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Study on Friction Stir Welding of Copper Metals

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ABSTRACT:

This paper includes the process parameters of FSW and optimized the parameters in respect to achieve the desire response and to investigate the effect of these parameters on mechanical properties of the welded jointIn this study, L18(2^1×3^2) mixed level design of Taguchi's methodology has been used to design the experimental run table. Development Signal-To-Noise and their statistics analysis including analysis of variance (ANOVA) for response, tensile strength and microhardness have been done using of MINITAB version 18.0 software. Effects of main parameters and interaction parameters from ANOVA analysis on response have been studied and its found that selected parameters which are Tool Rotational speed, welding speed and Tool Tilt Angle all are significant for tensile strength of welded joint with different contribution ratios but for microhardness of welded joint only Tool Rotational Speed is found to be significant.

Keywords: FSW, Joints, Anova, Metals, Tool

1. Introductions

Using heat, pressure, or both at the connecting edge, the fabrication process of welding connects two metal pieces. During welding, the edges of metal pieces vanish in the welding zone, and both parts melt into one another to create a permanent type union. Some welding processes allow the use of extra or filler materials. In the course of welding, materials are atomically bonded. According to the welding state, there are three different types of welding processes: liquid state welding, solid state welding, and liquid/solid state welding. Due to a number of its appealing features, including as strong electrical and thermal conductivities as well as exceptional corrosion resistance, copper and its alloys have a wide range of engineering uses. Several issues limit the weldability of copper and its alloys when employing traditional arc welding procedures. friction stir welding (FSW) is unique technique as it permits welding dissimilar materials in solid-state to overcome fusion welding problems.

A revolving cylindrical tool with a profiled pin (also known as a probe) that has a diameter smaller than its shoulder is used to perform friction stir welding. In order to weld, the tool is inserted into the butt joint between two objects that are clamped until the probe pierces the object and the tool's shoulder touches the object's surface.[13] The tool shoulder of the probe rests atop the work surface and is slightly shorter than the necessary weld depth.[14] Following a brief dwell period, the tool is advanced at the predetermined welding speed along the joint line.

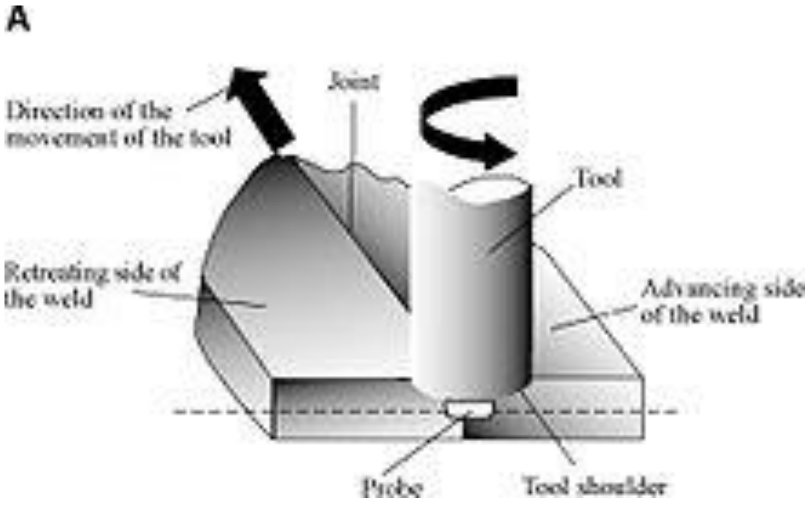

Fig. 1 Two metal workpieces butted

The wear-resistant tool and the workpieces create frictional heat. The heat produced by stirring causes the materials to soften without melting, together with heat produced by the mechanical mixing process and adiabatic heat within the substance. A unique probe profile forces plasticized material from the leading face to the rear as the tool advances, where the strong forces help the weld to forge together. A plasticized tubular shaft of metal undergoes significant solid-state deformation as a result of the tool moving along the weld line, which dynamically recrystallizes the base material.

2. Literature Reviews

A recent development is the FSW process, which efficiently joins similar, different metals and their alloys, as well as non-metals such polymers, with or without the need of filler material. That is why this method is increasingly being used in a variety of production sectors, including aerospace, automotive, etc.

Table 2: Outline of some research works

K KMugada and K Adepu 2017		H13 tool steel AA6082	Shoulder diameter,	Temperature ,zenerholloman (Z)parameter, strain , strain rate	Torque and axial load are on higher side with particular shoulder geometry. The figured log Z esteems for various districts on AS results in stable stream locale under the procedure guide of the AA6082
S Fouladiet,al, (FSW) 2017		WC and HSS with 65 HRC AA5052	Vibration frequency 33 Hz. Rotation Speed, Transverse Speed (mm/min)	% elongation Tensile strength kN	Vibration during the process provides better mixing aftermath increases the ductility and strength of weldment.
J Murali et,al,	Taguchi	HSS Conical tapered tool profile AA2014 and AA6082	welding speed, tool rotation speed, tilt angle.	Tensile strength Fracture surface by SEM analysis.	Dominating process parameter among the considered process parameters tilt angle being the most effective parameter followed by rotational and welding speed.
L.H Shah et,al		H13 tapered threaded pin AA6061	Welding speed, tool rotation, With and without tool offset of 0.2mm	Tensile strength MPa %elongation Hardness	The eccentric motion of tool due to offset of 0.2mm from the spindle axis drastically improve the material flow in the NZ region although there is no change in mechanical properties of weldment.
M M Sayed et,al		K720 Cylindrical tapered and threaded probe AA5083-O	Welding speed Pin geometry	Tensile strength, Micro hardness, Temperaturedis tribution	In case of threaded probe if we increase the feed rate tensile strength decreases and vice versa for same rotational speed. Geometry of tool pin has no significant affect on temperature distribution or peak temperature at constant rotational speed and same feed rate.
S Eslamiet,al,	Taguchi L9 design	Teflon with threaded probe High density poly ethylene 3mm plates	Rotational speed, welding speed, axial load, diameter of shoulder	UTS, joint efficiency, temperature in nugget zone	L9 design reveals that rotational speed has maximum effect in joint strength and physical properties followed by traverse speed, diameter of tool and axial load respectively. High welding speed is recommended to avoid surface deterioration.
SugimottoIttoet,al[		WC Mild steel	Welding speed, Rotational speed. Axial load	Grain size, micro hardness	Since external heating is also done so, high welding speed is recommended to produce defect free joint in mild steel plates. High productivity in terms of joint preparation can be achieved through

					this process because of higher feed rate and low axial load is required in this hybrid process.

Simple butt joints are the preferred joint configurations in the FSW process from the beginning, where two faces of adjacent materials are placed together and properly clamped to prevent abutting. After that, a specially designed tool is inserted slowly so that the initial plunge pressure is low to avoid any misalignment, which is why extra care should be taken throughout the entire process [3-5,24]. The results of previous studies indicate that, as shown in the figure, the butt joint and lap joint have received the most attention, with the other joint configurations described still being developed.

Table 2.1: Joint successfully configured by FSW

Paper/author	**Joint configuration**	**Tool/ Workpiece**	**Conclusion**
H.Zhaoet,al,	Lap joint	H13 tapered Al 7075-T6 sheets	Tool pin geometry influence most in welded macrostructure, hook geometry and fracture load. The overlap shear fracture load decreases with increase of hook height.
C.Rajendaranet,al,	Lap joint	HSS toolTapered angle 4.96 with thread pitch 0.75mm AA2014-T6	The tool tilt angle was observed to play most important role in joint shear strength although welding speed and rotational speed are not dominating.
Xiangchen Meng et,al,	Lap joint	H13 AA2060 and AA 2099	At advancing and retreating side of nugget zone hook height and cold laps are observedas a result of removal of lap crossingpoint. To reduce EST, HA, and HR, high feed rate is desirable.
M.I.Costaet,al,	Lap joint	H13 AA6082-T6 and AA5754-H22	The expectation of defect formation in lap welding is more in heat treated alloys. lap joint strength is independent of EJW(effective joint width).
R.Rafieiet,al,	Lap joint	SKD61 concave shoulder AMX602 and ADC12	Al-Mg lap joint configuration is easier than Mg-Al lap joint configuration due to its better deformation capacity PEO interlayer reduce growth, formation of IMC
E.Lertoraet,al,	T- Lap joint	H13 AA8090 T8	Increased WR show defect free or smaller defects. Heat dissipation is problem for material plasticization. Doubling WR but without oxide formation only pass the bending test
Yao Shi et,al,	Lap joint	H13 tool steel AA2198-T8	Keyhole can be successfully refilled using RFSSW and small voids can be eliminated by using higher the rotation speed.
Y.Gaoet,al,	Lap joint	SKD61concave shoulder AMX602 and ADC12	Effective dissimilar joints are achieved when magnesium based alloy subjected to PEOT(plasma based electrolytic oxidation treatment). Growth of IMC was restricted by the PEOT interlayer since it reduce the reaction time.
E.E.Feistaueret,al,	T-butt joint	H13 tapered threaded pin AA5083-H111	Second pass welding helps in reduction of kissing bond defect in T-butt configuration. Joint fatigue strength increases under skin loading.
M.R.Hajidehet,al,	Edge butt joint	H13 Shoulder surface is coated with Teflon	Using copper powder in between the adjoining surfaces produce sound weld. Also it helps in increasing tensile strength.

		PP and ABS	

3. Experimental Details

This chapter contains brief description about machine setup, selection of workpiece, selection of tool material and tool type, parametric study, to find out the ranges and levels of input process parameters and fixed process parameter, process performance characteristics and design of experiments technique to plan the experimental runs. The procedure and the measuring instrument and machine utilized for quantifying the process performance characteristics are also discussed in this chapter. A flow chart is illustrated in Fig 3.1 to show the proposed plan for research work.

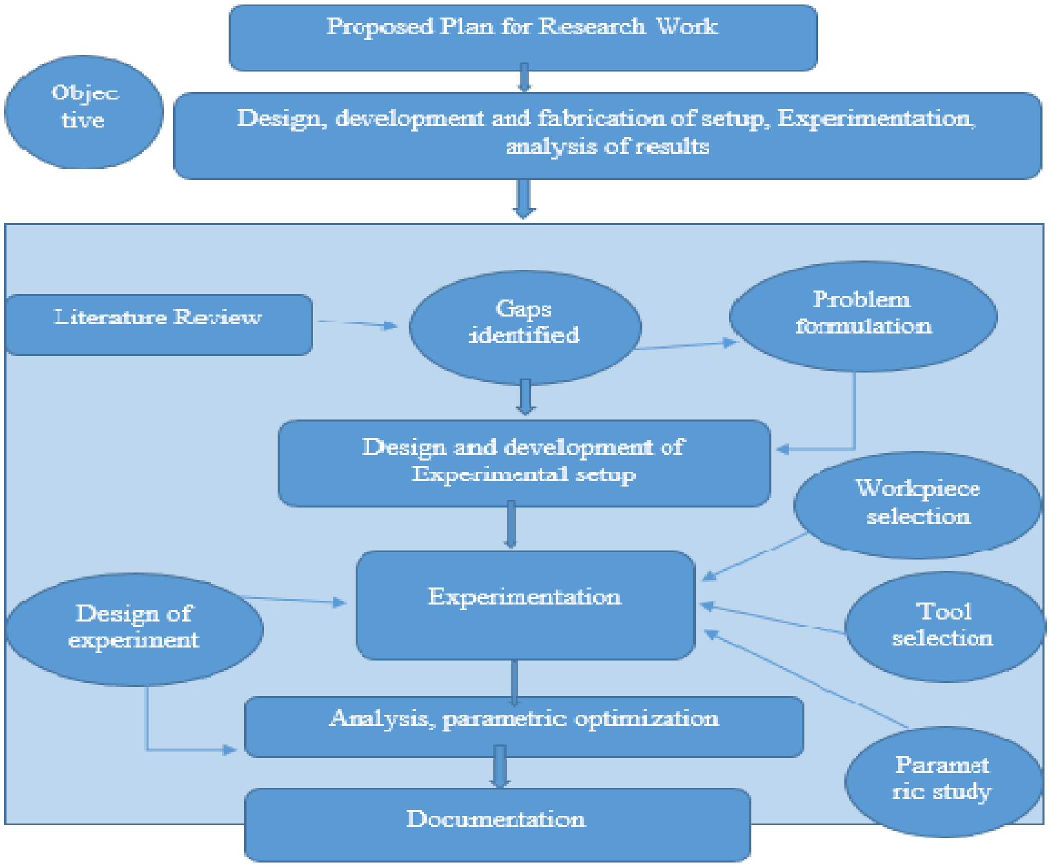

Fig. 3.1 Proposed Plan For Research Work

Table 3.2 lists the normal ranges, levels of the input process parameters and the parameters that were held constant for the experimental run.

Table 3.2: Ranges and levels of input and fixed parameters

Process parameters				
Parameter	**Range**	**Level**		
		L1	**L2**	**L3**
Welding speed (mm/s)	25-60 mm/s	25	40	60
Tool rotation (rpm)	710-2000 rpm	710	1400	2000
Tilt angle (degree)	0°-2°	0	2	-
Fixed process parameters				
Parameters	**Value**	**Fixing criteria**		
Shoulder profile	Flat face			
Pin profile	Flat cylindrical			

Shoulder diameter	16mm	Literature review and pilot experiments
Pin diameter	4.6mm	
Pin length	2.7mm	

In this research work, tensile strength and microhardness are used as response parameters. The measuring techniques of these response parameters are discussed below in brief.

3.3 Experimental Procedure

In this research work, four phases. (a) Trial experiments to check the working condition of the machine setup, (b) Pilot experiments to establish the levels and ranges of the input process parameters, experiments to investigate the impact of the process parameters on the process performance characteristics, and confirmation experiments to verify the analytical study.

3.3.1 Design of Experiment

DOE is a substantial approach to improves performance characteristics and product design, DOE can be very well being utilized to diminish process duration and cycle time required for the development of new productand procedures. DOE techniques permits designers to determine simultaneously the effect of individual factor and interactive effects of number of factors that might have an effect on the output outcomes in any model design.

3.3.1.1Taguchi's methodology

Taguchi technique was developed by the Japanese Scientist Dr. Genichi Taguchi. The Taguchi technique is proved to be effective tool to reduce the number of experimental runs and time in order to optimize the different number of factors associated in a process design. This is the effective approach to optimize the responses related to process performance. It offers a very simple and efficient integrated strategy for higher quality, performance, and computational cost.For off-line quality control, the Taguchi technique entails three stages, namely:

1. Design of System

2. Design of Parameter

3. Design of Tolerance

3.3.1.2 Noise factors and control factors

The noise factors are very difficult and unacceptable to control, responsible for the performance characteristics variation of the process parameters. If an outer array is used, The Taguchi approach suggests using the inner arrays for the controllable factor and the outer arrays for the noisy factors. An experiment is compelled to include the noise variation..

3.3.1.3 Signal to Noise (S/N) ratio

The S/N ratio is one of the contributions of Dr. Genichi Taguchiand introduced as a proactive equivalent to the reactive loss function. It is used for robustness measurement of system design. The control factor setting"that minimize the effect of noise factor on the responses[66]. The static problems are optimized through three forms of S/N ratio.

3.3.1.4Analysis of Variance (ANOVA)

ANOVA is a statistical tool which is applied to the experimental outcomes to evaluate the significant process parameters affecting the quality characteristics or performance of the product or process. The study of ANOVA gives an idea about which factor need to be control and which factor not with help of table containing quantities such as degree of freedom, sum of squares, mean squares, variance and percentage contribution of each factor thereby obtain optimum settings or condition [14].

3.3.1.5 Taguchi's Orthogonal Array

Orthogonal array (OA) is simplified criteria for selection to test each level of each parameter and putting together an experimental run order. method examines each of the variables on two levels and determines which one contributes the most to the final outcome. By altering the rows or columns, the orthogonal features of the OA are unaffected. Individual experimental runs are compelled by the array to create almost identical experimental runs. By conducting various trials, it ensures uniformity of design [15].

4. Results and Discussion

The experimental runs are conducted according to trial runs designed and planned by L18($2^1 \times 3^2$) mixed level of Taguchi's methodology to explore the effect of input process parameters: tilt angle, tool rotation and welding speed on process performance characteristics: tensile strength and microhardness. The experimental results for tensile strength and microhardness are given in Table 4.1. The experimental outcomes are further processed and analyzed using MINITAB (version 18) software to carry out the S/N ratios, analysis of variance, interaction effect of factors, parametric optimization and development of mathematical models to identify the best process efficiency characteristics with particular combination of process parameters.

Table 4.1: Experimental results

Experiment No.	Tilt angle (°)	Tool rotation (rpm)	Welding speed (mm/s)	UTS(MPa)		Hardness (Hv)	
				Trial 1	Trial 2	Trial 1	Trial 2
1	0	710	25	85.015	80.189	81	78.2
2	0	710	40	69.236	62.332	82.9	81.1
3	0	710	63	41.502	44.801	79.2	76.5
4	0	1400	25	224.794	212.231	82.4	83.2
5	0	1400	40	198.035	194.621	77.8	79.2
6	0	1400	63	152.934	164.128	78.6	76.3
7	0	2000	25	299.111	289.765	93.4	90.1
8	0	2000	40	267.091	261.873	90.3	89.9
9	0	2000	63	256.033	241.732	83.3	84.2
10	2	710	25	76.431	79.139	76.6	78.2

4.2 Tensile Test Analysis

The tensile test results are evaluated and transformed into means and S/N ratios such that influence of each parameter can be identified.The experimental results in terms of means and (S/N) ratio is presented in Table 4.2 The signal-to- noise (S/N) ratio for tensile strength is calculated by using criteria “larger-the-better” characteristics in order to maximize response.

Table 4.2: The Experimental results and S/N ratios values for Ultimate Tensile Strength

Experiment No.	Tilt angle (°)	Tool rotation (rpm)	Welding speed (mm/s)	UTS(MPa)		Average	S/N Ratio
				Trial 1	Trial 2		
1	0	710	25	85.015	80.189	82.602	38.3398
2	0	710	40	69.236	62.332	65.784	36.3624
3	0	710	63	41.502	44.801	43.151	32.6999
4	0	1400	25	224.794	212.231	218.512	46.7895
5	0	1400	40	198.035	194.621	196.328	45.8596
6	0	1400	63	152.934	164.128	158.531	44.0023
7	0	2000	25	299.111	289.765	294.438	49.3799
8	0	2000	40	267.091	261.873	264.482	48.4479
9	0	2000	63	256.033	241.732	248.882	47.9199
10	2	710	25	76.431	79.139	77.785	37.8179

4.2.1 Analysis of variance

Analysis of variance is a statistical tool used to determine the degree of similarity or difference between any two or more group data, which is important to find out the major significant factor that affects the output performance characteristics and quality by using the quantity domains like sum of square (SS), degree of freedom (DF), variance (V), mean of square (MS), percentage contribution of each factor (F ratio) and P-values are to be determined and the parameters which have highest F-ratio and lowest P-value indicates the most influencing parameter. It is observed from the ANOVA Table 4.4 that the Tool rotation (A) has highest value of F-ratio and lowest P-value indicating most significant parameter followed by Welding speed (B) having moderate values and Tilt Angle (C) has least significant parameter among two. Other interaction A*C not seems to be affect the optimum combination of process parameters presented in Table 4.4 below.

Model Summary

S = 7.25076 R-sq = 99.68% R-sq (adj) = 99.32%

Table 4.4: Analysis of Variance (ANOVA) for Ultimate Tensile Strength

SOURCE	Degree of Freedom	Sum of Square	Mean Square	F-Ratio	P-Value	% Contribution
TILT ANGLE	1	364	363.9	6.92	0.030	0.2786
TOOL ROTATION	2	123650	61825.0	1175.97	0.000	94.6313
WELDING SPEED	2	5965	2982.4	56.73	0.000	4.5651
TILT ANGLE*TOOL ROTATION	2	220	110.2	2.10	0.185	0.1684
TILT ANGLE*WELDING SPEED	2	46	22.8	0.43	0.663	0.0352
Error	8	421	52.6			
Total	17	130665				

4.3 Microhardness Test Analysis

The tensile test results are evaluated S/N ratios such that influence of each parameter can be identified.The experimental results in terms of means and (S/N) ratio is presented in Table 4.2 The signal to noise (S/N) ratio for microhardness is calculated by using criteria "larger-the-better" characteristics in order to maximize response.

4.3.1 Analysis of variance (ANOVA)

It is observed from the ANOVA Table 4.4 that the Tool rotation (A) has highest value of F-ratio and lowest P-value indicating most significant parameter followed by A*B interaction i.e. interaction between Tilt Angle and Tool Rotation seems to be second significant factor influencing the microhardness of nugget zone under the variation of tilt angle, welding speed (B) having rank third and Tilt Angle (C) has least significant parameter among all.

Table 4.5: Analysis of Variance (ANOVA) for Microhardness

SOURCE	Degree of Freedom	Sum of Square	Mean Square	F-Ratio	P-Value	% Contribution
TILT ANGLE	1	3.125	3.125	0.88	0.376	0.6832
TOOL ROTATION	2	351.301	175.651	49.32	0.000	76.8045
WELDING SPEED	2	28.037	14.018	3.94	0.065	6.1296
TILT ANGLE*TOOL ROTATION	2	31.163	15.582	4.37	0.052	6.8131

5. Conclusion

The results obtained through optimization of process performance parameters of friction stir welding to weld the similar copper plates by using Taguchi's approach followed by ANOVA technique are evaluated and from the analysis of the Taguchi design approach following conclusions has been obtained:

- From the ANOVA result of ultimate tensile strength, it is concluded that the tool rotational speed is the most significant factor with percentage contribution of 94.63%, followed by the welding speed of 4.57% and tilt angle of 0.28%.
- From the ANOVA result of microhardness it is concluded that only tool rotational speed is the significant parameter with P-Value less than 0.05 with percentage contribution of 76.8%.
- The optimum condition for higher tensile strength and for maximum microhardness are A3, B1, C1, i.e., Rotational speed (2000 rpm) followed by Welding speed (25 mm/min) and Tilt angle (0°).
- The contribution of each parameter from the ANOVA results indicates that tool rotational speed is most significant factor whereas tool tilt angle is least significant factor for both tensile strength and microhardness of welded joint.
- The available interaction from the Taguchi design i.e., Tilt angle*Tool rotation and Tilt angle*Welding speed found to be no major effect on output weld quality as indicated from the ANOVA results.

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