated mean (average) and S/N ratio for each combination of parameters. S/N ratio is used to calculate the deviation from the desired level of quality and the category of “larger the better” was set. Table 3 shows the calculation from mean and S/N ratio for each parameter at all 3 different levels. The mean response states the average value of the performance characteristic for each parameter at different levels. The mean of one level is calculated as the average of all responses obtained in that particular level. Delta (Δ) helps assessing which parameter has the greatest effect on the response by measuring the amplitude or effect intensity. This is the difference between the highest and the lowest level result for each parameter, from this number the ranking is set from higher to lower numbers, indicating then the biggest amplitude of variation per parameter, setting 1 to 3 from the greatest to the least effect on the response respectively. For both analysis, PT has the most significant effect on the weld, followed by RS (which is less relevant) and PD is the last one on the rank, indicating the lowest effect among the other two parameters.

Values from Table 3 are plotted on Figure 2 and since larger S/N values correspond to better quality characteristics with minimum variance, the purpose of DOE is to determine not only the maximum mean LSS but also the highest possible S/N ratio [7]. From the information taken from Figure 2, it’s clear from both Mean LSS and S/N ratio that the highest quality parameter is achieved at 2.1mm PD and 1.2s PT, however the RS induces two different options, 2000rpm by LSS and 2700rpm by S/N analysis. Both conditions were tested and RS of 2000rpm was confirmed the highest quality parameter combined. Note that this parameter combination is already included in the L9 orthogonal array (Taguchi 4 in Table 2).

The selected parameter from Taguchi’s approach acquired contained the minimum level estimated for PT (1.2s), hence this, the borders selected at first could be narrowed and centered to this value in order to verify if there is still a better condition to perform FSpW on Al 6082 T6 with two overlapped 2 mm thickness plates, since the main value differences for PT and RS were very distant, with 0.6s and 700rpm respectively. Table 4 was developed with a smaller difference between parameters in order to verify the availability of better results around the levels found before. All combinations were tested with the new levels of parameters and shown together with the results in Table 5.

Parameter	Level 1	Level 2	Level 3
PD (mm)	*1,9*	*2,1*	*2,3*
PT (s)	*0,9*	*1,2*	*1,5*
RS (rpm)	*1700*	*2000*	*2300*

Table 4 - New levels of parameters.

Experiment	Parameter			Response			Mean (N)
	PD (mm)	PT (s)	RS (rpm)	LSS 1 (N)	LSS 2 (N)	LSS 3 (N)	
FP 1	1,9	1,2	2000	*7939,61*	*8656,88*	*8643,45*	8413,3
FP 2	2,3	1,2	2000	*8235,28*	*7722,06*	*7918,68*	7958,7
FP 3	2,1	0,9	2000	*9089,95*	*9099,81*	*8930,91*	9040,2
FP 4	2,1	1,5	2000	*7982,12*	*7929,85*	*7915,71*	7942,6
FP 5	2,1	1,2	2300	*8041,44*	*8040,59*	*8011,62*	8031,2
FP 6	2,1	1,2	1700	*8964,94*	*8907,72*	*8605,13*	8825,9

Table 5 – All possible combinations for new set of levels.

The experiment **FP 3** presented a lap shear mean result of more than 9 kN, confirming Taguchi’s approach in ranking the parameters that are most effective on this weld. The only change among the levels was the Time for Plunge Depth, and this is presented on Table 3 as having the most significant effect by S/N Ratio and LSS respectively with ranking number 1.

The PT for this Parameter (0.9 s) is the lowest value from Table 4, and from these results there could also have a better value for the LSS with an even lower value for PT. This insinuated another welding sequence with the same parameter redefinition procedures used before. For this new sequence of welding, no better tensile results were acquired.

4. Conclusion

The parameters used for friction spot welding of Al 6082 T6 were investigated by the Taguchi method and successfully optimized. Plunging time was found to have the greatest influence on both mean and S/N ratio, followed by rotational speed and plunging depth. The parameter combination was optimized by first setting a border of possible levels, and the parameter with the most influence was distinguished. Therefore level adaptions were made due to possibly better LSS results from the border first established. The optimum combination found was 2.1 mm of Plunging Depth, 0.9 s of plunging time and 2000 rpm of rotational speed. Results acquired were higher than expect achieving more than 9 kN mean for LSS.

5. Acknowledgments

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6. References:

[1] Schilling, C., dos Santos, J., 2004. Method and Device for Linking at Least Two Adjoining Work Pieces by Friction Welding. US Patent 6,722,556 B2. April 20, 2004.

[2] DA SILVA, A.A.M. et al. Microstructure and Properties of Friction Spot Welds in a 2-mm Thick Alclad AA2024 T3 Alloy. In *FABTECH International and AWS Welding Show*. 2007. Chicago, USA.

[3] DA SILVA, A.A.M. et al. Friction Spot and Friction Stir Spot Welding Processes – A Literature Review. In *The Bulletin of National R&D Institute for Welding and Material Testing*. 2007. Timişoara: ISIM. p. 36-44.

[4] DA SILVA, A.M. et al. Friction Spot and Friction Stir Spot Welding Processes – A Literature Review. Bulletin of National R&D Institute for Welding and Material Testing, v. 3, p. 36-44, 2007.

[5] ARBEGAST, W.J. Refill Friction Stir Spot Welding of Aluminum Alloys. In *IIW International Seminar on Friction based Spot Welding Processes*. 2007. Geesthacht, Germany.

[6] AMERICAN SOCIETY FOR TESTING AND MATERIALS. **ASTM D 1002-05**: Standard Test Method for Apparent Shear Strength of Single-lap Joint Adhesively Bonded Metal Specimens by tension Loading (Meta-to-Metal). 2005. 5 p.

[7] Leonardo Contri Campanelli, Parameters Optimization for Friction Spot Welding of AZ31 Magnesium Alloy by Taguchi Method