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Optimizing the process parameters during friction stir welding on AA2024 weld joints using Taguchi method

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Abstract: *FSW (friction stir welding) is a solid state joining technique winch Is use for similar and dissimilar alloys which has been used in defence, aerospace, marine and industires. The AA2024 is a heat treatable alluminum alloy finds wide application in defence and Aerospace due to its high strength to weight ratio. The rotational speed, traverse speed and different tool pin profiles as taper square, taper pentagon, taper hexagon are the parameters taken into consideration to weld 6.4mm of AA2024 thick plate by using AISI H13tool. The tensile strength, yield strength, % of elongation is carried out to know the effect of process parameters on the weld joints, and taguchi method is used to analyse the obtained values. The better value is obtained at rotaional speed 1000rpm, traverse speed 30mm/min. Taguchi method is used to minimize the number of experiments, time and cost.*

Keywords: *Analysis of variance, FSW, Tensile strength, yield strength, % of elongation.*

I. Introduction

Friction Stir Welding (FSW), an innovative solid state welding technique, now a day's this method is widely using in defence and aerospace applications. This method is environmentally free and energy efficient method can be used to join high strength aluminum alloys and other materials that are difficult to weld using conventional welding process [1]. FSW is a mechanical process were two plates were joined by creating a friction between the plates, a tool is used to create the friction and it takes place in the solid phase, the welding defects related to the solidification of a material are avoided, and thermal efficiency of friction stir welding is almost 90% and above [2]. Frictional heat is generated by the welding tool which is penetrated into the base material and surrounding of material causes softening the material and allows the tool to move along the weld line initially, the AA2024 is plasticized, and it is transferred from the leading edge of the tool, leaving a solid bond between the weld plates [3].

The friction stir welding is process based on the parameters mainly on rotational speed and traverse speed which creates the frictional heat, if any defects were occurred during the FSW process it cannot eliminated, whereas in conventional welding it can be corrected by reworking of the material [4]. The weld zone, Thermo Mechanically Affected Zone (TMAZ) and Heat Affected Zone (HAZ) are the regions of the friction stir welding plate regions across the width of weld joints. The friction stir welding is the single pass welding process to fabricate the similar and dissimilar materials [5]. Most of the areas steels were replaced by aluminum and nonferrous alloys. Change of material is happening due to its low weight and having almost all equal mechanical properties with steels. Joining of these materials with conventional welding method causes defects, FSW, is a solid state welding process which is used to overcome the defects appearing in welding of these materials [6]. Non consumable tools made of AISI H13 steel tool to weld the aluminum alloy AA2024. In this investigation, found that the tool pin profile is the main factor for affecting the weld joints. The aluminum alloy used in this process is AA2024 has it is widely used in aerospace, marine industries in the construction of pipelines, storage tanks and frames [7]. The FSW process parameters and tool pin profiles are the main factors affecting the weld joint.

II. Experimental Procedure

The material used in this investigation is 6.4mm thick plate of aluminum alloy 2024, and the chemical compositions and mechanical properties for AA 2024 were shown in Table 1 and Table 2. The weld plates were cut into dimension of [200 × 100 mm] into rectangular samples and the welding was carried out using CNC vertical milling machine as shown in "Fig 1". The AISI H13 welding steel tool is used in this investigation. The different tool pin profiles were used and they are Taper Square, Taper Pentagon, and Taper Hexagon as shown in "Fig 2". The process parameters and the results obtained are shown in below Table 3 according to the sequence level of experiments. The samples were prepared according to ASTM E8 standards for mechanical properties; UTM (universal testing machine) is used to carry out the results of AA2024.

Table 1: AA2024 composition of Al-Alloys

Al-Alloy	Mg %	Cu %	Si %	Zn %	Mn %	Cr %	Ti %	Specific heat J/g ^{o}C	Thermal conductivity W/m-k
AA2024	1.514	4.307	0.043	0.095	0.494	0.005	0.054	0.86	121

Table 2: AA2024 Mechanical properties

Material	Tensile Strength N/mm2	Yield Strength N/mm2	% of Elongation	Hardness (HV 0.5)
AA2024	472.4	384.168	17.54	127.5

Table 3: AA2024 Process parameters for FSW

Material	Tool profile	Rotational speed (rpm)	Traverse speed (mm/min)	Tensile Strength N/mm2	Yield Strength N/mm2	% of Elongation
AA2024	Taper square	1000	20	290.73	265.97	11.4
AA2024	Taper pentagon	1000	30	284.48	257.00	12.2
AA2024	Taper hexagon	1000	40	297.09	270.69	14.5
AA2024	Taper pentagon	1200	20	241.37	210.44	13.2
AA2024	Taper hexagon	1200	30	327.155	291.62	14.1
AA2024	Taper square	1200	40	154.61	132.61	9.6
AA2024	Taper hexagon	1400	20	173.65	141.47	12.9
AA2024	Taper square	1400	30	205.08	178.46	13.9
AA2024	Taper hexagon	1400	40	278.45	246.18	13.0

The tool pin profile geometry is taken from the relation between the pin length, profile diameter and shoulder diameter as showing in Table 4, and 140 of taper angle is taken for pin profile as shown on "Fig 2".

Table 4: Formulas for Tool Geometry

Pin profile length (mm)	Pin profile diameter (1 to 1.5 Ø)	Shoulder Diameter (2d to 3d Ø)
0.96 x material thickness (mm)	1.25 x pin length (Ø)	2.25 x pin profile diameter (Ø)

Fig 1: Set up for friction stir welding

Figure 2: a) Tool pin profiles before weld b) Tool pin profiles after weld

The tool geometry has major impact on the weld strength due to the shoulder diameter and pin diameter as they were not in the ratio of D/d that is 1:3. Due to this a linear kissing bond, tunnel defect is found on the weld and blow holes are observed. The material is stick to the tool due to the variation of the axial load and insufficient load is acted on the weld plates due to this the material is stick to the tool profiles and a defects were observed during the welding.

2.1 Design of experiments

The process parameters were considered for this investigation as rotational speed rpm, traverse speed mm/min and tool pin profiles and their levels as show in Table 2.

2.2 Genichi taguchi method

Genichi taguchi method is used for designing the number of experiments for a system. This method the number of experiment is reduced to 9. The degree of freedom is calculated to choose the correct orthogonal array. The DOE (degree of freedom) is 8 for L9 orthogonal array and nine experiments were conducted for friction stir welding as per Taguchi L9 orthogonal array [5].

2.3 S/N ratio

Taguchi method is used to analyze the optimal process parameters by S/N ratio method. This method helps in identifying the significant values for finding the optimal parameters.

III. Results And Discussion

3.1 Tensile Strength

The tensile strength is the maximum stress that a material can with stand while stretched or pulled before breaking. Tensile test of AA2024 was carried out according to ASTM E8 standards, here we use larger the better S/N ratio to know the effect of the process parameters on the weld joints as shown in Table 5.

Table 5: AA2024 S/N Response table for Tensile Strength.

Level	Speed	Feed	Tool
1	**49.27**	47.24	46.43
2	47.24	**48.54**	**48.54**
3	46.64	47.38	48.18
Delta	2.63	1.30	2.11
Rank	1	3	2

From Table 5, we can conclude that at rotational speed 1000 rpm and traverse speed at 30 mm/min and taper pentagon tool has the high tensile strength values. “Fig 3” shows the main effects plot of tensile strength.

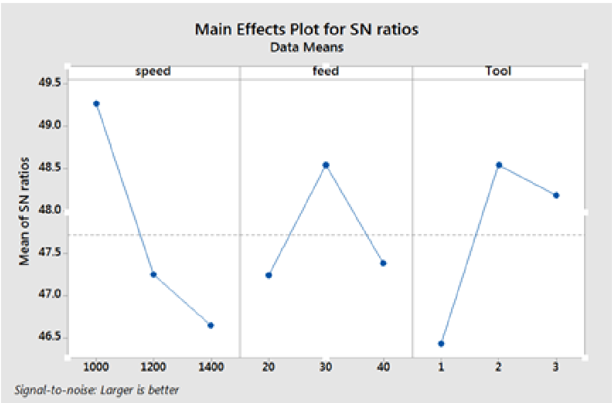

fig 3: AA2024 Main effects plot for tensile strength

3.2 Yield Strength

Yield strength is the material property at which a material begins to deform plastically. Therefore S/N ratio larger the better is used to know the effect of parameters on the yield strength and the values are placed in Table 6.

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Table 6: AA2024 S/N Response table for yield strength

Level	Speed	Feed	Tool
1	**48.45**	45.99	45.33
2	46.07	47.51	**47.50**
3	45.29	**47.31**	46.99
Delta	3.16	1.52	2.17
Rank	1	3	2

From Table 6, we can conclude that at rotation speed 1000 rpm, traverse speed at 40 mm/min and taper pentagon tool has the high Yield strength value as shown in "Fig 4".

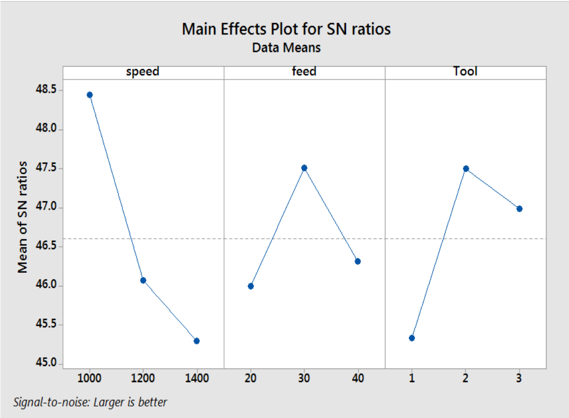

fig 4: AA2024 Main effects plot for Yield strength

3.3 Percentage of Elongation

The optimum process parameters obtained for % of elongation is at the rotational speed of 1000rpm and traverse speed of 40mm/min and the tool pin profile is taper hexagon tool as shown in the below graph "Fig 5" and the table 7.

Table 7: AA2024 S/N response table for % of elongation

Level	Speed	Feed	Tool
1	22.05	21.96	21.24
2	21.70	22.52	22.15
3	22.46	21.72	22.82
Delta	0.76	0.80	1.58
Rank	3	2	1

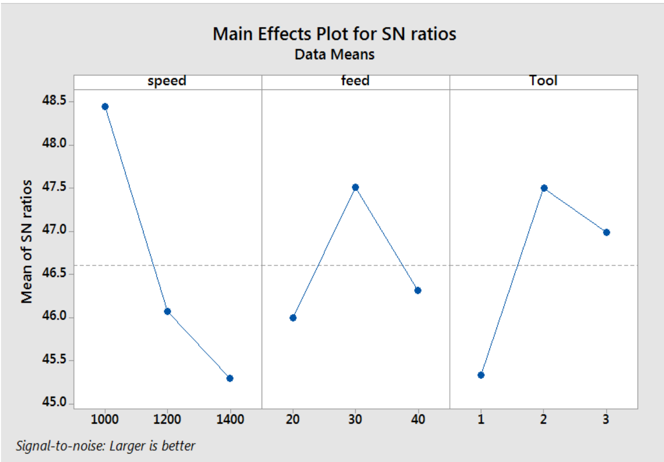

Fig 5: Mean of SN ratio plot for % elongation

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IV. Conclusion

In this investigation, Taguchi method is used to analyses the optimal parameters for FSW of AA2024. The results can be drawn as follows

- The results include that the shape of tool pin profile has the main effect on the weld joints and the better result is obtained to the tapered hexagon tool pin profile.
- The rotational speed, traverse speed as impact on the weldments. The higher the rotational speed and lower the traverse speed gives the better joints.
- Fig 3,4,5 shows the optimal values and got the better mechanical properties at rotational speed of 1000 rpm and traverse speed 30 mm/min to taper pentagon tool pin profile.
- The highest tensile strength is got at the rotational speed of 1200 rpm, traverse speed of 30 mm/min to taper hexagon tool profile.
- From the above results I can conclude the optimal value as traverse speed 30 mm/min which gives the better results to taper pentagon and taper hexagon tool profiles at rotational speed of 1000 rpm, 1200 rpm.

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