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Effect of Process Parameters on Tensile Behaviour of FSW AA 6061-AA 7075 Reinforced with TiO_2 Particles using Statistical Approach

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Abstract

Joining of dissimilar materials especially aluminium alloys through friction stir welding approach has been effectively carried out in different experimentations resulting in enhanced mechanical properties and meeting various application sectors. Process parameter plays an exceptional influence on the joint properties and determines the mechanical characterization. Here the objective is to investigate the AA6061 and AA 7075 reinforced with titanium dioxide (TiO2) nanoparticles using Taguchi and ANOVA methods considering pin profile, welding speed, tool rotational speed, and tilt angle utilizing this process. TiO2 powder was added at the weld juncture. All the specimens were welded subjected to various levels of operating conditions of the process parameters and further processed for tensile evaluation. Result shows that the most significant parameters are the tilt angle and pin profile for ultimate tensile strength.

Keywords: *ANOVA, Friction stir welding, Larger is better, Orthogonal array, Taguchi technique.*

1.0 Introduction

Due to advantages like enhanced strength to weight ratio, design flexibility, along with low manufacturing costs, structured engineered materials are increasingly being used in the design sector. Structural uses of these materials are now part of the dissimilar material production unit of components including polymers and metals. When conventional welding isn't an option due to differences in the physical and chemical qualities of the pieces being joined [1-5], dissimilar joining can be a viable option. Examples of these industries include aerospace, missiles, and shipbuilding. It is possible to achieve improved characteristics and full application coverage by joining dissimilar materials using a practical technique [6-10]. Weight reduction in vehicles improves everything from fuel efficiency to handling dynamics to greenhouse gas emissions to the environment. Rising gasoline prices and stricter automotive rules encourage automakers to design engines with low fuel consumption and lightweight vehicles. Lighter metals and polymers, such as aluminium and magnesium, can be used in place of heavier steels to reduce vehicle weight. Lightness structure is an important design factor in the aircraft industry [11-12]. Thus, low density of aluminium alloys compared to steel, these materials can be used in the aerospace industry [13-15]. Marine frames, pipelines, storage tanks, and aircraft have all utilized AA6061. The 7XXX series of AA7075 T6 alloy has been considered in the aerospace sector because of its higher

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toughness and better resistance to corrosion [16]. These materials have a wide range of applications across several industries because of their technical advantages [4]. As it provides improved and desired qualities to fulfill current demand and application fields, joining dissimilar materials using an appropriate procedure will help facilitate new difficulties. Contrary to popular belief, the joining of different materials with the addition of filler material results in an enhanced metal's physio-chemical resistance and lightweight structure when combined. High strength-to-stiffness ratios are possible with metal structures, and reinforcing particles can produce unique features [17-20]. Different joint geometries and tool profiles, as well as workpiece materials, have been used since 1991 for friction stir welding (FSW). Understanding the flow is critical in determining the accuracy of accurate thermomechanical processing conditions. However, there is a need to perform critical experiments to elucidate specific issues such as the frictional contact conditions at the tool–workpiece interface. Ideally, it would be very useful to perform simulations to predict the effects of tool geometry and weld parameters on the material flow fields along with accuracy [24]. Recent research has shown that various bonding procedures can improve the quality of welded materials and alloys. Friction stir welding and processing (FSW/P) approach nowadays considered as well-known application for its capability to join and thermo-mechanical lightweight metallic materials. The major parameters that influence the FSW/P are (i) tool geometry, (ii) plunging depth, (iii) rotational and traverse speed and (iv) tool tilt angle [25].

Several other alloys are being combined by researchers and practitioners, such as aluminum–aluminum, aluminum–magnesium, and various alloys of brass and copper, mild steel, and titanium [1]. Guo et al., revealed that when the AA6061 alloy is positioned on the advancing side and several vortexes centers are generated vertically in the nugget, the material mixing is considerably more effective. All three levels of the nugget zone's nugget zone showed grain refinement, with smaller grains in AA7075. As heat input is reduced, tensile strength improves at the dissimilar joints. Alloys like AA6061 and AA7075 have undergone dynamic recrystallization and when welding speed increases, grain size falls dramatically. Compared to their respective base metals, the tested specimens showed a little decrease in microhardness at the weld. There is a higher minimum hardness profile for joints with the lowest heat input [2]. Bahrami et al., examined friction stir welds with Sic nanoparticle reinforcement to see how pin geometry affected their macrostructure, microstructure and mechanical characteristics. Except for the FSWed with the FFC pin tool. Material flow around the pin tool indicates stir zones free of defects. The high consistent particle distribution was attained by using a threaded tapered pin. A well grained microstructure was created within the stir zone by plastic deformation and frictional warming during the operation. The average microhardness of the four flutes cylindrical specimen was the highest [3]. Pasha et al., observed that tool speed, weld speed, weld tilt, and weld pin shape are the most important welding characteristics to take into account. Reinforcing material and percentage of reinforcing material showed significant impact on welding joint characteristics according to the findings. Friction in comparison with the parent metal, stir welded joints with and without reinforcing have worse mechanical properties [5]. Nikoo et al., showed that pinned Al_2O_3 particles may be responsible for the lack of difference in grain size among PWHTed and AW specimens, because of pinning action during solution treatment. In microstructure research, it was discovered that dynamic recrystallization creates tiny, equiaxed grains (DRX). Particles of Al_2O_3 prevent grain growth by obstructing grain borders and so restricting their motion. Abrasive and adhesive wear were the mechanisms of wear in the FSWed and PWHTed specimens. An optimum value of travelling speed proved to be the homogeneous dispersion of Al_2O_3 particles [7]. Jafari et al., investigated the residual stress distribution of dissimilar Al-7075-T6 and Al6061-T6 with the addition of SiO_2 nanoparticles. Rotational speed and welding speed were considered as process parameters. H13 hot work steel was used as the material for the designed tool. Heat induced tension in a welding bond may be seen to be reduced. As a result, it can be stated that the use of SiO2 reinforcement can reduce residual stresses. Increasing rotating and welding rates increases heat output, which reduces the residual stress-reducing impact of SiO_2 nanoparticles [21].

Hence the current research focused on integrating friction stir welded characterization of AA6061 - AA7075 with titanium dioxide (TiO_2) nanoparticle as a strengthening factor along with several tool pin profiles to evaluate process variables considering statistical procedure and evaluating the behaviour of process parameters on the mechanical characterizations. An experiential evaluation was conducted using specifications considering rotational speed, welding speed, and tilt angle. Design of experiments were employed to accurately measure the factors influencing process parameters.

2.0 Methods and materials

2.1 Work material details

The materials used for specimen preparation in the present study involve aluminium alloys specifically AA 6061 T6 and AA7075 T6. AA 6061 T6 contains elements of magnesium AA7075 T6 contains zinc as the primary alloying component. These materials are cut by using a CNC machine of dimension 140x70x6mm. After the cutting process, work pieces are cleaned with acetone solution to eliminate the dust and dirt. Chemical and mechanical properties were stated in the following Tables 1 and 2 respectively.

To facilitate the insertion of nanoparticles in the workpiece abutting edges, separate geometries at weld interface of depth 4mm and 10 mm apart from subsequent holes were drilled at the peripheral state of both the alloys and along the joining direction as shown in Fig.1.

2.2 Tool material

Joints of aluminium alloys are assembled by five different tool profiles: Threaded Cylindrical (Th C), Taper Cylindrical (TC), Simple Cylindrical (SC), Taper Square (TS), Taper Hexagon (TH), High Speed Steels of D2 is used as a tool material with shoulder diameter of

Table 1: Chemical composition of AA7075 T6 and AA6061 T6 [16]

Constituents	AA6061 T6	AA7075 T6
Aluminium	90.31	97.76
Chromium	0.2	0.06
Copper	1.31	0.19
Iron	0.17	0.25
Magnesium	2.28	0.8
Manganese	0.01	0.12
Zinc	5.61	0.11
Silicon	0.1	0.7

Table 2: Mechanical properties aa7075 t6 and aa6061 [9]

Material	AA 6061 T6	AA 7075 T6
Ultimate tensile strength (MPa)	300	583.34
Yield strength (MPa)	260	536.24
Tensile elongation, (%)	19	11.26
Hardness (VHN)	110	183.9

Figure 1: Representation of Al 6061 - Al 7075 plates along with holes for TiO_2 nanoparticle insertion

Figure 2: Friction stir welding tools of various pin profiles

24 mm, shoulder length of 20mm. Tool material is an air hardened which has high wear and abrasion resistant properties. It is heat treatable and will offer hardness in the range 55-62 HRC, and is machinable in the annealed condition. Due to high chromium content it possesses moderate corrosion resistance properties in the hardened condition. Tools with various pin profile is shown in the Fig.2. The several pin profiles used in the present investigation contributes for effective process operation under different tool rotations, welding speeds and tilt angle. Dimensions of the various pin profiles has been shown below:

1. Threaded Cylindrical: Pin diameter and pin length of 6 mm.
2. Taper Cylindrical: Pin length of 6 mm, top dia 4mm, bottom dia of 6mm.
3. Simple Cylindrical: Pin diameter and pin length of 6 mm.
4. Taper Square: Pin length of 6 mm, top dia 4mm, bottom dia of 6mm.

5. Taper Hexagon: Pin length of 6 mm, top dia 4mm, bottom dia of 6mm.

2.3 Titanium dioxide (TiO_2)

The addition of nanoparticle enhances joint strength as well as better mechanical properties. Present study employed the usage of TiO_2 as reinforcement nanoparticle of average fragment size 10-20 nm. TiO_2 is a native-born oxide originated from ilmenite and rutile present in the mineral barite. Titanium oxide is a divalent, alkaline metal. Nanoparticles are added in the peripheral section of the workpiece. Properties of Titanium dioxide are shown in Table 3.

2.4 Experimental set up

A major part of friction stir welding is the effective utilization, handling and setting it up of equipment which is very much important for operating processes for the duration. In this study, a vertical milling machine consisting friction stir welding fixture set up has been done to execute the experimental works along with a welding tool for making joints that are attached to a vertical head accommodating high spindle speeds. Fixtures were used as clamping to prevent longitudinal motions of work plates. Fig. 3 shows an arrangement made for experimental conduction using friction stir welding.

Table 3: Properties of titanium dioxide

Properties	Value	Unit
Density	4.23	GM/CC
Tensile strength	367.5	MPA
Compressive strength	3675	MPA
Flexural strength	379	MPA
Young's Modulus	288	GPA
Elastic Modulus	367.5	GPA
Shear Modulus	112.5	GPA
Bulk Modulus	218.5	GPA

Figure 3: Friction stir welding process setup with tool holding fixture

This process creates significant forces that head on the base plate, causing the plates to flow apart. In turn, the tool plunges into the workpieces to be welded. An inflexible clamping fixture is needed to hold the joint together, otherwise plasticized material will be forced down through the joint and cause damage. During friction stir welding, the plates undergo thermal expansion and buckling behaviour throughout welding conditions. This can be limited by suitable clamping. For the current project, mild steel plates are used to build the fixture components. HC-HCr steel is commonly used to make friction stir welding equipment and backing plates for welding aluminium alloys. For this welding procedure, the tool was positioned in a manner that the tool pin's upper surface only touches both abutting work parts. Weldments were obtained by securing two pieces of (140 x 70 x 6) mm plates. TiO_2 reinforcement particles are added proportionally for each set of conduction and subsequently for all the combinations. Parameters employed in investigation are listed in Table 5. Friction stir welding was accomplished by positioning high strength aluminium alloy AA7075-T6 at the retreating side (RS), and aluminium alloy AA6061-T6 at the advancing side (AS) as shown in Fig 3.

Process carried out with respect to experimental set up with the help of HMT FN2EV Vertical milling machine with hydraulic power pack motor 5.5/1500 kW/rpm with 1800RPM maximum rotational speed; 800mm/min as X axis rapid traverse speed and maximum axial thrust as 5kN. Dimensional parameters with thicknesses of both the plates were of 6 mm. The plates were developed for butt joint configuration and welded in a single pass, perpendicular to the rolling direction of the plates. Proportions of the alloying plates are of 140 mm in length and 70 mm width.

2.5. Taguchi method

Taguchi method is a controlled statistical tool for creating a process based on the Orthogonal Array (OA). ANOVA is a statistical method for reducing the number of experiments while also improving the efficiency of operations [21]. The response value of wear rate is considered in this study, and the factors include Tool Pin Profile, Tool Rotational Speed, Welding Speed and Tool Tilt Angle, as indicated in Table 4. The design of L25 orthogonal array experiments is the

Table 4: Process parameters

	Operating Parameters			Levels				
	Factors	Codes	Unit	1	2	3	4	5
1	Tool Pin Profile	A	—	SC	TC	Th.C	TS	TH
2	Tool Rotational Speed	B	RPM	600	800	1000	1200	1400
3	Welding Speed	C	mm/min	30	50	70	90	110
4	Tool Tilt Angle	D	Deg	0	1	2	3	4

subject of this research. This process involves selection of parameter along with identification of process controlling factors for determining the level of individual element. Running the matrix experiment to the orthogonal Array columns, performing the data examination to estimate the best value and assess behavioral performance. Finally, verification and validation of the facts that has to be analyzed.

In the Taguchi technique, the loss function is utilized to estimate the variance between the experimental and predicted values. S/N ratio is calculated using this loss function. There are three sorts of S/N ratios used to gauge quality: smaller is better, greater is better, and nominally better. Here the study involving, the ultimate tensile strength and total elongation are estimated using the S/N ratio characteristic "Larger is better," which may be derived using the equation: [22-23].

$$S/N = -10 \log 1/n \frac{(\Sigma 1/y^2)}{n} \qquad \text{... (1)}$$

where,

S/N = Signal to Noise ratio.

n = Measure response in the factors used.

y = Reaction for the given factor level combination.

3.0 Results and discussion

Experimental tensile strength and total elongation outcomes, along with their transformations into S/N ratio, are tabulated in Table 5. Analysis based on Taguchi method was performed in the program using MINITAB 18. To determine the critical factor affecting the ultimate tensile strength (UTS) and Tensile elongation (TE), it's necessary to perform an analysis of the variables (ANOVA) and evaluating the optimal conditions. Based on the S/N ratio results, it can be evaluated to determine the controlling factor having notable effect on the tensile strength (Table 6) and total elongation (Table 7). It provides information that which parameter has the highest delta value is measured as a greater weightage on the reactions of tensile strength and total elongation.

Optimal strength and elongation specifications of these controlled elements could be governed by S/N ratios shown in Table 8&9 and Fig.4 and Fig.5. It illustrates the relationship between main effect plot for ultimate tensile strength and total elongation of AA 6061- AA 7075 reinforced with TiO_2 respectively. Figs.4 and 5 indicate while increase in the welding speed, the value of ultimate strength is drastically varied. It can be noticed that welding speed was a major influence factor to others. Optimum ultimate tensile results in the combination of control factors: A5, B5, C4, D3 and for total elongation is A2, B1, C2, D5

Figs.6 and 7 illustrate the contour maps belonging to the ultimate tensile strength based on total rotation speed, welding speed and tilt angle of the tool. Graphs were analyzed to understand the impact of rotation speed, welding speed and tool tile angle on ultimate tensile strength. From Fig.6 it was observed that, higher value of tensile strength at rotational speed of 1400 rpm and welding speed of 90 mm/min. From Fig.7, it was observed that higher value of ultimate tensile strength that for rotational speed of 1400 RPM and tilt angle of 2 degree. Though, the least value of ultimate tensile strength was observed at lower tilt angle.

Figs.8 and 9 illustrate the contour maps of total elongation based on total rotation speed, welding speed and tool tilt angle. Graphs were visualized to study the impacts of total rotation speed, welding speed and tool tile angle on total elongation. Fig 8 exhibits higher value of total elongation at minimum rotational speed of 600RPM and tilt angle 2 degree. From Fig.9, it was observed that higher value of total elongation at minimum rotational speed of 6008000 RPM and tilt angle 2 degree. Though, the least value of ultimate tensile strength was observed at welding speed 30-50 mm/min.

Table 5: Experimental results of UTS and Elongation (TE) with s/n ratio

Exp. Run	Tool pin profile	Tool rotational speed	Welding speed	Tool tilt angle	UTS	S/N ratio (dB)	TE	S/N ratio (dB)
1	SC	600	30	0	224	47.00	12.1	21.65
2	SC	800	50	1	205	46.23	11	20.82
3	SC	1000	70	2	212	46.52	9	19.08
4	SC	1200	90	3	217	46.72	7	16.90
5	SC	1400	110	4	227	47.12	14.2	23.04
6	TC	600	50	2	209	46.40	13.7	22.73
7	TC	800	70	3	211	46.48	12	21.58
8	TC	1000	90	4	223	46.96	12.2	21.72
9	TC	1200	110	0	210	46.44	11.3	21.06
10	TC	1400	30	1	197	45.88	9.6	19.64
11	Th.C	600	70	4	204	46.19	9.4	19.46
12	Th.C	800	90	0	215	46.64	8.3	18.38
13	Th.C	1000	110	1	218	46.76	11.4	21.13
14	Th.C	1200	30	2	206	46.27	11.1	20.90
15	Th.C	1400	50	3	210	46.44	10.2	20.17
16	TS	600	90	1	216	46.68	10.2	20.17
17	TS	800	110	2	214	46.60	10.5	20.42
18	TS	1000	30	3	198	45.93	9.5	19.55
19	TS	1200	50	4	204	46.19	12	21.58
20	TS	1400	70	0	202	46.10	9.4	19.46
21	TH	600	110	3	208	46.36	9.6	19.64
22	TH	800	30	4	216	46.68	13.2	22.41
23	TH	1000	50	0	218	46.76	12.1	21.65
24	TH	1200	70	1	206	46.27	9.4	19.46
25	TH	1400	90	2	250	47.95	11.2	20.98

Table 6: Response for signal to noise ratios for larger is better for Tensile strength

Level	Tool pin profile	Tool rotational speed	Welding speed	Tool tilt angle
1	46.72	46.53	46.36	46.59
2	46.44	46.53	46.41	46.37
3	46.47	46.59	46.32	46.75
4	46.31	46.38	47.00	46.39
5	46.81	46.70	46.66	46.63
Delta	0.51	0.32	0.68	0.38
Rank	2	4	1	3

Table 7: Response for signal to noise ratios for larger is better for Elongation				
Level	Tool pin profile	Tool rotational speed	Welding speed	Tool tilt angle
1	20.30	20.73	20.83	20.44
2	21.35	20.73	21.39	20.25
3	20.01	20.63	19.81	20.83
4	20.24	19.98	19.63	19.57
5	20.83	20.66	21.06	21.65
Delta	1.34	0.75	1.76	2.07
Rank	3	4	2	1

3.1 Anova

The impact of process parameters involving tool pin profile, tool rotational speed, welding speed, tilt angle (input) on friction stir welding of AA 6061-AA 7075 Reinforced with TiO_2 (output) were investigated using analysis of variance (ANOVA). Obtained R2 value is 97.77% and 89.3% of R2 (predicted) for ultimate tensile strength and for total elongation R2 value is 98.85% and 95.15% of R2 (predicted). The percentage contributions of input features like tool tilt angle, tool pin profile, welding speed and tool rotational speed are 56.76 per cent, 23.57 per cent, 17.52 per cent and 0.70 per cent respectively for ultimate tensile strength. Percentage contributions of input features like,

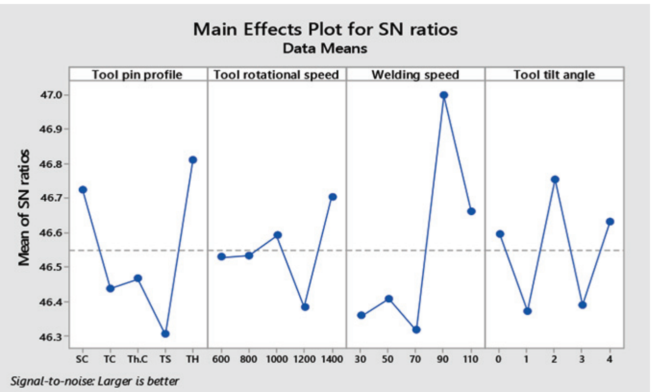

Figure 4: Effect plot for tensile strength

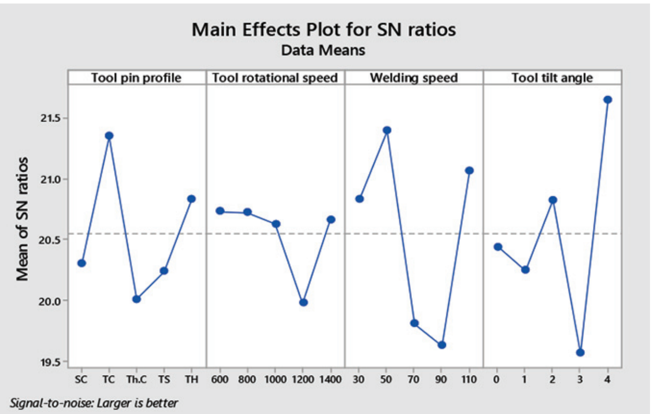

Figure 5: Effect plot for total elongation

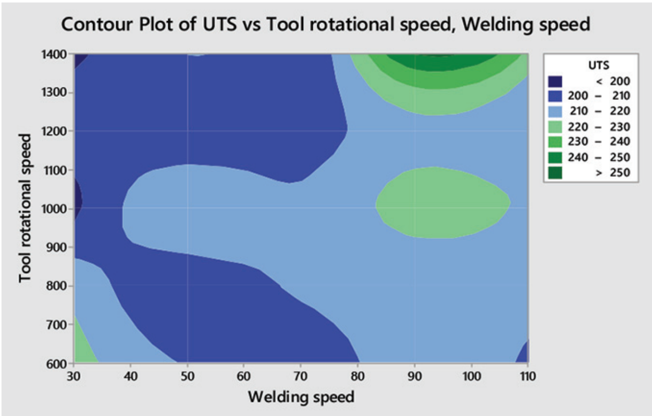

Figure 6: Contour maps of ultimate tensile strength vs. total rotation speed and welding speed

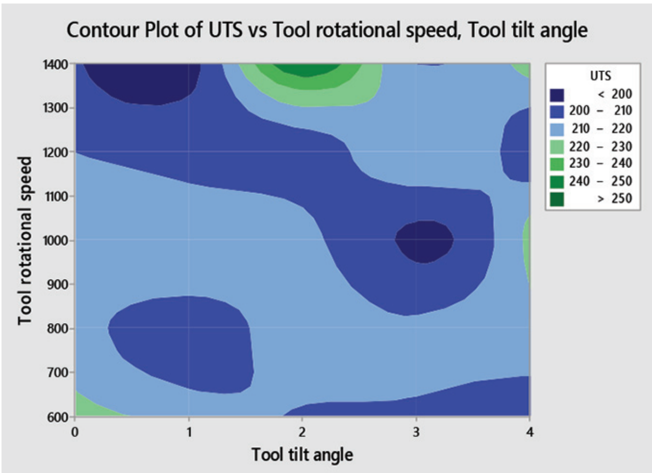

Figure 7: Contour maps of ultimate tensile strength vs. total rotation speed and tool tilt angle.

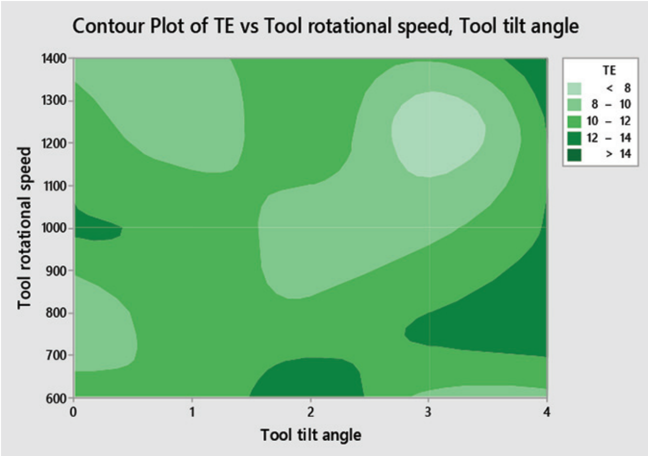

Figure 8: Contour maps of total elongation vs. total rotation speed and tool tilt angle.

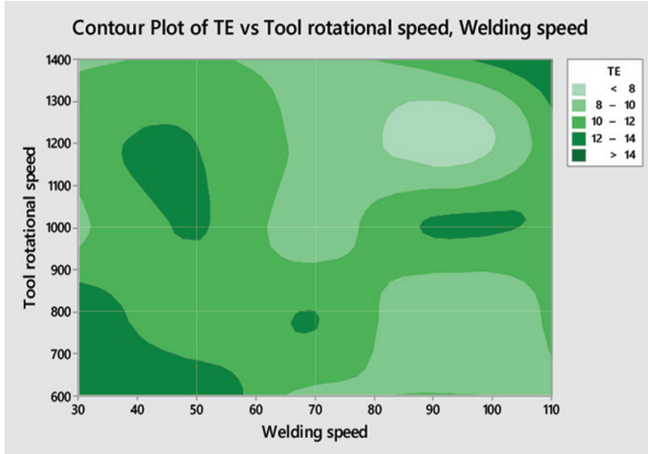

Figure 9: Contour maps of total elongation vs. total rotation speed and welding speed

Table 8: Anova results (ultimate tensile strength)

Source	DF	Adj SS	Adj MS	F-Value	P-Value	Contribution (%)
Tool pin profile	4	140.17	140.17	9.79	0.0065	23.57%
Tool rotational speed	4	4.17	4.17	0.29	0.59	0.70%
Welding speed	4	104.17	104.17	7.28	0.0159	17.52%
Tool tilt angle	4	337.50	337.50	23.58	0.0002	56.76%
Error	2	8.62	8.62			1.45%
Total	14	594.63				100%
	R2 = 97.77%		R2 (adj) = 95.81%		R2 (Pred) = 89.3%	

Table 9: Anova results (Elongation)

Source	DF	Adj SS	Adj MS	F-Value	P-Value	Contribution (%)
Tool pin profile	4	2.34	2.34	47.12	0.0001	4.01%
Tool rotational speed	4	20.72	20.72	416.58	0.0001	35.60%
Welding speed	4	23.80	23.80	478.50	0.0001	40.89%
Tool tilt angle	4	11.07	11.07	222.57	0.0001	19.01%
Error	2	0.28	0.28			0.01%
Total	14	594.63				100%
	R2= 98.85%		R2 (adj) = 97.84%		R2 (Pred) = 95.15%	

welding speed, tool rotational speed, tool tilt angle and tool pin profile are 40.89 per cent, 35.60 per cent, 19.01 per cent and 4.01 per cent respectively for total elongation. In comparison with input features, the most significant variable is tool tilt angle and tool pin profile (Tables 8 & 9).

4. Conclusions

The experimental investigations to find out the tensile behaviour on differing friction stir welded alloys of aluminium AA 7075 T651 and AA 6061 T6 (butt welded) strengthen with TiO_2 nano-particles which are used extensively in the aeronautical applications is successfully conducted using various parameters like pin profile of the tool, rotational speed, welding speed and tilt angle. Influence of process parameters and the output values of predicted outcomes (Ultimate tensile strength and elongation) were analyzed with experimental results. Taguchi method was applied to influence the preferable results as well as controlling factors.

The following conclusions are made from the experimentation:

- Tensile strength properties at the stir zone of the welded joint strength increases with increase in the rotational speed.
- Optimum ultimate tensile results in the combination of control factors: A5, B5, C4, D3 and for total elongation is A2, B1, C2, D5.
- The percentage contributions of input features like tool tilt angle, tool pin profile, welding speed and tool rotational speed are 56.76 per cent, 23.57 per cent, 17.52 per cent and 0.70 per cent respectively for ultimate tensile strength.
- The percentage contributions of input features like, welding speed, tool rotational speed, tool tilt angle and tool pin profile are 40.89 per cent, 35.60 per cent, 19.01 per cent and 4.01 per cent respectively for total elongation.
- Tool tilt angle and pin profile were observed as the most significant parameters influencing the ultimate tensile strength.

5. References

[1] Cole, Fehrenbache ,Duffie , Zinn , Pfefferkorn , Ferrier 2013 *Int J Adv Manuf Techno* Dec 2013 “Weld temperature effects during friction stir welding of dissimilar aluminium alloys 6061-T6 and 7075-T6” DOI 10.1007/s00170-013-5485-9:

[2] Guo, Chen, Sun, G. Bi, Z. Sun, J. Wei 2013 Materials and Design 56 2013 Elsevier Publications “Friction stir welding of dissimilar materials between AA6061 and AA7075 Al alloys effects of process parameters” doi.org/10.1016/j.matdes.2013.10.082

[3] Bahrami, BesharatiGivi, Dhegihan, Nader 2014 “The role of pin geometry in microstructure and mechanical properties of AA7075/SiC nano-composite fabricated by friction stir welding technique” http://dx.doi.org/10.1016/j.matdes.2013.07.049 Elsevier Publications pp 519-527.

[4] Singh, Khan, Siddiquee 2015 “Study on the effect of FSW process parameters on Joint quality of dissimilar materials” *International Journal of Research in Engineering & Advanced Technology* (May 2015) ISSN: 2320 – 8791 volume 3, Issue 2.

[5] Pasha, Reddy, Laxminarayana, Khan 2016 “Aluminium oxide particulate reinforced friction stir welded joint of Aluminium Alloy 6061” *International journal of engineering science and computing* (May 2016) ISSN 2321 3361.DOI: 10.4010/2016.1417 .

[6] Patel, Patel, Vadher 2016 “effect of process parameters on AL6061 t 6 using friction stir welding by RSM method” *International Journal of Mechanical and Production Engineering* (July 2016) ijmpe-iraj-doionline-504 ,ISSN: 2320-2092 Volume- 4, Issue-7.

[7] Farahm, Nikoo, Azizi, Parvin, Naghibi 2016 “ The influence of heat treatment on microstructure and wear properties of friction stir welded aa6061-t6/Al_2O_3 nano composite joint at four different traveling speed” *Journal of Manufacturing Processes* (March 2016) http://dx.doi.org/10.1016/j.jmapro.2016.01.003.

[8] Shanavas and Raja dhas 2016 “Parametric optimization of friction stir welding parameters of marine grade aluminium alloy using response surface methodology”, *Transactions. Nonferrous Metals Society* (Dec 2016) DOI: 10.1016/S1003-6326(17)60259-0.

[9] Kumar and Ramana 2017 “Effect of Tool Pin Profile on dissimilar friction stir welding of Aluminium Alloy Aa 7075 T6 51 And Aa 6061 T6" *International Journal of Latest Trends in Engineering and Technology* (Dec 2017)vol. (8) DOI: http://dx.doi.org/10.21172/1.83.015 ISSN:2278-621X.

[10] Melwin, Sridhar, Adhichelvan 2017 “Influence of friction stir welding parameters on microstructural and mechanical properties of dissimilar AA6061 and AA7075 Alloy Joints “*International Journal of Science Technology & Engineering* (Nov 2017) Volume 4 Issue 5.

[11] Rao and Rao 2017 “Impact of mechanical properties & microstructures on aluminium alloys (AA6061-AA7075) by using friction stir welding process” (March 2017) volume 5 issue 3, pp 362-365.

[12] Ugrasen,Kumar, Sagar, Shivu, Keshavamurthy 2018 “optimization of process parameters for Al6061-Al7075 alloys in friction stir welding using Taguchi’s technique” materials today: proceedings 5 Elsevier Publications ,pp 3027-3035.

[13] Reddy, Sandeep, Kishore 2019 “experimental

studies of friction stir welding on dissimilar aluminium alloys" *International journal of research* (June 2019) ISSN NO: 2236-6124volume 8, issue 6, pp 55-65.

[14] Singh, Tiwari, Shukla 2019 "Friction-stir welding of AA6061-T6: the effects of Al2O3 nano-particles addition" Elsevier Publications, Results in Materials https://doi.org/10.1016/j.rinma. 2019.100005.

[15] Senthil, Dinesh, Gokul, Diwakar Raju, Rakesh 2019 "Friction stir welding of dissimilar aluminium alloys 7075 and 6061" *Journal of applied science and computations* (May 2019) ISSN NO: 1076-5131 volume 6, issue 5.

[16] Babu and Anbumalar 2019 "An experimental analysis and process parameter optimization on AA7075 T6-AA6061 T6 alloy using friction stir welding" *Journal of advanced mechanical design, systems, and manufacturing* (April 2019) DOI: 10.1299/jamdsm.2019 jamdsm. 0027 vol.13, no.2.

[17] Veerabhadrappa Algur, V R Kabadi, Ganechari S M, Vithal Rao Chavan 2017. Effect of Mn content on tribological wear behaviour of ZA-27 alloy, Materials today: Proceedings 4, (2017).: 10927-10934.

[18] Patel, Krishna 2016 "Experimental Investigation of Friction Stir Welding of Aluminium Alloys Using Response Surface Methodology" Scholars *Journal of Engineering and Technology* (SJET) (Jul 2016) ISSN: 2320-2092,vol.4 Issue-7.

[19] Veerabhadrappa Algur, Poornima Hulipalled, V Lokesha, Madeva Nagaral, V Auradi 2022 Machine Learning Algorithms to Predict Wear Behaviour of Modified ZA-27 Alloy Under Varying Operating Parameters, *Journal of Bio-and Tribo-Corrosion*, (2022). Vol. 8(1): 1-10

[20] Vithal rao chavan, K.R. Dinesh, K.Veeresh, Veerabhadrappa Algur 2017, Manjunath Shettar, Taguchi's orthogonal array approach to evaluate drilling of GFRP particulate composites, Materials today: Proceedings, 4: 10927- 10934, (2017).

[21] Jafari, Mansouri, Honarpisheh 2019 "Investigation of residual stress distribution of dissimilar Al-7075-T6 and Al- 6061-T6 in the friction stir welding process strengthened with SiO_2 nanoparticles" *Journal of Manufacturing Processes* (May 2019)

[22] Vithal Rao Chauhan, Dr. K R Dinesh, Pavan Hiremath, Manjunath Shettar, Dr. K Veeresh, Veerabhadrappa Algur, (2015), " Fabrication and Experimental Study on Optimization of Process Parameters for Drilling of GFRP with Iron Ore as Filler Material using Taguchi And ANOVA", *International Journal of Applied Engineering Research*, 10(22)

[23] Poornima Hulipalled, Veerabhadrappa Algur, V. Lokesha, (2022), "An Approach of Data Science for the Prediction of Wear Behaviour of Hypereutectoid Steel ", *Journal of Bio- and Tribo-Corrosion*, 8(69)

[24] Reynolds 2008 "Flow visualization and simulation in FSW" *Scripta Materialia* 58 doi:10.1016/j.scriptamat.2007.10.048.

[25] Malik, Kailas 2020 "Understanding the effect of tool geometrical aspects on intensity of mixing and void formation in friction stir process" *Journal of Mechanical Engineering Science, sage publications*, (June 2020) DOI: 10.1177/0954406220938410