A comparison study for the Different Geometry of Tools used in the FSW

M. Jafar1, A.Hameed2 and O. Altemeemi3
1 Assistant Lecturer, College of Engineering, Iq
2 Senior lecturer, College of Engineering, Iq
3 Lecturer, Kut College University, Iq
E-mail: mohanedsalah@uowasit.edu.iq, azzam@uowasit.edu.iq

Abstract. This research aims to investigate the influence of different tool geometries on the tensile strength of Al alloys joints (AA 6060), which have performed by the friction stir welding process (FSW). Three types of tool geometries were used that, cylindrical, a conical with threads, conical. Taguchi method was used to design the experiments to chose fewer experiments, ANOVA analysis was used to find the significant parameter which affects the output such as tensile strength of the weld joint, the parameters such as rotation speed, welding speed, and tool shape have been chosen for each parameter three-level were chosen. The results show that the parameter of tool shape was the significant factor with contribution 79.4% compared to other parameters and the other parameters like rotation speed and welding speed have less effect, and between the three shapes, the conical shape with thread is better to achieve higher tensile stress.

Keywords:- FSW, Taguchi method, Optimization, ANOVA

1. Introduction
Fricitions stir welding (FSW), which was convened in 1991 by the United Kingdom's Welding Institute (TWI) [1]. FSW is a solid-state operation, meaning the material is in the solid-state at any point of processing. A particular rotating tool consisting of a pin and shoulder with pin length nearly equal to the thickness of the sheet in FSW. The touchline of the two sheets that want to be welded is penetrated by the pin and then traverses in the desired direction. The friction between the revolving tool and workpiece generates heat, that softens the material of the workpiece under the sheet's melting temperature then the material within the welding zone undergoes extreme deformation with the mechanical stirring induced by the pin, creating a fine grain microstructure. FSW is most popular joining process because it has numerous benefits, for example, low temperatures of welding, short time, low distortion, low energy, and makes a good quality weld for many materials [2]. The rule of different shapes of the tools on properties of FSW has been a major challenge for any researcher. The effect of different shapes of the tool as well as other factors, like rotational tool speed, welding speed on the tensile strength needs to be analyzed [3]. Extensive research on the effect of welding parameters has been carried out by R. K. Kesharwania et. al[4] used the Taguchi grey method to find optimum parameters of the friction mixed welding process for dissimilar alloys for thin sheets welding, the results showed that the rotational speed, crossover speed and shoulder diameter, and the shape of the pin were 1800 rpm, 50 mm / min, 20 mm, square respectively, that were optimal. et.al they have presented new design for the tools which are used in friction stir welding process compared with the conventional tools which give benefits when the thick plates have been welding, high speed has applied. Liu et al. [3] studied the influence of tool threads on the tool wear. They showed that the tool threads reduced the tool life. Azzam et al. [5] investigate the effects of tilt angle and other parameters, the optimum level has found and they investigate that the tilt angle has significant factors among other parameters to get the maximum tensile strength through using
Taguchi method as the design of experiment method. P. Satish Kumar et al [6] investigated the effect of threaded tool on the mechanical properties of 5083 aluminium composite welds using rotation speed, traverse speed, 710 rpm, 40 mm/min respectively. A. Deveraiu et. al [7] conducted experiments to find better rotational speed for high mechanical properties. They found that the optimum speed was 900 rpm while the welding speed had been fixed.

FSW process parameters should be optimized to get the maximum tensile resistance. A crucial rule is played by tools shapes flow of material and, in turn, controls the welding factors of the FSW. Hence an effort has been made to optimize the FSW factors to maximize the tensile strength of Al alloy welds using the design of experiment theory (the Taguchi method). This research aims to compare different types of tool shapes and find which one is a significant factor that can affect the mechanical properties of the weld joint by FSW.

2. Experimental details
2.1. Materials and methods
In current experimental work, the milling machine was used is shown in fig (1). A milling machine is a power-driven machine that was used to conduct the experiments, where the tool was being manufactured, has fixed on it. the workpieces were fixed on the table of this machine in a manner that prevents them from displacement from its location during the work.

![Figure 1. Milling machine](image)

2.2. Tools geometry
Three shapes of tools (conical, conical with threads, and cylindrical) were used in this study that made from H13 steel and it has shoulder with 20 diameters and pins length 6 mm diameter that was manufactured in the lab as shown in fig (2).
2.3. Material selection
Aluminium alloy plates AA 6060) have been chosen to be welded by the FSW process because of their wide applications. These plates have (180×70×6) mm Dimensions. The chemical composition of the alloys used for practical experiments was examined in the Central Organization for Standardization and Quality Control, as shown in Table (1).

| Table 1. percentage of the chemical composition of Al- alloy |
|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
| Si    | Fe    | Cu    | Mn    | Mg    | Cr    | Ni    | Zn    | Ti    | Pb    | Al    |
| 0.12  | 0.29  | 4.2   | 0.6   | 1.2   | 0.01  | 0.01  | 0.16  | 0.016 | 0.009 | Bal   |

2.4. Experimental Design
To optimize the process factors of FSW, the Taguchi method was used, which is a method to statistical analysis to provide low cost and high quality, with L9 orthogonal array of 3*3 columns, rows respectively, which means nine experiments for each experiment different levels of parameters, as shown in table 3. The FSW parameters like the rotational speed, travel speed, the shape of the tool were chosen for this work. The Taguchi method was conducted to obtain the signal to noise ratio (S/N) for each experiment that contains a combination of levels, there is three-level for each parameter as shown in table 2, the S/N analysis was used to find optimum level for every process parameters. A higher (S/N) ratio matches to a preferable quality characteristic. Therefore, the optimal level of the process parameters is the level with the highest S/N ratio. The optimal combination of the process parameters can be then predicted by taking the highest value of each S/N three levels from each parameter. The design of the L9 orthogonal array was used to conduct the experiments.

| Table 2. process Factors and their levels |
|-----------------|-----------------|-----------------|
|                  | Level 1          | Level 2          | Level 3          |
| Rotation speed A | 1250 rpm         | 1600 rpm         | 2000 rpm         |
| Welding speed B  | 12.5 min/m       | 16 min/m         | 20 min/m         |
| Tool shape C     | 1 cylindrical    | 2 Conical with thread | 3 Conical       |
Table 3. L9 Designed Experimental

| Ex. | Rotation speed | Leaner speed | Tool Shape |
|-----|---------------|--------------|------------|
| 1   | 1250          | 12.5         | 1          |
| 2   | 1250          | 16           | 2          |
| 3   | 1250          | 20           | 3          |
| 4   | 1600          | 12.5         | 2          |
| 5   | 1600          | 16           | 3          |
| 6   | 1600          | 20           | 1          |
| 7   | 2000          | 12.5         | 3          |
| 8   | 2000          | 16           | 1          |
| 9   | 2000          | 20           | 2          |

2.5. Welding process

A tool which has specific geometry is revolved and slowly penetrated the line of welding between contacted plates of workpieces (Al-Alloy) that are to be welded in FSW. The workpieces need to be supported in a way that avoids the joint faces from being separated or moved out of position. The heat generated in the workpieces to be welded is a result of the friction between the pin and the shoulder of the welding tool on one side and the workpieces to be welded on the other side, as well as the plastic deformation of the workpieces to be welded and this heat softens the metal around the penetration pin, due to rotation tool of the workpiece, it works to move the soft metal from the front of the penetration pin to the back of it, which leads to the filling of the gap formed by the previous welding tool. After completing the penetration and heating process, the plates are linearly moved relative to the rotating tool, and this leads to the completion of the fastening process along the seam. After the welding process was completed, the samples were cut in the traverse direction perpendicular to the welding line, then it was tested using the tensile machine in university o technology.

Figure 3. During welding process
3. Results and Discussion

3.1. Results for Tensile strength

The results of T.S, S/N ratio for each of the 9 trials with their conditions are given in Table 4.

| NO | Rotation Speed | Linear speed | Tool shape | Tensile Strength(Map) | S/N ratio |
|----|----------------|--------------|------------|-----------------------|----------|
| 1  | 1250           | 12.5         | 1          | 23.73                 | 27.50595 |
| 2  | 1250           | 16           | 2          | 255.46                | 48.14646 |
| 3  | 1250           | 20           | 3          | 204                   | 46.1926  |
| 4  | 1600           | 12.5         | 2          | 241                   | 47.64034 |
| 5  | 1600           | 16           | 3          | 48.26                 | 33.67175 |
| 6  | 1600           | 20           | 1          | 27.73                 | 28.859   |
| 7  | 2000           | 12.5         | 3          | 84.53                 | 38.54022 |
| 8  | 2000           | 16           | 1          | 26.4                  | 28.43208 |
| 9  | 2000           | 20           | 2          | 412                   | 52.29794 |

3.2. Analysis of variance (ANOVA)

To find the statistically relevant weld parameters, variance analysis (ANOVA) was performed. The goal of ANOVA is to study the significance of process factors affecting the mean of FSW welds. Tables 3 gives the ANOVA results for tensile strength of the means. Also, To decide which parameter has a major impact on process, the F-test named can be used. In general, the change in the process parameter, when F is high, greatly affects the quality characteristics. The tool geometry is a highly important factor in our investigation and plays a major role in influencing the weld's tensile strength. The influence of the speed of rotation does not affect the results at all. As shown in Table 5 the p-value of tool shape is 0.0022 which means the tool shape is a significant factor but the others factor rotation speed and linear speed nonsignificant factors which have 0.254, 0.116 respectively.
Table 5. The ANOVA table for output results.

| Source         | DF | Seq SS | Adj SS | Adj MS | F     | P     | C%  |
|----------------|----|--------|--------|--------|-------|-------|-----|
| Rotation speed | 2  | 7957   | 7957   | 3978   | 2.93  | 0.254 | 5.25|
| linear speed   | 2  | 20603  | 20603  | 10302  | 7.59  | 0.116 | 13.58|
| Tool shape     | 2  | 120416 | 120416 | 60208  | 44.37 | 0.022 | 79.38|
| Error          | 2  | 2714   | 2714   | 1357   | 1.79  |       |     |
| Total          | 8  | 151691 |        |        |       |       |     |

S = 36.8381   R-Sq = 98.21%   R-Sq(adj) = 92.84%

The combine contribution of rotational speed (5.25) and liner speed(13.48) is much lesser than the contribution of tool shape(79.38). The major contribution was 79.38 by tool shape as shown in table 3. By the response table, 5 can find the optimum machining parameters.

From Table 6, Optimal Parameters for FSW are A1, B3, and C2. The difference of between level 1, 2 and 3 indicates that tool shape contributes the highest effect (276.87) followed by liner speed (104.54) and rotation speed (68.65).

Table 6. Response for Means (Larger is better)

| Level | Rotation Speed | Liner speed | Tool Shape |
|-------|----------------|-------------|------------|
| 1     | 161.06         | 116.42      | 25.95      |
| 2     | 105.66         | 110.04      | 302.82     |
| 3     | 174.31         | 214.58      | 112.26     |
| Delta | 68.65          | 104.54      | 276.87     |
| Rank  | 3              | 2           | 1          |

Table 7. Response for S/N ratios (Larger is better)

| Level | Rotation Speed | Liner speed | Tool Shape |
|-------|----------------|-------------|------------|
| 1     | 40.62          | 37.90       | 28.27      |
| 2     | 36.72          | 36.75       | 49.36      |
| 3     | 39.76          | 42.45       | 39.47      |
| Delta | 3.89           | 5.70        | 21.10      |
| Rank  | 3              | 2           | 1          |

The table 6, 7 and figure 5, 6 show the optimum factors to get high tensile strength are the rotation speed of 2000 p.m., welding speed of 20 mm/min, and tool number 2(conical with thread).
3.3. Effect of process parameters

The tool shape plays a major role in affecting the tensile strength of the joints. The tool shape with conical threads allows the material to flow around the pin. In this research, conical with threads is found to be the optimum tool shape among the cylindrical, conical, and conical with threads. The rotation speed is directly proportional to the tensile strength of the joints weld by FSW when the rotation speed increases, the heat input is increased because of that the increase of rotation speed enhances the heat of the process which causes a better flow of material so the tensile strength is also increased when the rotation speed is set at a higher level.

4. Conclusion

1- The maximum tensile strength of the fabricated FSW joints was obtained by applying the optimum parameters obtained through the Taguchi method with optimum parameters of 2000 revolutions/min for rotation speed, welding speed of 20 mm/min, and tool No. 2 conical with thread.
2- Tool shape was the significant factor affecting tensile strength with p-value 0.022 and 98% confidence level.
3- Rotational speed has less effect on tensile strength.
4- The tool shape plays a crucial role, and its contributes was 79.38% to the overall effect.

5. References:

[1] W.M. Thomas, E.D. Nicholas, J.C. Needham, M.G. Murch, P. Temple smith, C.J. Dawes, G.B. Patent Application. 9125978.8 December 1991.

[2] Liu HJ, Fujii H, Maeda M, NogiK. s.l. Tensile properties and fracture location of friction-stir-welded joint of 2017-T351 aluminium alloy. J Mater Process Technol, 2003, Vol. 142, pp. 692-696.

[3] Preuss M, Withers PJ. Microstructure, mechanical properties and residual stresses as a function of welding speed in aluminum AA5083 friction stir welds 3, s.l : Acta Mater, 2003, Vol. 51, pp. 1359-6454.

[4] R. K. Kesharwania, S. K. Multi-Objective Optimization of Friction Stir Welding Parameters. 2014, Proclia material of science, pp. 178-187.

[5] Azzam Sabah Albunduqee, Hussein R Al-Bugharbee. Optimization of Process Parameters of Friction Stir Welding by Taguchi Method. 2019, Wasit Journal of Engineering Sciences, pp. 17-23.

[6] Kumar PS, Shastry, C S R and Devaraju, Influence of Tool Revolving on mechanical Properties of Friction Stir Welded 5083 Aluminum alloy, 2017, Material Today: Proceedings, pp. 330-335.

[7] Devaraju A, Shalem M J and Manichandra, "Effect of Rotation Speed on Tensile Porperties and Microhardness of Dissimilar al alloys 6061-T6 to 2024_T6 welded via solid state joining technique," 2019, Material Today: Proceedings, pp. 3286.