OPTIMIZATION OF PROCESS PARAMETERS IN FRICTION STIR WELDS OF AA6061-T6 USING TAGUCHI TECHNIQUE

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Abstract

Friction stir welding (FSW) is a ‘new solid-state joining process’ which is multifaceted, ecologically friendly and power capable. Some of the leading companies have been adapted this process for the manufacturing of automotive, locomotive, shipping and aerospace. In this study, the friction stir welding (FSW) method is used to connect the AA6061-T6 alloy plates and enhance the process parameters. Research is underway to analyze the various process parameters on the welded joint's quality impact. The different process parameters consequence, such as axial force, traverse speed, tool rotational speed, shoulder diameter, incline angle, and instrument geometry have been optimized by using the Taguchi technique.

Keywords: Friction stir welding, 6061 Aluminium alloy, Mechanical properties, Taguchi method of optimization

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1 Introduction

In 1991, the Welding Institute (TWI) of the UK, the solid-state amalgamation method initially applied to aluminium alloys for lap and butt welding[1]. Due to the poor hardening microstructure and porosity in the joining region, aluminum alloys are normally categorized as non-weldeable. Furthermore, the mechanical characteristics loss is extremely important when compared to the base material. These elements create the fusion of alloys that are unattractive through a conventional welding process. A few aluminum melanges can be resistance welded however the exterior creation is costly and exterior oxide being the most important trouble. The FSW tool performs three major operations: (i) The workpiece heating (ii) The material motion to produce the fusion and (iii) The hot metal regulation underneath the instrument shoulder. During this procedure, the heat is produced which is assumed to arise mostly beneath the shoulder owing to its better exterior and must be identical to the essential power to beat the contact services betwixt the instrument and the workpiece. The input value of heat into the welds improves when the shoulder diameter enhances to a certain level[2]. Due to its hardening and small heat input, the FSW provides numerous benefits[3]. Also, this process gives good strength and excellent exterior finish than other conventional joining methods. An experimental relationship has been expanded through response surface methodology[4]. Aluminium alloys have a broad variety of characteristics compared to other all aluminium alloys AA6061 aluminium alloys performs a significant part in Aerospace in which the Silicon and Magnesium are the Principle Alloying Element[5]. He demonstrated the use of a common milling machine with the less optimal tool for FSW of aluminium alloys[6]. The effort has been created to realize the effect of FSP region revolving speed creation and instrument pin profiles. He investigated the correlation between the creation of the FSP region and flexible characteristics of friction stir welded AA2219 aluminium alloy fusions[7]. Moreover, the effort has been creating to calculate and estimate the power of the FSW procedure parameters on the weldments.

The radiography, Vickers firmness, and flexible power are considered for analysis through instrument sustain, changing the speed of the instrument, and managing the stable depth of the weld perforation. An experiment was done on AA6351 aluminium alloy in a CNC Vertical Machining Centre and the Vickers firmness tester, UTM, and Radiography apparatus are utilized to calibrate the outcome elements. The prolong percentage improves owing to upgrades of the welding speed[8]. He analyzed the welding factors, such as the speed of the welding, instrument revolving speed, and axial strength which performs the main function in resolving the combined features also analyzed the different welding speed effects and instrument pin profiles on the AA6082-O aluminium weld quality[9]. Besides, the effect of instrument shoulder geometry on mechanical features of friction stir welded 6082-T6 alloy was analyzed. Due to shoulder geometry, the outcomes showed that there were no significant variations in the transverse tensile force of the weld. The mathematical replica and amalgamated design method were generated in this investigation through response exterior technique via applying three stages, three factors and 20 runs for enhancing the relationship betwixt the responses (Tensile power, Yield power (YS) and the FSW factors (rotational speed, traverse speed, axial force) and %Elongation (%E) were demonstrated. The speed of the welding, instrument revolution speed, and tool axial force with the UTS and YS of the FS welded intersections are improved up to the greatest value and then diminished[10].They deliberated on enhancing the process factors, through the ANOVA technique depend on L_9 orthogonal arrangement[11-13]. The exact FSW calibration process is done through conducting experiments by experiment design. The FSW factors can be control through Regression investigation method to get the desired outcome through relating the input with output weld process variables[14].

FSW parameters had a vital effect on the sharing and disintegration of strengthening elements on the stir region was found that in the present analysis[15]. He investigated the mechanical properties and microstructure of AA7075 and found that average grain size and precipitate sizes have a linear relationship with tool rotation and travel speed ratio[16]. For researchers, several vital parameters effect on weld characteristics are the most important region. The majority of the researches follow the heritage experimental methods to learn the FSW process parameters effect. This traditional technique takes more time for the parametric design of the experiment. Taguchi statistical design plays a powerful instrument for finding the major aspect from various factors through fewer numbers of experiments conducting comparatively. By changing the revolving speed, axial strength shoulder diameter, speed of the welding and tilt angle of the joints, experiments were conducted and keeping the others stable to discover the parameter working range. The process parameters possible stage was select to free from the imperfections for the welded joints. The drawing of intrusions on appropriate factorial effects that are permitted through an experimental approach with a subspace of treatment amalgamation is called sectional factorials or sectional reflection. A vital class of sectional factorial strategy is one that is based on orthogonal arrays[17]. This work provided a Taguchi technique for applying a rigorous method of engineering quality control[18]. The number of experiments decreases significantly by influential design of experiments instruments which are necessary to enhance and model the responses moreover; it preserves the cost of the experimental and large amount of time[19]. The Taguchi technique is concocted in specified responses for process optimization and detection of the most favorable stages of process parameters. The feature of quality such as all the trials impact strength is calibrated then statistical investigation of variance (ANOVA) was taken out. The contribution of every factor in the feature of the quality is calibrated depend on the ANOVA, also a most favorable combination of a factor was forecasted and justified[20]

In all experiments, tool pin diameter and its length kept constant. Three tool profiles, i.e., straight cylindrical, square and triangular tools have been used to conduct the experiment. The experiments were designed and the information of the experimental was investigated, using the commercial software Minitab 17. These permits the essential information is gathering to analyze which aspects typically affect the quality of the product with the least number of experiments, thus preserving resources and time.

2 Materials and Methods

The aluminium AA6061-T6 alloy with 82 mm in width size, 100 mm in length, and 6.3 mm in thickness is used for the research investigation. In 6000 series, AA 6061-T6 alloy is broadly used because it is the typical structural alloy, also most of the heat treatable flexible alloy. It has good roughness properties and more prominent for medium to high power necessities. Besides, has outstanding erosion resistance to atmospheric circumstances and sea water. This material is broadly used in aircraft industries, automotive parts, for yatch construction, etc.

Fig. 1 details about the workpiece have been used for the FSW process. The standard AA 6061-T6 aluminum alloy with chemical combination features are represented in Table 1 and mechanical characteristics are illustrated in Table 2.

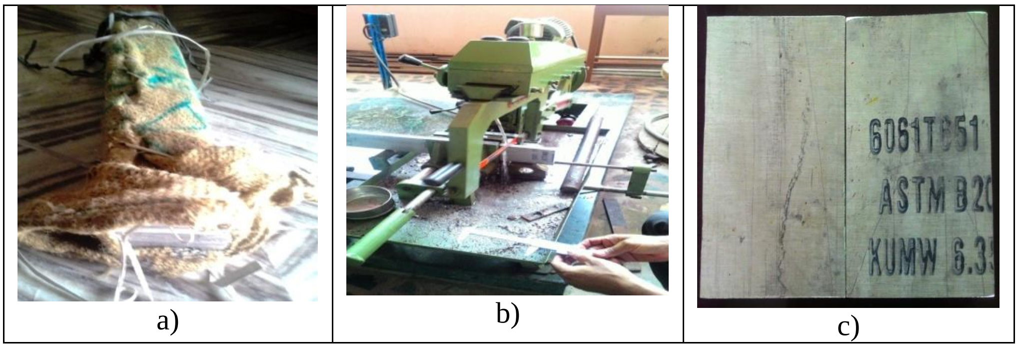


Fig.1 — AA6061-T6 a) Raw material, b) Cutting on hydraulic hacksaw and c) Work piece

Table 1 — Chemical composition in wt. %

Name of the aluminum alloy	Mg	Si	Fe	Cu	Cr	Mn	Zn	Ti	Al
AA 6061	0.9	0.62	0.33	0.28	0.17	0.06	0.02	0.02	Balance

Table 2 — Mechanical properties

Name of the aluminum alloy	Yield strength in MPa	Ultimate strength in MPa	Elongation %	Hardness in HV
AA 6061	110	207	16	75

2.1 FSW tools and dimensions

For this, the instrument shoulder diameter (D) was taken16 mm to 20 mm that of the pin length (L) and insert pin diameter (d) are 4.2 mm and 6 mm. The tools are subjected to heat treatment before conducting the experiment. The material of the tool is (D2) high carbon high chromium steel is used. The FSW tools have hardening and tempering process. Each instrument has an average hardness value of 55-58HRC.Fig. 2 show the graph for the hardening and tempering process to get the desired hardness. The different tool profiles are used for FSW joints, having probe shapes cylinder, triangular and square, as exposed in Fig. 3. Their dimensions are shown in Fig.4, Fig. 5 and Fig. 6, respectively. For all tool profiles, pin length is kept constant. The instrument material chemical combination is shown in Table 3

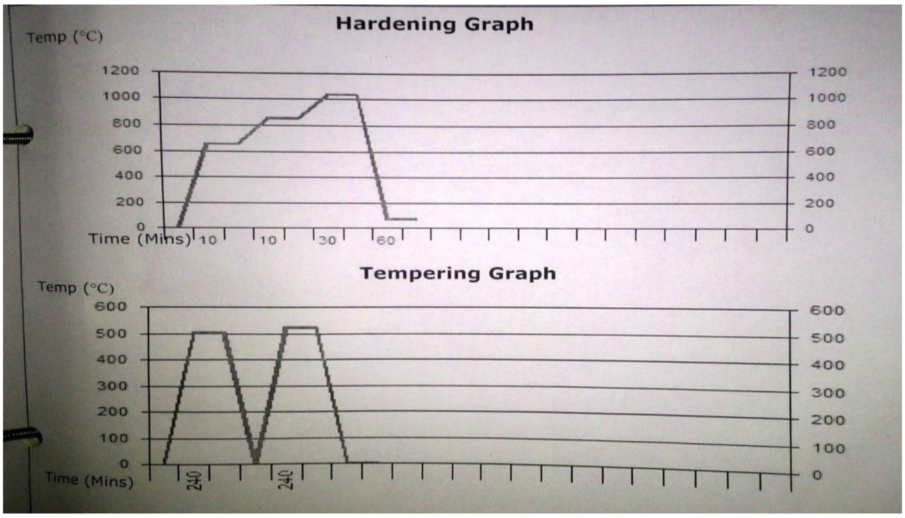


Fig. 2— Hardening and tempering graph for D2 Tool Steel

Fig. 3 — Different shapes of FSW tools

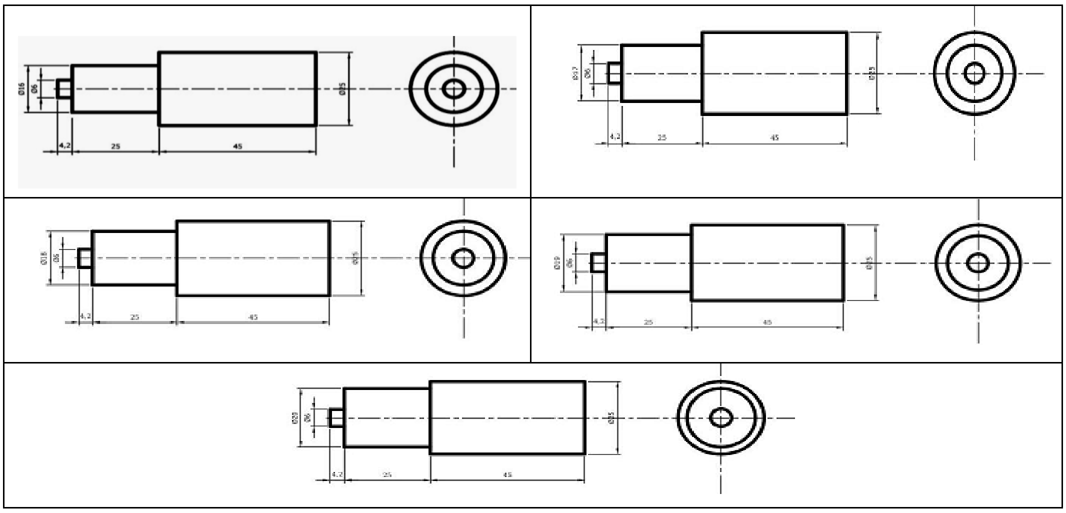


Fig. 4 — Dimensions of FSW for Cylindrical Tools (Dimensions are in mm)

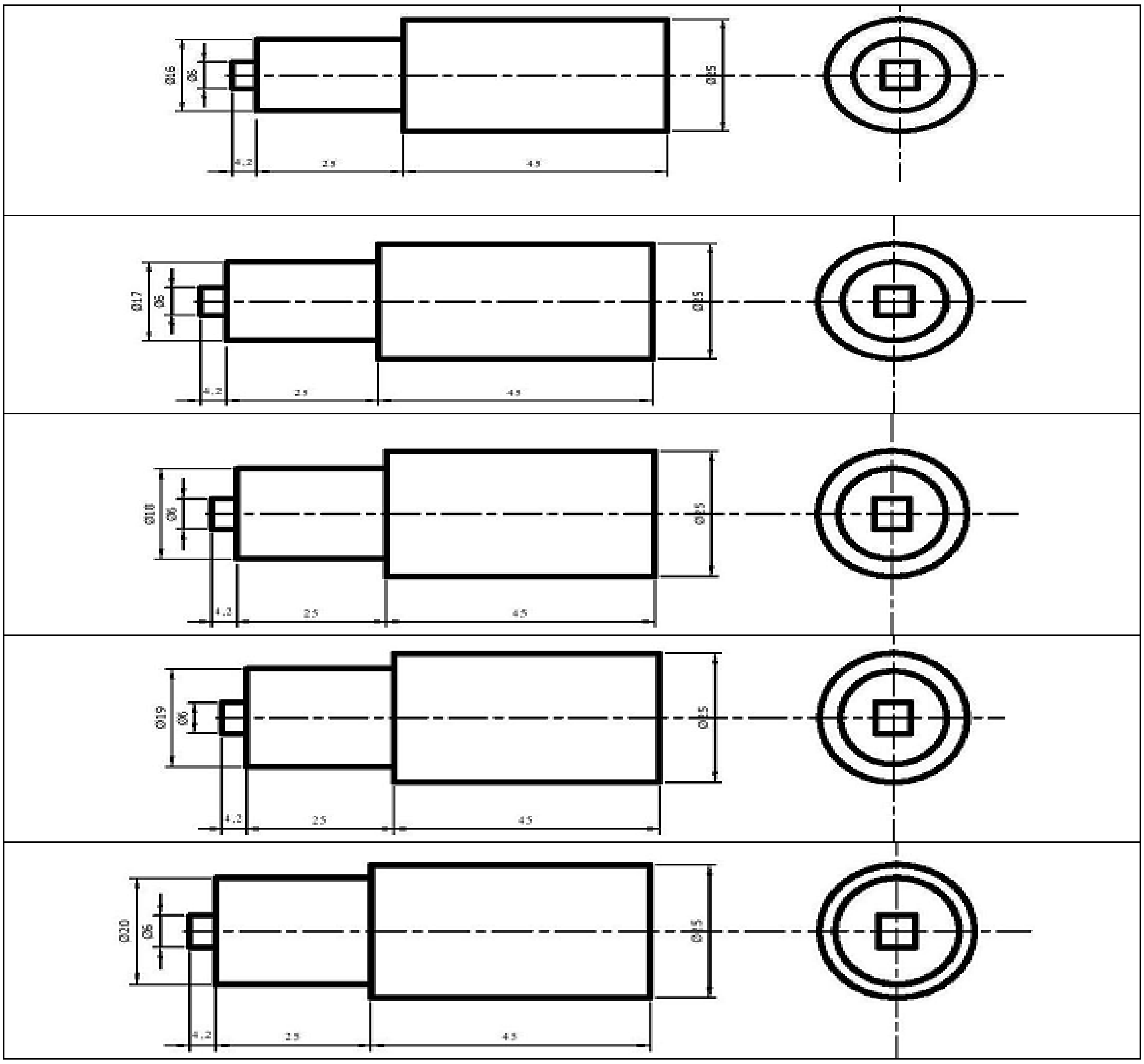
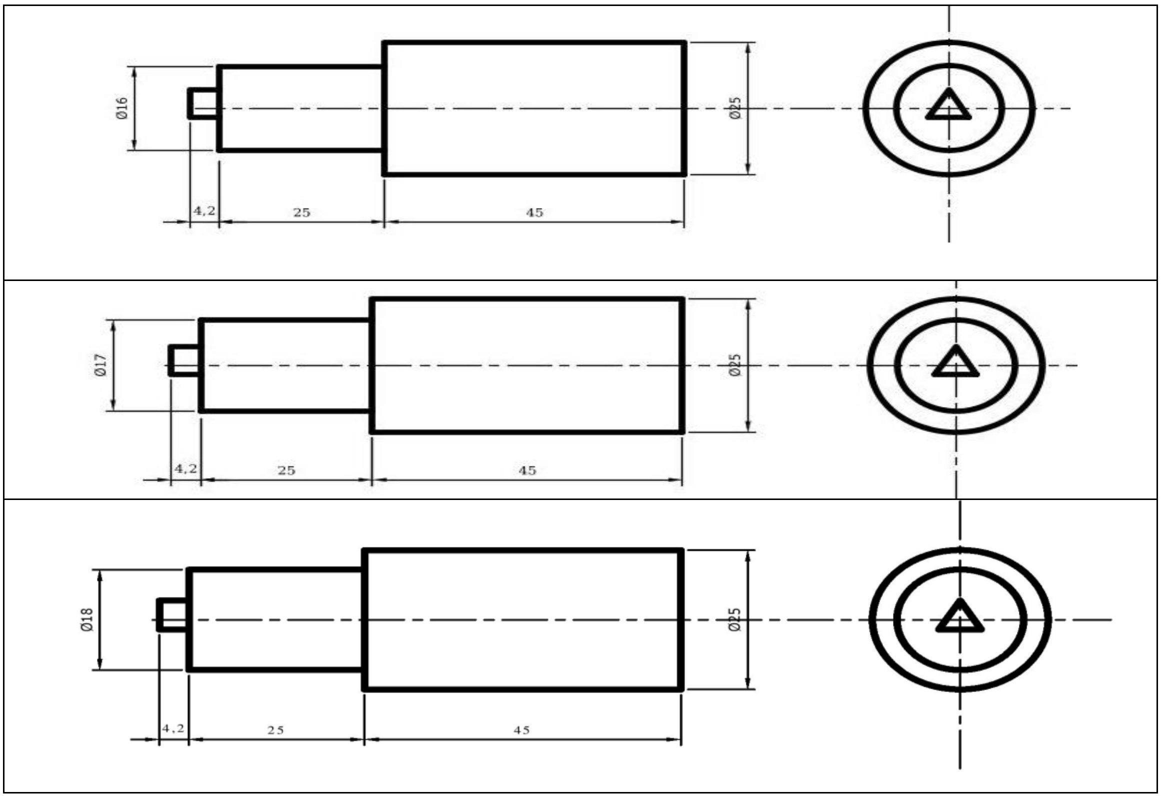


Fig. 5 — The FSW dimensions for Square instruments (Dimensions are in mm)



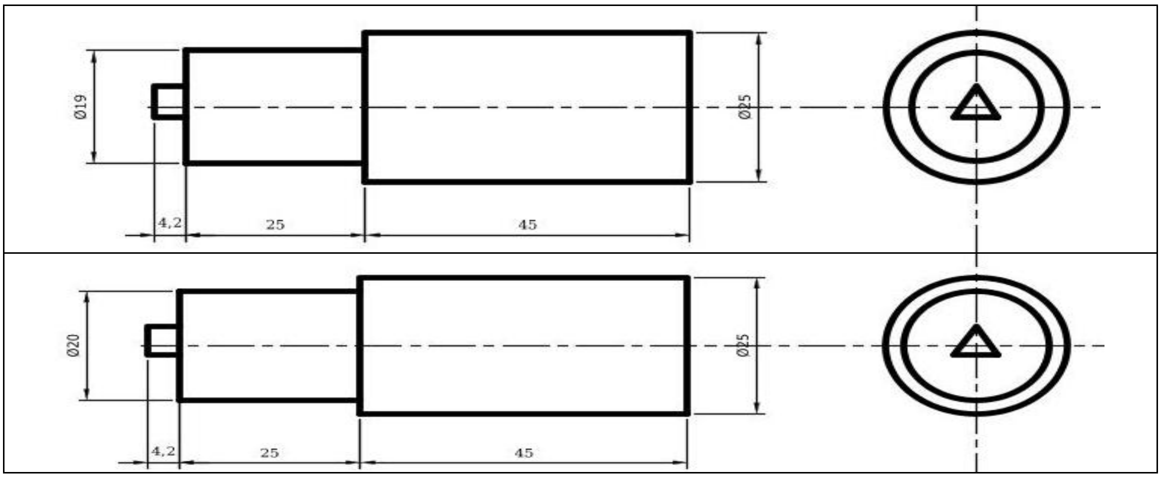


Fig. 6 — Dimensions of FSW for Triangular Tools (Dimensions are in mm)

Table 3 —The D2 instrument steel chemical composition

Element	C	Mn	Si	S	P	Cr	Mo	V	Iron
Content (%)	1.42	0.334	0.48	0.0011	0.026	12.35	0.841	0.807	Balance

2.2 Machine

The available milling machine (BFU-5) was converted into the FSW machine by using vertical attachment as illustrated in Fig.7.

Name of the Company: Batliboi Ltd, Surat		
Name of the Machine: Universal Milling Machine (BFU-5)		
	Spindle	ISO 40
	Table Size	1430 x 320
	Transverse:Longitudinal	810 mm
	Cross	405mm
	Spindle Speed	45-2000 rpm
	Spindle Feed	14-750 mm/min
	Spindle Power	5.5 kw

Fig. 7 — Universal Milling Machine with perpendicular connection

2.3 Process parameters

Five process parameters have been chosen from the state of art, its length and pattern of the available instrument pin diameter and universal milling machine kept constant for experiments. Three FSW tool profiles have been studied. By the commercial software MINITAB 17, the experiment was planned. This allows essential data compilation to identify the most affected parameters which include the quality of the product, with the least amount of experiments, thus preserving resources and time. The major advantage of this technique is diminishing the cost, inventing important parameters hastily, preserving the experiments conducting and preserving experimental time. Five factors and five levels have been used for experimentation as given in Table 4.

Table 4 — Five-level experiment with five factors used for experimentation

S.N.	Process parameters	Level					DOE Taguchi design
		1	2	3	4	5	Factors = 5
1	Speed (rpm)	500	710	1000	1400	2000	Levels = 5
2	Feed (mm/min)	14	20	28	40	56	Runs= 25
3	Axial force (kN)	5	6	7	8	9	
4	Shoulder diameter (mm)	16	17	18	19	20	Total Expt. Readings = 25
5	Tilt angle (degree)	0	1	1.5	2	3	

3 Experimental Set Up

To carry out the FSW process, a Universal Milling

Machine (Model no. BFU-5) was used. Initially, AA6061 T-6 materials have seventy-five pieces with a size of 82 x 50 x 6 mm produced for friction stir weld joint function as per DOE. Later than the appropriate plate's size cutting, these plate boundaries are prepared directly through corners and files and are made of angle 90^0 on all the pieces. Cutting is done by the power hacksaw machine. Furthermore, plates are prepared burr-free through filing consequently for friction welding two plates are kept in a match at the same time, afterward there is no gap present betwixt two pieces, to create superior samples for friction welding. The samples were made, as per the Taguchi scheme. The plates are equipped for manufacturing the FSW joints situated in the fixture. The test specimens are welded by D2 hot worked instrument steel with the plane shoulder. The FSW tool was plunged into the pilot hole of size 6 mm, already made in the workpiece. The axial load measurement was done by the load cell. When the essential throw was offered, the instrument detached several substances initially and produce heat, also the instrument was crossways by plate length. Welding was carried out by setting various parameters, as per the Taguchi Design, using orthogonal array.

3.1 Design of experiments

Design of experiments (DOE) implies a series of runs or test, in which alterations are prepared to input variables and the responses are noticed. It can be used systematically investigate the process parameters that influence the product quality. Design of experiments concepts have been used since Sir Ronald a, Fisher's work in agriculture experimentation during the late 1920s. In the present work, list of all possible process parameters was prepared and set up restrictions and shortlisted based on machine suppleness. As the researches were directed on a universal milling machine having provision of to change tilt angle so this was also taken as one of the parameters. This restricted the factor consideration like instrument stiffness to avoid a large number of instruments having dissimilar stiffness. Experiments conducted on environment conditions.

3.2 Taguchi method

Taguchi techniques are the statistical systems which is one of the majority influential DOE technique presented by Genchi Taguchi for experimental investigations. Taguchi first applied these methods was Toyota, since the late 1970s. The variation in a process can be reduced in the Taguchi technique by experiments vigorous design, also the high-quality product at low cost for producing to the manufacturer is the main aim of this technique. He presented a technique for designing the experiments to examine how the procedure variance and the mean dissimilar elements performance features are affected which describe how the procedure is executing The design of the experiments are advanced through Taguchi technique includes, for managing the factors devastated the stages and procedure at which they should be changed through the orthogonal arrays. The Taguchi technique examines the amalgamation pair's contrary to all probable combinations like the design of the factorial. These permits the required information gathers to establish which aspects most affect the quality of the product with the least experimentation value, thus preserving resources and time. The Taguchi technique plays a major part when only a little variable contribute extensively, when there are a median number of variables (3 to 50), and the minority relations between the variables The designs of conventional experimental techniques are not simple to use and too difficult. When the numeral of procedure parameters is improved then the huge numeral of experiments has to be taken out. This problem is overcome by the Taguchi method which used the design of an orthogonal array to learn the complete space of the parameter with a miniature number of experiments.

Table 5 — Array selector.

Level	Parameters										
	2	3	4	5	6	7	8	9	10	11	12
2	L_4	L_4	L_8	L_8	L_8	L_8	L_{12}	L_{12}	L_{12}	L_{12}	L_{16}
3	L_9	L_9	L_9	L_{18}	L_{18}	L_{18}	L_{18}	L_{27}	L_{27}	L_{27}	L_{27}
4	L_{16}	L_{16}	L_{16}	L_{16}	L_{32}	L_{32}	L_{32}	L_{32}	L_{32}		
5	L_{25}	L_{25}	L_{25}	L_{25}	L_{25}	L_{50}	L_{50}	L_{50}	L_{50}	L_{50}	L_{50}

3.3 Array selector

The number of factors and interest interactions along with the number of levels and interactions of interest was considered before the selection of particular OA. An orthogonal arrangement can be used to calibrating the experimental runs that are essential to perform and the parameter stages for every element in each run/trial. Moreover, degrees of freedom (DOF) are used for suitable orthogonal selection in an experiment. The minimum number of experiments should be conducted to fix before choosing an OA to depend on the given formula.

$$N\ Taguchi = 1 + NV\,(L - 1)$$

Where, $N\ Taguchi$ is the Number of conducted experiments, L is represented as the number of stages and NV is denoted as the number of factors.
Here, five factors and five stages are selected for deliberation.
Consequently,

$$N\ Taguchi = 1 + 5\,(5 - 1) = 1 + 5(4) = 21\,.$$

Based on standard orthogonal array L25, i.e. 25 experimental runs to be selected from the given Table 5. The Orthogonal Array Selector of the Taguchi techniques exposes the stages and factors in the orthogonal arrangement. From the array selector, L25 orthogonal arrangement was elected for five stages and five factors.

3.4 Taguchi orthogonal array design

The design of the experiments is advanced through ANOVA includes, for managing the factors devastated the stages and procedure which changes with one another through the orthogonal arrays. The amalgamation pair was analyzed by the ANOVA method. The twenty-five experiments in every instrument profile set have been executed on AA6061 T-6 alloy plates based on L25 orthogonal array. The parameter process stages and the aspect are expressed in Table 6. It shows the combination of five parameters. The experiments are taken to weld the FSW of AA6061 alloy plates by the five parameters. L25 (5^5), Factors: 5, Level 5, Runs: 25.

Table 6 — Design of experiments using the Taguchi technique.

S.N.	Speed (rpm)	Feed (mm/min)	Axial force (kN)	Shoulder diameter(mm)	Tilt angle (degree)
1.	500	14	5	16	0.0
2.	500	20	6	17	1.0
3.	500	28	7	18	1.5
4.	500	40	8	19	2.0
5.	500	56	9	20	3.0
6.	710	14	6	18	2.0
7.	710	20	7	19	3.0
8.	710	28	8	20	0.0
9.	710	40	9	16	1.0
10.	710	56	5	17	1.5
11.	1000	14	7	20	1.0
12.	1000	20	8	16	1.5
13.	1000	28	9	17	2.0
14.	1000	40	5	18	3.0
15.	1000	56	6	19	0.0
16.	1400	14	8	17	3.0
17.	1400	20	9	18	0.0
18.	1400	28	5	19	1.0
19.	1400	40	6	20	1.5
20.	1400	56	7	16	2.0
21.	2000	14	9	19	1.5
22.	2000	20	5	20	2.0
23.	2000	28	6	16	3.0
24.	2000	40	7	17	0.0
25.	2000	56	8	18	1.0

3.5 Planning of experiments based on Taguchi's method

The Taguchi's technique is extremely efficient to manage with a response that is influenced by numerous parameters and it is a proficient, easy, and systematic technique to decide the optimal methodology parameters. These methods reduce the numeral of experiments that are necessary to optimize and model the responses; also, it saves a huge amount of time and investigational price. For development procedure and recognition of best levels of process parameters in given responses, the Taguchi method is designed. In the present study, the Taguchi technique was used to experimental data through arithmetical software Minitab17.

4 Conclusions

The FSW experiments on aluminium alloy AA6061-T6 were taken from Table 6. The design of experiments was done by Taguchi's technique, by using Minitab 17 Software. For five parameters and five levels, L25 orthogonal array was selected.

(i) The process parameters optimization in FSW, of alloy AA6061 T-6 was successfully designed by using Minitab 17 to the Taguchi method. The difficult maximization of multi-response troubles can be easily reduced by the Taguchi-depend methods in the present analysis.

(ii) The Taguchi method main benefit is reducing the cost, finding the important aspect rapidly, preserving the time of experimental, and need low conduction of experiments.

(iii) This technique permits several dissimilar parameters without the restriction of the large quantity of experimentation for investigation. Different materials need to be considered for a better understanding the parameters of the process effect. In the future, the scope of Taguchi's method of optimization will be further exposed to the other fields, like the health sector, financial sectors, processing industries, software industries, civil and construction sector, electronic and electrical industries, biotechnology, etc.

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