OPTIMIZING THE PROCESS PARAMETERS IN FRICITON STIR SPOT WELDING OF DISSIMILAR ALUMINUM ALLOYS USING GENETIC ALGORITHM

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Abstract. Welding of dissimilar aluminum alloys by Resistance spot welding and Self-piercing rivets requires high energy consumption, increased cycle time, and costs. Friction stir spot welding (FSSW) is one of the best alternative welding techniques to join dissimilar aluminum alloys with the help of frictional heat and plastic deformation. However, the drawback of this process is the keyhole left behind by the tool. Hence this study focusses on avoiding the keyhole post welding process by the use of pinless tools to join thin sheets of Al 6061 and Al 5754. The influence of process parameters such as tool rotational speed, plunging speed, dwell time, plunge depth, and shoulder diameter was studied on the Tensile shear force of the joint. The optimal welding condition was predicted with the help of the Genetic algorithm. The confirmation tests showed that the predicted optimal conditions were in closer agreement to the experimental value.

1. INTRODUCTION

Joining of dissimilar aluminum alloys by conventional welding methods like Resistance spot welding (RSW) and Self-piercing rivets (SPR) requires high energy consumption, increased cycle time and costs. Hence an alternative welding technique like Friction stir spot welding (FSSW) is employed by the automakers to overcome the disadvantages of RSW and SPR [1]. The FSSW is a solid-state welding technique that joins similar and dissimilar materials with the help of frictional heat and plastic deformation. However, the keyhole left behind by the tool acts as a stress concentration factor and also acts as a corroding agent. To avoid this issue, Refill Friction stir spot welding (RFSSW) was developed to join weldments without producing the keyhole. However, this technique involves complex tool design, increased welding time and is suitable for joining thick plates [2]. For joining sheets with thickness <2 mm, pinless or flat tools are preferred. The use of pinless tools with and without features were reported to produce joints with higher load-bearing capacity when compared to that of joints welded with pin tools. Moreover, with the use of pinless tools also reduces the formation of the hook at the interface, which tends to act as the crack nucleation site and reduces the joint strength [3-4]. In pinless FSSW, the shoulder diameter and the shoulder plunge play a vital role in obtaining the joint with superior mechanical and metallurgical characteristics. The shoulder diameter and plunge depth help in inducing the plastic deformation and the flow of plasticized material flow to form stronger joints [5-6]. Various optimization techniques like Taguchi, Response Surface Methodology (RSM), Artificial neural network (ANN) and Fuzzy logic have been reported to find the optimal welding conditions in joining dissimilar aluminum alloys by FSSW [7-13]. Since there is scarce literature available in pinless FSSW of Al 6061 and Al 5754, in this paper, the optimal welding conditions are identified using the Genetic Algorithm (GA).
2. Experimental Methods
Al 6061 and Al 5754 alloys of thickness 1 mm, were placed onto the 10 mm thick mild steel backing plate and rigidly clamped onto the worktable. The FSSW machine of 30 kN axial force, 11 kW capacity, was utilized to join the dissimilar Al sheets with the help of pinless tools. Three pinless tools of H-13 steel with 52 HRC and different shoulder diameter were considered for this study. The chemical composition and mechanical properties of the alloys are listed in Table.1 and Table.2, respectively.

Table 1. Chemical composition of Al 6061 and Al 5754

|       | Al 6061 |       | Al 5754 |
|-------|---------|-------|---------|
|       | Element | Wt %  | Element | Wt %  |
|       |         |       |         |       |
|       | Si      | 0.42  | Si      | 0.25  |
|       | Fe      | 0.21  | Fe      | 0.31  |
|       | Mg      | 1.0   | Mg      | 3.2   |
|       | Cu      | 0.19  | Cu      | 0.02  |
|       | Mn      | 0.15  | Mn      | 0.38  |
|       | Cr      | 0.27  | Cr      | 0.23  |
|       | Zn      | 0.25  | Zn      | 0.18  |
|       | Al      | Bal   | Al      | Bal   |

Table 2. Mechanical properties of Al 6061 alloys and Al 5754

|       | Al 6061 |       | Al 5754 |
|-------|---------|-------|---------|
|       | Yield Strength (MPa) | Ultimate Tensile Strength (MPa) |
|       | 276     | 312   |
|       | 130     | 222   |

The experimentation sequence, Table.3, was done based on 5 factors, 3 levels Box-Behnken design, which is generated using Design Expert 11 software. Box-Behnken Design helps the experimenter to determine the second-order models instead of predicting the response values at the extreme points. The process parameters like tool rotational speed, plunging speed, dwell time, plunging depth, and shoulder diameter was considered for this study, as they were identified to affect the mechanical and metallurgical properties of the weldments from extensive experiments and literature survey. The mechanical testing of the weldments was done at a cross-head speed of 1 mm/min in a 50 kN capacity UTM machine. The Model-based calibration tool (MBC) in Matlab 2015 is employed for finding the optimal welding conditions by the Genetic algorithm, GA. The MBC toolbox utilizes the experimental sequence generated based on the Design of experiments to determine the optimal processing conditions.

Table 3. Experimental sequence with results

| Ti   | Tool Rotational Speed, A, RPM | Plunging Speed, B, mm/s | Dwell Time, C, s | Plunge depth, D, mm | Shoulder diameter, E, mm | Tensile shear Force, Ts, kN |
|------|-------------------------------|-------------------------|-----------------|---------------------|--------------------------|---------------------------|
| 1    | 1300                          | 0.04                    | 8               | 0.5                 | 25                       | 5.174                     |
| 2    | 1000                          | 0.04                    | 4               | 0.75                | 20                       | 3.979                     |
| 3    | 1000                          | 0.04                    | 8               | 0.75                | 15                       | 2.915                     |
| 4    | 1000                          | 0.02                    | 8               | 0.5                 | 25                       | 3.484                     |
| 5    | 1000                          | 0.02                    | 12              | 0.5                 | 20                       | 1.239                     |
| 6    | 1000                          | 0.04                    | 4               | 0.25                | 20                       | 2.525                     |
| 7    | 700                           | 0.04                    | 8               | 0.75                | 20                       | 4.589                     |
| 8    | 1300                          | 0.02                    | 8               | 0.5                 | 20                       | 3.116                     |
| 9    | 1300                          | 0.04                    | 4               | 0.5                 | 20                       | 4.460                     |
| 10   | 1000                          | 0.06                    | 4               | 0.5                 | 20                       | 3.330                     |
| 11   | 1000                          | 0.04                    | 4               | 0.5                 | 25                       | 5.704                     |
| 12   | 1300                          | 0.04                    | 12              | 0.5                 | 20                       | 3.332                     |
| 13   | 1000                          | 0.04                    | 12              | 0.75                | 20                       | 4.898                     |
From the above table, it is observed that maximum Ts of 6.323 kN was obtained for sample no. 46 at processing conditions of 700 RPM rotational speed, 0.04 mm/s plunging speed, 8 second dwell time, 0.5 plunge depth and 25 mm shoulder diameter. The sufficient heat input during and mechanical and metallurgical interlocking at the interface should have been achieved at these processing conditions to obtain a joint with the superior mechanical property.

3. Results and Discussion

The genetic algorithm (GA) is a metaheuristic optimization technique employed to solve constrained and unconstrained problems by biological evolution methods. The algorithm continuously regenerates itself from the population to obtain the optimal solution concerning its previous iterations. Between each iteration, the algorithm randomly chooses the solution from the population space, as the parents start to reproduce for the next iteration [14]. The steps in GA are listed in Fig.1.
Figure 1. Steps in Genetic Algorithm

The experimental sequence generated from the Design expert software is stored in an excel file (.xlsx) format and then fed into the MBC toolbox in Matlab 2015. The MBC toolbox is a multipurpose toolbox designed to optimize the engine outputs based on the experiments conducted through the design of experiments. The objective of the genetic algorithm is to find the best set of process parameters that obtains the maximum Ts. The GA parameters are listed below.

- Crossover function: scattered
- Crossover fraction: 0.8
- Mutation function: uniform
- Selection function: tournament
- Population size: 100
- Generations: 500

The maximum Ts of 5.625 kN was predicted at the welding conditions of 999.415 RPM, 0.039 mm/s, 7.997 s, 0.75 mm and 24.845 mm. The confirmation test at the predicted processing conditions showed a Ts of 5.682 kN. The percentage error was computed to be 1.02 %, which shows that the GA’s prediction is highly accurate.

3.1 Influence of Process parameters

The objective plot, Fig.2 explains the effects of the process parameters on the Ts of the joint. The tool rotational speed and plunging speed parameters play a vital role in heat generation during FSSW. The heat generated during FSSW is the combination of frictional heat from tool rotational speed and heat generated due to plastic deformation from the plunging speed. The Ts is observed to increase with the increase in the magnitude of plunging speed, whereas tool rotational speed has minimal effect on the load-bearing capacity of the joint, with the maximum contribution in heat generation is obtained from plastic deformation [15].
The shoulder diameter has a significant role in frictional heat generation by establishing contact between the tool and the workpiece. In pinless FSSW, the frictional heat during welding is generated by shoulder diameter and tool rotational speed. Hence with the increase in shoulder diameter, there is sufficient heat achieved to form a stronger interfacial bonding between the two sheets [6]. The dwell time helps in the conduction of heat generated during welding, however, with the increase in dwell time results in increased thermal exposure that results in coarse grain microstructure and dents the load-bearing capacity of the weld joint. The plunge depth is vital in pinless FSSW as it helps to form a stronger interfacial bonding between the sheets [13]. With the absence of the pin in this process, the material flow between the upper and the lower sheet is entirely dependent on the plunge depth provided by the tool onto the top sheet. Hence a sufficient plunge depth is necessary during pinless FSSW to obtain a stronger weld joint [4]. However, an increase in these two parameters results in reduced joint strength due to and an increase in plunge depth resulting in the formation of a hook at the interface that acts as a crack nucleation agent [16]. Moreover, the increase in joint strength is also due to the formation of fully developed nugget with increased nugget width, which is credited to increased shoulder diameter and increased plunge depth.

Conclusions

Al 6061 and Al 5754 of 1 mm sheet thickness were joined by pinless FSSW. The genetic algorithm is employed to identify the optimal welding conditions. The maximum Ts of 5.625 kN was obtained at tool rotational speed of 999.415 RPM, plunging speed of 0.039 mm/s, Dwell time of 7.997 s, plunge depth of 0.75 mm and shoulder diameter of 24.845 mm. The confirmation test conducted at the predicted welding conditions showed that the prediction capability of the Genetic algorithm was highly accurate. The objective plots, shows that shoulder diameter, plunge depth, plunging speed and dwell time has a significant effect on the Ts, whereas tool rotational speed was observed to have minimal effect on the Ts.
REFERENCES

[1] Kim D, Badarinarayan H, Ryu I, Kim J. H, Kim C, Okamoto K, and Chung K, Numerical simulation of friction stir spot welding process for aluminum alloys. Metals and Materials International, 2010, 16(2): 323-332.

[2] Farmanbar N, Mousavizade S.M, and Ezatpour H.R. Achieving special mechanical properties with considering dwell time of AA5052 sheets welded by a simple novel friction stir spot welding. Marine Structures, 2019, 65: 197-214.

[3] Tozaki Y, Uematsu Y, and Tokaji K. A newly developed tool without probe for friction stir spot welding and its performance. Journal of Materials Processing Technology, 2010, 210: 844-851.

[4] Bakavos. D, Chen. Y, Babout. L, and Prangnell. P, Material interactions in a novel pinless tool approach to friction stir spot welding thin aluminum sheet. Metallurgical and Materials Transactions A, 2011, 42(5). 1266-1282.

[5] Zhang G. F, Wei S. U, Zhang J, Wei Z. X, and Zhang J. X. Effects of shoulder on interfacial bonding during friction stir lap welding of aluminum thin sheets using tool without pin. Transactions of Nonferrous Metals Society China, 2010, 20. 2223-2228.

[6] Paidar M, Khodabandeh A., Sarab M. L, and Taheri M. Effect of welding parameters (plunge depths of shoulder, pin geometry, and tool rotational speed) on the failure mode and stir zone characteristics of friction stir spot welded aluminum 2024-T3 sheets. Journal of Mechanical Science and Technology, 2015, 29(11): 4639-4644.

[7] Bozkurt Y and Bilici M.K, Application of Taguchi approach to optimize of FSSW parameters on joint properties of dissimilar AA2024-T3 and AA5754-H22 aluminum alloys. Materials and Design, 2013, 51. 513-521.

[8] Karthikeyan R and Balasubramanian V, Predictions of the optimized friction stir spot welding process parameters for joining AA2024 aluminum alloy using RSM. International Journal of Advanced Manufacturing and Technology, 2010, 51. 173-183.

[9] Klobčar D, Tušek J, Smolej A, and Simončič S, Predictions of the optimized friction stir spot welding process parameters for joining AA2024 aluminum alloy using RSM. Welding in the World, 2014, 59. 269-281.

[10] de Castro C. C, Plaine A. de Alcântara H. N.G, and dos Santos J. F, Taguchi approach for the optimization of refill friction stir spot welding parameters for AA2198-T8 aluminum alloy. International Journal of Advanced Manufacturing and Technology, 2018, 99. 1927-1936.

[11] Pattanaik A. K, Pradhan. S, Panda. S. N, Bagal D.K., Pal. K, and Patnaik. D, Effect of Process Parameters on Friction Stir Spot Welding Using Grey Based Taguchi Methodology. Materials Today Proceedings, 2018, 5. 12098-12102.

[12] Zhang A, Chen. X, Pan. K, and Wang. J, Multi-Objective Optimization of Friction Stir Spot-Welded Parameters on Aluminum Alloy Sheets Based on Automotive Joint Loads Metals (Basel). 2019, 520. 1-17.

[13] Chu Q., Li W.Y, Yang X. W, Shen J. J, Vairis. A, Feng W.Y, and Wang W. B, Microstructure and mechanical optimization of probeless friction stir spot weld joint of an Al-Li alloy. Journal of Materials Science and Technology, 2018, 34. 1739-1746.

[14] Babu K. K, Panneerselvam K, Sathiya P, Haq A. N., Sundarrajan S, Mastanaiah P, and Murthy C. S. Parameter optimization of friction stir welding of cryorolled AA2219 alloy using artificial neural network modeling with genetic algorithm. International Journal of Advanced Manufacturing and Technology, 2018, 94 (9-12): 3117-3129.

[15] Khosa S. U, Weinberger. T, and Enzinger. N, Thermo-mechanical investigations during Friction Stir Spot Welding (FSSW) of AA6082-T6. Welding in the World, 2010, 54. 134-146.
[16] Badarinarayan H, Yang Q, Zhu S. Effect of tool geometry on static strength of friction stir spot-welded aluminum alloy, International Journal of Machine Tools and Manufacture, 2009, 49 (2): 142-148.