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Predict the machining performance of FSW of dissimilar material of Al5052 and AZ31 using Multi-Objective Dragonfly Algorithm

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Abstract. In this study, two dissimilar materials (Al 5052 and AZ31) have been welded using the Friction stir process (FSW). Taguchi's philosophy has been used to design the experiment using four input parameters (Tool types (TP), Tool traverse speed (TTS), Tool tilt angle (TTA), and Tool rotation Speed (TRS)). The machining performances have been identified using ultimate tensile strength (UTS) and Vickers hardness (HV). The models are evaluated for sufficiency, and then the most significant parameters are determined using analysis of variance (ANOVA). The ANOVA results revealed that TTS has a maximum contribution of 50.2% and 46.5% towards obtaining the high UTS and HV, respectively. The mathematical model using the non-linear model for UTS and HV has been created to predict the mechanical properties of FSWed joints. The prediction welding accuracy of a multi-objective optimization has been performed using the Multi-Objective Dragonfly Algorithm (MODA). The adopted strategy shows a high welding accuracy with minimum computational time.

Introduction

There has been a rise in the utilization of low-density materials such as aluminum and magnesium alloys in the manufacturing sector to enhance fuel efficiency and performance. Aluminum alloys are widely utilized in various sectors due to their combination of properties and ductility. Aluminum plays an important role in engineering due to its lightweight and strength. It has a different number of aluminum alloys used in making automotive parts and aircraft structural parts. Moreover, magnesium alloy also shows its potential in different engineering applications due to its lightweight strength and its high abundance [1]. Moreover, magnesium will also play a significant role in engineering due to its lightweight strength and high abundance. The AZ series of magnesium alloy stands out as the most commonly utilized alloy series. Magnesium alloy az31 is used to manufacture aerospace components, automotive parts, electronic devices, etc. [2, 3]

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When manufacturing aerospace structures, welding and joining various materials is crucial for ensuring high quality. Friction stir welding has been demonstrated to meet the necessary welding quality for various materials, particularly those with low-softening-temperature alloys such as aluminum and magnesium alloys. Joining these different materials has become popular in various industries to reap its advantages. Friction stir welding (FSW) is widely used these days due to its good mechanical properties. FSW is a solid-state welding technique that can join similar or dissimilar materials without using filler materials. FSW joints exhibit enhanced and reliable fatigue strengths when compared to traditional fusion welding. A rotating tool with a pin and shoulder is inserted into the joint line and moved along the joint line. During the process, heat is generated between the tool and the workpiece. The maximum heat generated during the process is lower than the material's melting point [4]

The two major duties of the tool are to ensure constrained heating and control material flow. The geometry of the tool plays a crucial role in controlling the above two factors, as well as the traverse rate. As a result, it gives proper joining and a good welded zone. Moreover, the various input parameters are tool rotational speed, tool tilt angle, and tool depth. At various tool rotational velocities, al5052 and mgaz31 are successfully fused together with the help of FSW (friction stir welding).

Kanna et al. [1] discussed the joining of the two dissimilar methods of AA6011 and AA 8011 using FSW. The authors analyzed the tool offset effect and the base material's positioning on the advancing side. Moreover, high tensile strength was observed when tool offset increased in both materials. Rani et al. [5] studied the tensile strength characteristics of AA 6061 and AA 8011 using single- and double-pass various tool profiles and observed that the latter exhibited higher tensile strength. Marathe et al. [6] investigated the FSW of AA6061 plates using three distinct tool profiles such as square, tapered, and cylindrical. Tapered pins were utilized to achieve the maximum ultimate tensile strength at a tool speed of 2750 rpm and a welding speed of 10 mm/min. Devaiah et al. [7] found the highest Vickers microhardness value reached was 94.8 VHN by FSW joints of dissimilar alloys (AA5083 and AA6061) at specific tool speeds, feed rates and tool tilt angles. Panda et al. [6] studied AA6061 plates with a threaded cylindrical profile tool at 900 rpm and 60 mm/min, resulting in a joint with an increased tensile strength of 160.7 MPa. Elnabi et al. [2] Conducted an experiment on the friction stir welding (FSW) of AA5454 and AA7075 alloys, while manipulating the tool rotation and traverse speed. The researchers noted that a greater ultimate tensile strength (UTS) can be achieved by increasing the tool rotation speed to 1225 rpm, using a tapered pin profile, a traverse speed of 21mm/min, and a tilt angle of 2°.

Predicting the mechanical properties and microstructure features of the FSWed is a very important factor in designing and obtaining high-quality FSWed at the lowest possible cost. However, this procedure is complicated due to the nonlinear correlation between the properties of FSWed and the process factors. Most of the research has centred on the application of response surface methodology (RSM) to model this process. Nevertheless, RSM has significant drawbacks as it employs a second-order polynomial model to fit experimental data, regardless of the level of nonlinearity present in the data. The metaheuristic optimizers have been widely discussed in the literature as effective prediction machining parameters in various nonlinear engineering processes.

It is evident from the literature that multi-optimization using metaheuristic optimizers implementation in FSW is still in its under progress. Here in this study is mainly focused on welding the two dissimilar materials (Al5052 & AZ31) to get a high-quality welded zone and to identify the mechanical properties (Hardness, Tensile, and Bending). Identifying the optimum condition for welding using the metaheuristic optimizers technique like Multi-

Objective Dragonfly Algorithm (MODA) inspired by the swarming behaviors of dragonflies in nature. To obtain the microstructure of the welded zone using SEM analysis.

2 Experimental Procedures

The trials are conducted using the FSW15 300NC machine with the Z-axis position fixed. Figure 1 displays the arrangement, whereas Figure 2 illustrates a schematic diagram of the arrangement. The maximum capacity of the machine is 5 kN for axial force. The TRS has a rotational speed range of 1800 revolutions per minute. Following the conclusion of the welding procedure, the specimens were prepared according to ASTM E8 standards for the purpose of conducting a tensile test and a welding hardness test. For the welding hardness test, a weight of 0.2 kg was applied to the welding zone for a duration of 10 seconds. The machine parameters are displayed in Table 1 below. The workpiece is made of AA 6061 aluminium alloy material and has dimensions of 1000×600×3 mm.

2.1 Material selection

AA5052 and AZ31 alloys have been used for this study due to its most desirable properties. Due to its high VH and wear resistance, AISI H13 steel is used in this welding process.

Table 1: Machine parameters

Code	Control factor	Unit	Level I	Level II	Level III
A	Tool types (TP)	-	1^a	2^b	
B	Tool traverse speed (TTS)	(mm/min)	12	18	22
C	Tool tilt angle (TTA)	(°)	0	1	2
D	Tool rotation Speed (TRS)	(rpm)	400	500	600

3 Methodology

Determining the optimal solution for welded materials is a highly difficult process because of the large number of input parameters involved. The data book has a significant impact on determining the most effective solutions for industrial applications. On the other hand, hand book does not provide optimal solutions and has a negative impact on production costs. Analysis of Variance (ANOVA) is a statistical tool that can be used to analyse comparisons of means among many groups. It is employed to assess whether the means of distinct groups are equivalent or not. ANOVA is a useful tool for comparing group means and evaluating if the differences between them are significant. ANOVA has important uses in manufacturing industries, particularly in quality control. It is used to compare the means of production processes or products. ANOVA is also used in market research to compare the means of different consumer items. Moreover, Multi-Objective Dragonfly Algorithm (MODA) is a method that has been introduced as one of the optimisation strategies.

3.1 Multi-Objective Dragonfly Algorithm

MODA is a swarm intelligence-based optimization technique that was developed by Mirjalili [10]. The design draws inspiration from the dragonfly, a small insect renowned for its distinctive swarming habits during both hunting and migration. The program begins by creating a random population of dragonflies throughout the search space and evaluating their fitness using the objective function. The motions of dragonflies are controlled by both static and dynamic swarm behaviors, which involve the formation of sub-groups and the adjustment of static swarm steps to move within a specific area. Dynamic swarms exhibit the behavior of congregating into sizable collectives and traversing extensive distances. The dragonfly algorithm is derived from five distinct swarm behaviors shown by dragonflies: separation, alignment, cohesion, attraction, and distraction. The dragonflies' movements are influenced by these behaviors in intriguing ways, including maintaining distance, synchronizing their velocity with their neighbors, moving towards the center of mass of surrounding dragonflies, and flying towards food while evading predators.

4 Results and discussion

The machining responses have been selected as UTS and HV. The experimental result has been shown in Table 2. This study UTS and HV have been selected as “Higher-the better” criteria to calculate the single-to-noise (S/N) ratio. These S/N ratios are calculated using the MINITAB® and tabulated in Table 3.

4.1 ANOVA analysis

The coefficient of determination (R^2) indicates how closely the data matches the fitted mathematical model. The R^2 value illustrates the proportion of variance in the dependent variable that is explained by the mathematical model [11, 12]. A higher R2 value suggests that the data is more closely related to the fitted regression line. Here, the insight of the ANOVA test of UTS and HV is in Table 3.

Table 2. Experimental responses

Sl no.	A	B	C	D	UTS (MPa)	HV
1	1	1	1	1	95.6	90.45
2	1	1	2	2	80.7	99.9
3	1	1	3	3	111.4	111.45
4	1	2	1	1	65.2	102.15
5	1	2	2	2	63.8	110.25
6	1	2	3	3	84.7	117.45
7	1	3	1	2	101.9	105.75
8	1	3	2	3	98.4	116.1
9	1	3	3	1	109.9	111.15
10	2	1	1	3	118.5	98.1
11	2	1	2	1	105.7	94.05
12	2	1	3	2	132.4	103.05
13	2	2	1	2	86.7	105.3
14	2	2	2	3	86.6	113.85
15	2	2	3	1	101.1	107.55
16	2	3	1	3	132.8	109.35
17	2	3	2	1	108.3	105.75
18	2	3	3	2	129.7	114.75

Table 3: ANOVA of UTS and HV

Source	UTS	HV	UTS	HV	UTS	HV	UTS	HV	UTS	HV
	Degree of freedom (DF)		Sum of square (SS)		Mean Square (MS)		F- Ratio		PCR	
A	1	1	15.94	0.05	15.94	0.05	121.98	4.16	26.9	0.8
B	2	2	29.71	3.11	14.86	1.56	113.70	125.26	50.2	46.5
C	2	2	10.31	1.68	5.15	0.84	39.44	67.59	17.4	25.1
D	2	2	1.90	1.73	0.95	0.87	7.26	69.65	3.2	25.8
Residual Error	10	10	1.31	0.12	0.13	0.01				
Total	17	17	59.16	6.70						

4.2 multi-optimization technique

The experimental data cannot be used directly to obtain Pareto optimal solutions. Therefore, non-linear regression models are used to approximate the data, which serve as objective functions for the optimization of the FSW process. These models are optimized using MODA nature-inspired metaheuristic algorithms. The developed mathematical model for UTS and HV are provided as below:

$$UTS = 81.6067 \times A^{0.307148} \times B^{0.00759718} \times C^{0.0830884} \times D^{0.072475}$$

$$HV = 91.828 \times A^{-0.0174722} \times B^{0.0982829} \times C^{0.0776069} \times D^{0.0781757}$$

4.3 Pareto optimization performance

To obtain the Pareto optimal solutions and evaluate the Pareto optimization performance of all the considered nature-inspired metaheuristic algorithms, considered 100 search agents and 500 iterations. MODA been executed obtained pareto optimization performance. The top 10 rank solution among the best Pareto front is illustrated in Table 3. The pareto optimization ranked has been performed from grey relation analysis (GRA) method. Convergence curve for MODA has been depicted in Fig. 1

Table 3. Optimal parametric combination

Sl. no	A	B	C	D	UTS	HV
1	1	3	3	3	130.4	201.6
2	1	3	3	3	134.0	201.3
3	2	3	3	3	150.2	199.9
4	1	3	3	3	133.5	201.3
5	2	3	3	3	149.6	200.0
6	2	3	3	3	148.8	200.1
7	2	3	3	3	148.8	200.1
8	2	3	3	3	148.8	200.1
9	2	3	3	3	148.8	200.1
10	2	3	3	3	148.8	200.1

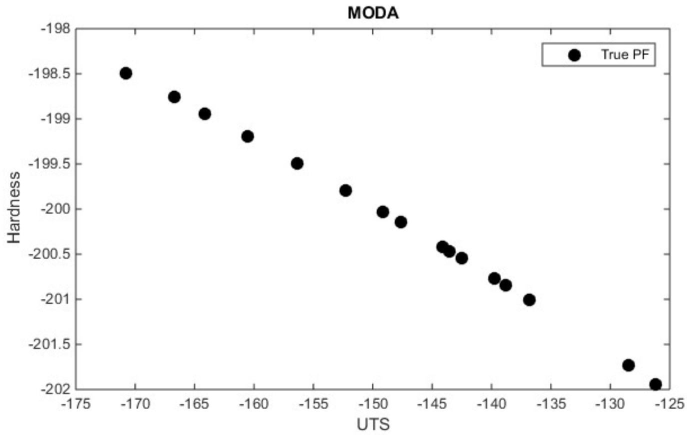

Fig. 1. Convergence curve for MODA

5 Conclusion

This research aimed to acquire experimental knowledge about the machining of welding of two dissimilar material and consider the most important process variables such as TP, TTS, TTA and TRS. UTS and HV have been utilized to examine the measurement machining characteristics.

- The experimental result shows that Al5052 and AZ31 has successfully welded with notably high UTS at TRS of 600 rpm. The high value of HV is 18 mm/min.
- The ANOVA results of UTS and HV indicate that the TTS (Contributing 50.20% and 46.5) has been found to be the most influential parameters among the remaining parameters.
- The mathematical model for predicting the accurate result of the said responses (UTS and HV) have been successfully formulated using non-linear regression model.
- The proposed optimization shows it significantly predicted FSW responses and minimizes computational effort.

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