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Implementation of hybrid RSM-GA optimization techniques in underwater friction stir welding

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Abstract. Standard friction stir welding process parameters have a considerable impact on the quality of functional parts produced by underwater friction stir welding (UWFSW) with additive water. Hybrid statistical techniques may be used to optimize operating parameters in order to improve the aim function. The tensile strength (UTS)of parts fabricated with UWFSW by Al 6063 material in accordance with ASTMD638-14 tests is investigated in this study. In the construction of test specimens, three parameters were varied: rotational speed from 1000 to 1800 rpm, travel speed from 4 to 10 mm/s, and shoulder diameter from 10 to 20 mm. The response surface methodology (RSM) based central composite design (CCD) matrix for the parametric combination was constructed using a second-order polynomial fitting model. The maximum UTS of testing samples on the 201T universal testing machine (UTM) was 208.27 MPa. These process parameters are also optimized using hybrid optimization approaches such as response surface methodology- genetic algorithm (RSM-GA). RSM-GA had the highest precision of 98.99 percent, which resulted in optimal characteristics such as rotating speed 1800 rpm, travelling speed 4 mm/s, and shoulder diameter 15 mm, which resulted in a maximum tensile strength of 199.0212 MPa.

1. Introduction

Modern technologies are becoming increasingly important in practically every sector, including the manufacturing business. Welding has always been a component of every manufacturing business, with the automobile industry being the most important partner. Welding processes are the subject of increasing study [1] [2]. Friction stir welding (FSW) is one among the most contemporary welding processes that has found widespread application in the automobile industry. FSW involves rotating and plunging a cylindrical tool with a contoured pin and a shoulder into the joint region between two plates. The plates must be secured throughout the welding operation to ensure effective welding [1]. FSW is a solid-state joining procedure in which the heat produced by the tool's rotation causes the materials to be bonded without melting. The plasticized material is carried to the tool pin's trailing edge, and the tool shoulder and pin are forged together. FSW is a method that is commonly used in the air and underwater. Underwater friction stir welding (UWFSW) is a stirred welding procedure that takes place in the water. When compared to fusion welding, the FSW technique is much more energy efficient and environmental-friendly. Despite the advantages of FSW against fusion welding, the thermal cycles required for softening heat-treatable aluminum alloys joints in FSW due to the coarsening and dissolution of strengthening precipitates, resulting in a reduction of mechanical characteristics. UWFSW is a is a realistic choice.

FSW involves stirring with a spinning tool pin to provide friction heating and local plastic flow in the joint site. FSW can fabricate lap or butt joints for different material thicknesses and lengths, and is capable of producing high-quality, high-strength joints with little distortion. The procedure involves plunging a spinning a tool composed of a hard-wearing material, highest-temperature-resistant material into the material to be jointed and translating it straight the desirable weld zone [3] [4] [5]. The heat created by friction on the tool surface and plastic dissipation in the deforming portions of the workpieces softens the material and causes it to become plasticized. It is then extruded and consolidated around the tool to make a weld. Because cooling water is used in the UWFSW, the welding zone environment is not influenced by high temperatures. Is the UWFSW solid state joining procedure effective in reducing issues like as hydrogen embrittlement, oxidation, and porosity [6] [7]. Ibrahim Sabry [3] UWFSW and FSW tests are carried out on AA 6063 pipe couplings by wont - designed fittings. The results of the FSW on mechanical properties utilizing rotation and travel rates there has also been examined.
SARUKADA.[8] The results of an experimental examination on UWFSW and FSW of AA 6061 aluminum alloy demonstrated that the joint had the same fatigue strength as FSW [9]. UWFSW is an NFSW version that can maintain low heat input while maintaining a steady heat input throughout the weld line. During UWFSW, heat conduction and dissipation limit the breadth of TMAZ and HAZ while also improving joint properties [10]. The possibility of enhancing the mechanical properties of traditional FSW joints by controlling the temperature level appears to be of interest. External liquid cooling has been employed in several experiments to achieve this during FSW. throughout UWFSW, Heat treatment has an influence on Frattini et al. [11] the grain refining impact of UWFSW is outstanding. The UWFSW's microstructures in the TMAZ and HAZ are significantly finer than the FSW's. UWFSW Al 7075 Al alloy with significantly finer-grained structure has much greater yield strength, elongation, and ultimate tensile strength than as-cast and FSW materials. A. M. El-Kassas [12][31] performed an FSW experiment on a piece of Al 1050 pipes alloy. He also talked about MCDM methodologies and how to enhance the FSW while taking the influence of diameter of tool pin into account [14]. Wahid [13] the effects of UWFSW process parameters on aluminum alloy 6082-T6 mechanical characteristic are investigated, and the process is then simulated using evolutionary optimization techniques (NSGA-II). Response surface methodology (RSM) and analysis of variance (ANOVA) were used to parametric the effect of FSW factor of input such as rotation speed, orientation, and traveling speed on the mechanical properties of joint [14][32]. The research design was used to determine how process factors influenced the ductility of UWFSW produced components [15-16]. The effect of different factors on the parameters of FSW was explored utilizing test components. Advanced optimization approaches include Taguchi, RSM, GA, ANN, and ANFIS [4] [17] [14]. were the first to use the UWFSW method to join. They were able to rotary friction weld Al-6061 underwater throughout their investigation.

A friction weld is created by pushing a cylindrical sample against another sample while spinning at a high speed [18-19]. UWFSW opposing input parameters and welded joint adequacy were found to have a exemplary relationship. To the best of authors knowledge, few work is done on underwater friction stir welding. It is an advanced welding technique. Few researchers have used the optimization technique in the friction stir welding field but very little in case of UWFSW. The ANFIS Integrated Hybrid Methods are provided in this study for successfully modeling the UWFSW parameters with performance reaction values [20-22]. The RSM-GA Integrated Hybrid Methods are suggested in this research for modeling the UWFSW parameters. Using hybrid RSM-GA, multiple evolutionary algorithms are used to maximize tensile strength at an ideal combination of device parameters.

2. Experimental work

2.1 Material and Experimental Setup:

The under-water FSW for pipe begins as the tool pin being positioned between two pipes before hits of the shoulder and pipes surfaces as shown in figure 1(a). The UWFSW is an underwater version of the FSW of pipes. The under-water FSW method was used to combine two sections of Al 6082-T6 pipes. Pipes were 30 mm in diameter and 3 mm thick. The chemical composition of the pipe's component Al 6082-T6 is shown in table 1. The primary process ingredients are shown in table 2 together with their associated working levels.

Table 1. the chemical composition of Al 6082-T6

Alloy	AA6061
Si	0.8
Fe	0.5
Cu	0.1
Mn	0.7
Mg	0.9
Ti	0.14
Cr	0.25
Zn	0.2

Table 2. The key process elements are listed, along with their corresponding working levels..

Parameter	Unit	Level		
		-1	0	1
Diameter of shoulder (D)	mm	10	15	20
Speed of rotation (N)	rpm	1000	1200	1800
Speed of travel (S)	rpm	4	8	10

2.2. Machine

A cylindrical tool with a threaded probe with a cylindrical cross section was utilized for welding. With a beginning diameter of 5 mm and a final diameter of 5 mm, the pin profile tapers 1 mm per pin length. Figure 1 depicts the tool used in the research to fabricate the welds. As indicated in table 2, the entire the three factorial design variables were selected in 3 phases and 27 trials of coded conditions were conducted in a central composite design matrix based on the response surface methodology.
Ultimate tensile strength as a function of rotational speed, shoulder diameter, and travel speed mathematical models have been devised to measure the UWFSW UTS.

These are written as Y = f (N, F, D), where Y tensile strength, N represents the rotational speed in rpm, S represents the travel speed, and D represents the shoulder diameter in mm. The chosen polynomial can be written as Y = b0 + b1 N + b2 F + b3 D + b12 N*F + b13 N*D + b23 P*D (1) for the three variables, where b0 is a constant, linear term coefficients are b1, b2, and b3, and the interaction coefficients are b12, b13, and b23. To determine the values of the polynomial equation, regression analysis was used. The statistical analysis was carried out using the Minitab application. The final mathematical models were developed in a coded form after the investigation [7-17-23].

2.3 UTS via UTM through parameters design matrix sophisticated

The UWFSW factors of input, such as traveling speed, shoulder diameter, and speed, were selection for their optimization and to progress the UTS of the test sample instituted on the organized literature. To investigate the effect of these 3 input parameters on UTS, a response surface model based central composite design (CCD) design matrix was created utilizing a second-order polynomial model. A 12 (half) factorial 2k design was utilized to keep the experimental run to a bare minimum. A three-level face central composite design (FCCD) was utilized to statistically analyze the primary interacting effects of three process factors on UTS. By evaluating the value of alpha one, FCCD is employed to keep the number of layers to a minimum. Where Y represents the response, N represents the rotational speed, D represents the shoulder diameter, and F represents the travel speed. The chosen polynomial might be represented as equation (1) for the three elements.

$$Y = \beta_0 + \beta_1 N + \beta_2 F + \beta_3 S + \beta_{11} N^2 + \beta_{22} F^2 + \beta_{33} S^2 + \beta_{12} NF + \beta_{13} NS + \beta_{23} FS \quad (1)$$

Where β_0 is the regression equation free term; the linear terms coefficients are β_1, β_2 and β_3; the quadratic terms coefficients are β_{11}, β_{22} and β_{33}; the interaction terms coefficients are β_{12}, β_{13} and β_{23}. The polynomial coefficient values are computed using regression analysis [15]:

$$\beta_0 = 0.1663 \sum(Y) - 0.0568 \sum\sum(X_{ii}Y)$$
$$\beta_j = 0.0732 \ (X_i Y)$$
$$\beta_j = 0.0625 \sum(X_{ii}Y) + 0.00689 \sum\sum(X_{ii}Y) - 0.0568 \sum(Y$$
$$\beta_{ij} = 0.1250 \sum(X_{ij}Y)$$

Where i; j = 1, 2, 3 and i < j

Table 2 shows how these factors were adjusted at three levels while leaving the other values constant. If the model's p(0.01) value is significant, the lack of fit should be non-significant, and the determination coefficient (R^2) should be near 1, the RSM model is regarded well fit. The UTS of the test specimens was determined using a UTM test machine, as illustrated in figure 1(c). As an output value, the calculated average of five specimens (made using the identical input parameters) is used.

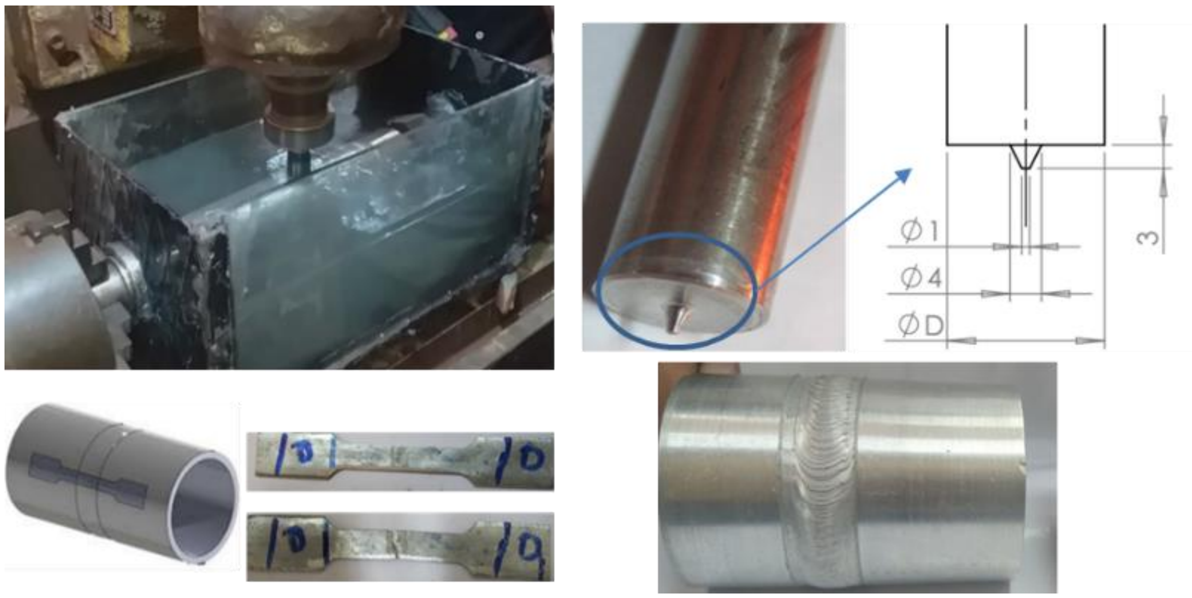

Figure 1.EG-FSW-M1 equipment, UWFSW of AA 6061 pipes.

(a) Test specimens produced to ASTM D638-14 standards (b) Conical friction stir welding tool (c) (d) Weld pictures of Al 6061 pipe are stirred by underwater friction.

2.4 The design matrix

In table 3, you'll find a design matrix. It's a three factors three levels design with 27 sets of coded conditions, including a full factorial of 24 = 16, as well as 6 center points and 5-star points.

Table 3. Full factorial analysis requires a design matrix and trials.

Test Run	Process parameter			
	N (rpm)	F(mm/min)	S (mm)	UTS
1	-1	1	-1	246.56
2	-1	-1	-1	256.32
3	1	-1	1	227
4	-1	1	1	242.58
5	0	0	0	246.25
6	1	1	1	228.6
7	1	1	-1	239
8	-1	-1	1	257.26
9	1	1	1	243.33
10	-1	-1	-1	224.4
11	1	-1	-1	260
12	-1	-1	1	225
13	1	-1	-1	238
14	1	-1	-1	243
15	-1	-1	1	225
16	-1	1	-1	248
17	1	1	1	229
18	0	0	0	236.9
19	1	-1	1	230
20	1	1	-1	251
21	-1	1	-1	230
22	-1	-1	-1	230
23	-1	1	1	246.39
24	0	0	0	241.7
25	1	-1	1	261
26	1	1	-1	266
27	-1	1	1	262

2.5 Process parameter training and optimization utilizing the RSM-GA procedure

The GA is a non-traditional tool that utilizes natural heredity and ordinary choice principles to distinguish the better solution to a multivariable optimization problem [22] [24]. Selection, Crossover, and Mutation processes are utilized to create new chromosomes called off-spring.

A chromosome with a high level of fitness value would have the greatest chance of being chosen. The algorithm eventually converges on the population with the best chromosome, regarded as the optimal solution to the problem [19]. The foregoing advancements were repeated until the ideal individual stopped evolving.

The following procedures are followed to generate the RSM -G.A. model:

1. A random population of credible solutions is generated first.
2. Values of process parameter have been established within the specified assortment.
3. The RSM equation is used to load the G.A. fitness function.
4. Using mutation and the crossover process, create a new population.
5. The computation is completed when the fitness function and the chromosomes reach a point of convergence, at which the optimum values of process parameter to maximal tensile strength is reached.

3. Results and discussion

3.1 Process parameter traineeship and optimization using the RSM-GA method

The test runs 27 * 5 = 135were done on UTM according to ASTM D3039 standard test criteria in order to optimize the UTS of the parts made by UWFSW. Matrix of experimental design obtained from DOE-6.0.8 program and assessed utilizing the second-order quadratic model supplied by equation (1). With respect to actual factors, equation (2) is the quadratic model produced for tensile strength.

$$UTS\ (MPa) = 257.8\ - 0.1298\, N\ - 1.847\, F\ + 65.36\, D\ + 5.083E - 005\, N2\ + 0.1464\, F2 \\ - 12.85\, S2\ - 0.002245\, NF\ + 0.008731\, ND\ - 0.1749\, FD \qquad (2)$$

Table 4 present the ANOVA of the produced quadratic model to assess the significance of the produced regression. The D and F test values of ANOVA determine which model is used to analyze the outputs. The P-value of 0.05 suggests that the model's input terms have a significant impact on the response value. The lack of fit determines if the proposed model fit the experimental data or not. The considerable lack of fit of the generated regression model and the resultant value of P.001 suggest that the UTS of UWFSW is highly dependent on input parameters.

Another technique to assess the adequacy of a created regression model is to look at the signal-to-noise ratio. The model may be utilized to steer the design space in this study because the ratio of 7.087 provides a sufficient signal. For UTS of parts, the obtained R2 = 0.6224, adjusted R2 = 0.4225, and anticipated R2 = 0.9812 values demonstrate that the constructed regression model is adequate. The R2 determination coefficient is a metric for determining how close data is to the regression line. The appropriate precision ratio of 72.303 also indicates that the proposed model is fit. As can be seen in table 4, the model terms N, F, D, N2 F2, D2, NF, ND, and F.D. are found significant when the p-value is less than 0.05, whereas the model terms N.F., ND, and F.D. are found insignificant when the p-value is larger than 0.1. The normal probability plot and residuals versus expected plot are shown in figure 2(a) and (b) reveal that this model is well-fitting to the experimental results in figure 2(c) shown that the GA-RSM assimilation results for tensile strength optimization. Figure 3-Dimensional 3D surface models show the process-parameter relationship. As shown in figure 3(a), increasing the UTS by increasing the rotation speed and the tool's shoulder while lowering the travel speed value. The explanation for greater UTS with a faster rotation speed and a 3mm shoulder diameter is an increase in internal resisting force as well as improved fusing in the weld zone, which is also supported by other authors. [25-30].

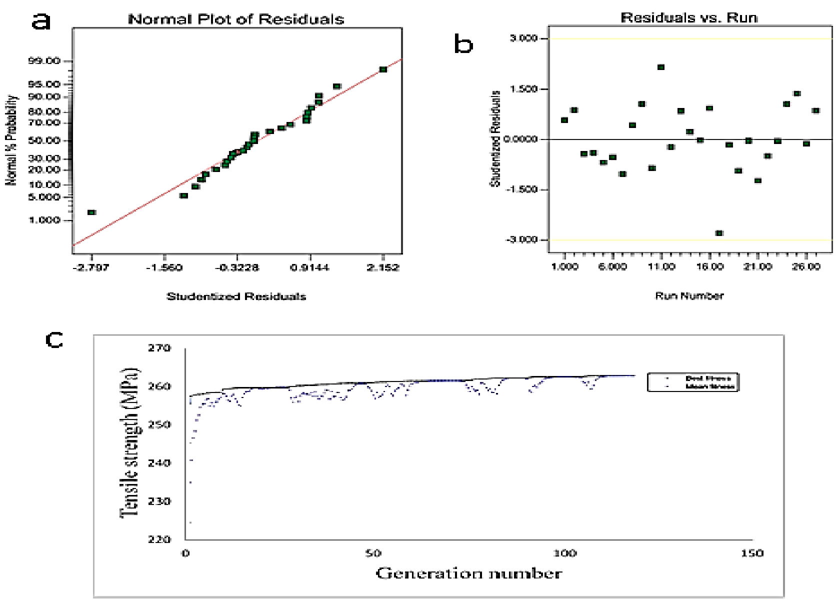

Figure 2. RSM-GA plot for optimized UTS: (a) studentized residual vs. expected, (b) normal probability versus studentized residuals, (c) RSM-GA plot for normal probability versus studentized residuals.

When the movement's speed value exceeds 10 mm / s, the UTS decreases, as seen in figure 3(a). As shown in figure 3(b), the UTS increases as the rotational speed increases, and the constant shoulder diameter increases at 3 mm while decreasing at 2 and 4 mm. This is due to insufficient material flow and lack of bonding between welded plates at low shoulder diameter. The larger heat generation at higher shoulder diameter causes heat dissipation to the workpiece which forms coarse grain at the weld zone and decreases the UTS[21]. Tool rotational speed influences the heat generation and deformation of material as it has a certain role in stirring the base metal to produce high strength of weld joints. At 1800 rpm, sufficient heat was generated which result in a sound welding with higher joint strength. However, as seen in figure 3(c), tensile strength decreases when various characteristics such as travel speed and shoulder diameter rise. This can be explained as, increasing travel speed decreases the temperature of friction on welded plate surface per unit time which forms weak bond between welded plates and decreases the UTS of the joint. The influence of UTS can be seen in figure 3: as rotation speed increases, shoulder diameter increases by 15 mm, while travel speed decreases, UTS increases, reaching a maximum value of 266 MPa.

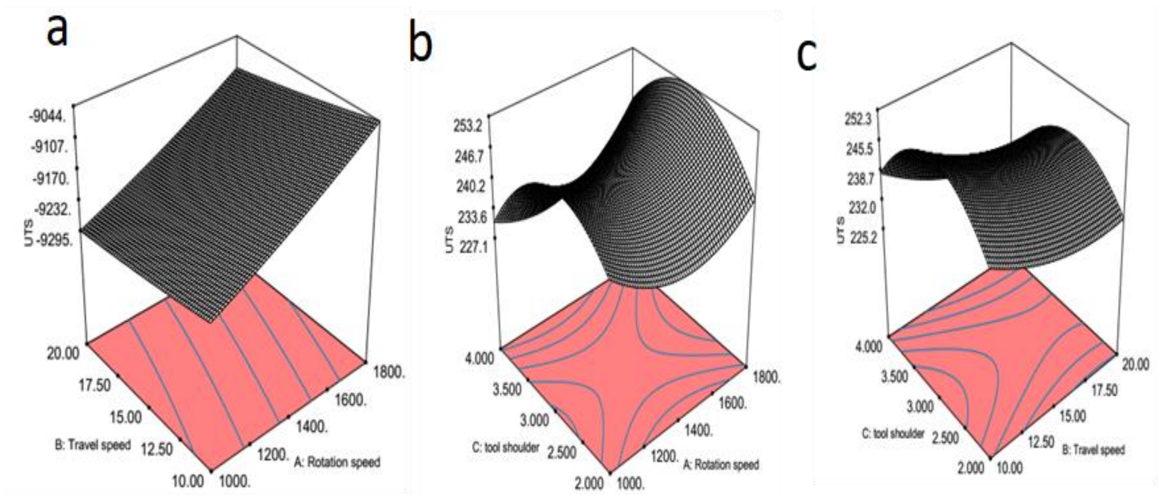

Figure 3.3D response surface plots: (a) travel speed vs. rotation speed, (b) tool shoulder vs. rotation speed, (c) tool shoulder vs. travel speed.

3.2 RSM-GA model for tensile strength optimization

The number of epochs that show the loop amount that the genetic algorithm processed defines G.A.'s output. A population scale of 50 generations and 500 is utilized in this study to determine the number of spirits that best match the analytical meaning. As shown in Table 4, multiple functions such as restriction-based mutation and crossover are applied in this study to bring the RSM-GA plot to a conclusion. The elite count is set at 0.05 for the population size. The crossover percent is set at 0.8 for the crossover percentage, all other G.A. and process parameters remaining within the prescribed range. At process conditions (rotation speed 1800 rpm, shoulder diameter 15 mm and travel speed 10 mm/s,), the maximum UTS obtained with RSM-GA is 266 MPa, which was further validated experimentally.

3.3 Discussion

The value of the tool RSM -GA for the parameters optimization for maximizing UTS is shown in table 5. The greatest UTS acquired throughout numerous tensile test runs was 266 MPa, which corresponded to various parameters values of 1800 rpm N, 15 mm D, and S 10 mm / min.

Table 4. ANOVA results for the constructed quadratic response surface model

Sources	Sum of Squares	DF	Mean Square	F-Value	p-value	Result
Model	2627.	9	291.9	3.113	0.0210	significant
N	152.6	1	152.6	1.627	0.2192	
F	14.23	1	14.23	0.1518	0.7017	
S	997.4	1	997.4	10.64	0.004598	
N2	396.9	1	396.9	4.232	0.05535	
F2	73.12	1	73.12	0.7798	0.3895	
S2	991.3	1	991.3	10.57	0.004698	
NF	245.2	1	245.2	2.615	0.1243	
NS	146.4	1	146.4	1.561	0.2285	
FS	9.301	1	9.301	0.09918	0.7566	
Residuals	1594.	17	93.78			
Cor Total	4222	26				
Std. Dev.	9.684			R-Squared		0.6224
Mean	242.0			Adj R-Squared		0.4225
PRESS	3807.			Pred R-Squared		0.09812
C.V.	4.001			Adeq Precision		7.087

Table 5.RSM-GA optimization process parameters

Tool for optimization	Optimized input parameters			Predicted UTS	Experimental UTS	Accuracy percentage
	N	S	D			
GA-RSM	1800	4	15	264.962	266	99.61

4. Conclusions

Cooperation among hybrid (RSM - GA) and additional manufacturing statistical techniques (RSM and GA) for producing UTS and VHN parts the door is opened to historically new-fangled extents of parts manufactured. This research contributes to the improvement of FSW welding issues in pipeline manufacture. Following the completion of this study, the following tangible and intangible benefits are listed:

1. The UWFSW technique has been used to successfully weld Al 6063 specimens. The N, S, and D have all been found to have a substantial impact on the mechanical characteristics of the welded joints.
2. The testing findings show that the mechanical characteristics of the UWFSW process with a D of 15mm are better than those of the UWFSW process with a shoulder diameter of 10 and 20mm.
3. A hybrid RSM-GA approach has been devised, and it has proven to be more successful than traditional RSM and GA methods.
4. It gives a higher RSM-GA of 99.61 % using D 15mm N of 1800 rpm, and S of 4 mm/min, which is 6.75% more than the traditional RSM and GA.

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