International Journal of Innovative Technology and Exploring Engineering (IJITEE)
ISSN: 2278-3075 (Online), Volume-9 Issue-5, March 2020

Multi-Response Optimization of Parameters in FSW for Tailor Welded Blanks AA5052-H32 and AA5083-O using Response Surface Methodology

Praveen Kumar, Satpal Sharma

Abstract: Tensile properties, microhardness, and formability of the tailor welded blank of AA5052-H32 and AA5083-O were investigated. To detect the influence of FSW parameters such as shoulder diameter (SD), rotational speed (RS), and travel speed (TS), a central composite design (CCD) was derived. The response surface methodology (RSM) technique is used to develop the mathematical model and optimization of multiple responses, i.e., ultimate tensile strength (UTS), Yield strength (YS), percentage elongation (TE), dome height (DH), and microhardness (μH). Analysis of variance (ANOVA) technique is used to validate the competency of the established model, and the regression equation is derived to predict the value of output responses. It is found that the welding parameter of FSW plays a significant role in fabricating the joint. It is observed that for the welded combination of AA5052-H32 and AA5083-O, the metallurgically defect-free and sound weld produced. The results are very much significant to a better understanding of the effect of the combination of SD, TS, RS to fabricate the FSW joint. The experimental and predicted result shows a good relationship with each other.

Keywords: AA 5052-H32, AA 5083-O, FSW, Tailor welded blank, Microhardness, Microstructure, Tensile test, Limiting dome height test.

I. INTRODUCTION

Aluminium alloy of AA 5xxx series widely used for the automobile, marine, aerospace applications because of good formability, weldability, strength after weld, good corrosion resistance, and lightweight. It is found that the combination with this aluminium alloy limited work on FSW is carried out [1, 2]. FSW was created by the welding institute year 1991. Especially, the FSW technique designed for welding or joining of the dissimilar aluminium alloy with the same and different thicknesses. The joining or welding of dissimilar aluminium alloy is more complicated by laser welding because of the metallurgical and mechanical properties of aluminium alloy [3-5]. Some investigation on the influence of pin profile on the tensile properties, microstructure, microhardness study of using dissimilar aluminium alloy. Different pin profiles such as threaded and tapered with triangle, tapered with spiral flute, square, straight octagon, taper cylinder, threaded cylinder, square, triangle, the hexagon was used. It is observed that the tapered pin, threaded pin, and square pin profile produced the defect-free FSW weld and a major influence on the formation of a mixed flow region [6-8]. The central composite design of the RSM technique is very much useful in developing the empirical relationship to the multiple responses. The mathematical model is developed to understand the interaction effect of the FSW parameter on the responses. RSM technique is used to optimized the welding parameter and to achieve maximum output such as UTS, YS, hardness, etc. [9-11]. In the limiting dome height test, the hemispherical punch of size Ø101.6 with die and blank holder with the locking bead is used. Different welding parameter is used to fabricate the FSW blank and find out the limiting draw ratio of the blank using the LDH test. Some researchers have been performed LDH test on friction stir tailor welded blank of dissimilar aluminum alloys. They found that the elastic limit, failure prediction, and formability of FSW samples [12-14]. Some literature studies on microhardness have been performed on dissimilar aluminium alloys by the researchers. The influence of the FSW process parameters on the different zone such as TMAZ, HAZ, and WNZ regions and investigated the hardness value and microstructure. The formation of material flow and mixing of the material in the region were investigated [15-18]. It is concluded that a very limited attempt has been made so far to study the effect of parameters on the combination of AA5052-H32 and AA5083-O. Therefore, in this paper, an investigation has been made to optimized the FSW process parameter such as shoulder diameter, rotational speed, and travel speed on tensile properties, microstructure, and formability of friction stir tailor welded sheets of dissimilar aluminium alloy AA5052-H32 and AA5083-O using RSM.

Revised Manuscript Received on March 30, 2020.
* Correspondence Author
Praveen Kumar*, Department of Mechanical, PhD scholar, Gautam Buddha university. E-mail: praveen.jbm@gmail.com
Dr. Satpal Sharma, Department of Mechanical, Assistant Professor, Gautam Buddha university. E-mail: satpal78sharma@gmail.com

II. MATERIAL AND METHODS

A. Material Selection

AA5052-H32 was selected as this material has high corrosion resistance. It has excellent formability and weldability. While in the case of AA 5083-O, it is corrosion-resistant to the chemical environment and seawater.

It also retains the tremendous tensile strength after the FSW process. Both the alloys have many industrial applications, and due to good corrosion resistance can also withstand marine environmental conditions. For carrying out this experimental study, two sheets of different aluminum alloys of AA5052-H32 and AA5083-O of dimensions 2 mm x 110 mm x 220 mm were selected. Sheets were welded parallelly along the grain direction of the sheet during the FSW process. The chemical composition of both the base materials was checked by the energy dispersive method (EDX), as given in Table I. The tensile properties and microhardness are also given in Table II.

Table I: Chemical Composition of base materials.

Alloys → / Elements ↓	AA5083-O	AA 5052-H32
Mn	0.83	0.10
Fe	0.48	0.48
Mg	4.37	2.72
Si	0.10	0.25
Cu	0.10	0.45
Zn	0.44	0.1
Ti	0.23	0.30
Cr	0.05	0.32
Al	93.4	95.28

Table II: Tensile property and microhardness of the base materials.

Alloys → / Properties ↓	AA5083-O	AA5052-H32
Yield stress (MPa)	143	125
Tensile strength (MPa)	253	170
Elongation at break	26.3%	9%
Vickers hardness (HV)	100	70

B. Experimental Setup

The FSW machine was used for the butt joining of the dissimilar aluminium alloy sheets of AA5083-O and AA5052-H32, as shown in Fig.1.The single-pass welding process is used to butt weld. During the FSW technique, both the sheets were clamped accurately by the welding fixture. The hydraulic clamps were used for proper clamping of the sheet. The feasible process parameters were selected based on the trial run. In this present study, the process parameter such as rotational speed (RS), travel feed (TS), and shoulder diameter (SD) were selected for the FSW process. Some parameters were taken constantly during FSW shown in Table III. H13 hot die steel material with 55 HRC hardness was chosen for the tool pin.

Fig.1. FSW setup

Table III: Constant FSW parameters

Process Parameter	Value
Tilt angle	0°
Axial force	10KN
Pin length	1.7
Tool hardness	55 HRC
Pin profile	Round profile
Shoulder profile	Flat

In the present study, tensile properties, microhardness, and formability of FSW joints were investigated. Tensile specimens cut by the water jet machining process as per the ASTM-E8M standard [11] to estimate the ultimate tensile strength, yield strength, and total elongation of the FSW joints. The test was performed on the universal tensile testing machine, as shown in Fig. 2 (a). The formability of the samples was evaluated by the limiting dome height test method [14]. For the microhardness value, the sample size of 25 mm X 25mm x 2 mm was prepared and polished by an emery paper. The hydraulic press and microhardness machine, as shown in Fig. 2 (b) and Fig. 2 (c).

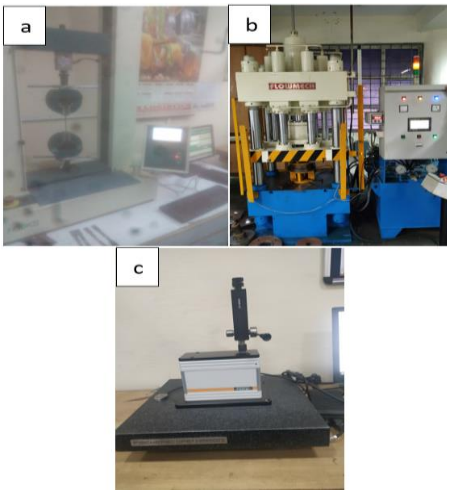

Fig.2. (a) UTM for tensile test (b) Hydraulic press for LDH test (c)microhardness machine for hardness test

C. Design of Experiment

RSM technique is a relationship between statistics and the mathematical modeling process [9]. RSM is used to evaluating the influence of the parameters on the output responses. Based on the literature review [8-11], the three most affecting process parameters are identified, such as shoulder diameter (SD), rotation speed (RS), and travel speed (TS). The output response, such as ultimate tensile strength (UTS), Yield strength (YS), total percentage elongation (TE), dome height (DH), and microhardness (μH) of FSWed joint of dissimilar aluminium alloy are a function of RS, SD, TS. The face-centered “central composite design” method is used to design the experimental trial run. The FSW parameter and their levels in the actual form are presented in Table IV.

Retrieval Number: E3205039520/2020©BEIESP
DOI: 10.35940/ijitee.E3205.039520
Journal Website: www.ijitee.org

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication

Table IV: Input parameters and their levels

Input Parameter	Unit	Symbol	LEVEL		
			+1	0	-1
Rotation speed	rpm	RS	1200	1550	1900
Travel speed	mm/min	TS	20	30	40
Shoulder diameter	mm	SD	12	14	16

III. RESULT AND DISCUSSION

A. Development of a mathematical model

As per the design of the experiment developed by RSM technique, all the 15 numbers of the run were successfully trial out as presented in Table V. The value of each output response was evaluated accordingly. The empirical correlation between responses was developed in the code form. Therefore, the regression equations were derived to determine the predicted value of responses. These equations are presented in (1) (2) (3) (4) and (5).

UTS=+391.22619-0.182857RS+6.84286TS-35.82143SD+ 0.000214RS*TS-0.000357RS*SD-0.1125TS*SD+0.000057 RS^2-0.085 TS^2+1.5 SD^2 (1)

YS=+2.60.73141-0.197431RS+4.85345TS-13.49790SD+ 0.001714RS*TS+0.000143RS*SD-0.175 TS*SD +0.000042 RS^2-0.074176 TS^2+0.795588 SD^2 (2)

TE=+2.16256+0.002563RS+0.047773TS-0.416576SD-0.00 004RS*TS-0.000557RS*SD+0.0075TS*SD+2.06723E-06 RS^2-0.001568 TS^2+0.040809 SD^2 (3)

DH=+12.614+0.003361RS+0.280042TS-1.10189SD-7.1428 6E-06RS*TS-0.003179RS*SD+0.026250 TS*SD+0.000013 RS^2-0.01441 TS^2+0.213971 SD^2 (4)

µH=+418.74409-0.220137RS+2.83139TS-32.33739SD-0.0 00136RS*TS+0.002607RS*SD+0.111250TS*SD+0.000063 RS^2-0.066059 TS^2+0.936029 SD^2 (5)

Table V: Design matrix and experimental result

Trial Run	RS, rpm	TS, rpm	SD, mm	UTS, rpm	YS, rpm	TE, %	LDH, mm	µH, HV
1	1200	40	16	134	121	3.52	21	89.5
2	1550	30	14	121	114	2.43	15.5	80
3	1900	30	14	127	112	2.64	17	91.9
4	1900	20	16	125	107	2.5	16	89.3
5	1200	30	14	130	121	2.69	17.5	87
6	1550	30	14	119	111	2.46	16	82.9
7	1550	30	12	123	107	2.4	15	83
8	1550	30	14	124	109	2.59	16.5	82.4
9	1550	30	16	132	122	2.75	18	88
10	1550	20	14	108	97.8	2.31	15	73
11	1550	30	14	120	112	2.3	14.8	81.5
12	1900	40	12	128	116	2.53	16.4	84
13	1200	20	12	116	106	2.21	14.5	82.9
14	1550	30	14	122	112	2.39	15.5	81
15	1550	40	14	118	110	2.2	14	77.3

Analysis of variance (ANOVA) process is used to testing the adequacy of developed empirical correlation between output response. The result of ANOVA for all the responses are presented in Table VI. In all the responses, it is found that the F-Value implies that the mathematical model is significant. Similarly, the lack of fit value is not significant. It is also observed that the F-values for all responses are higher than the tabulated values at above 95% confidence level. Hence the system consists of the adequate model. In this case, RS, TS, SD, RS*TS, RS*SD, TS*SD, RS^2, TS^2, SD^2 are significant model terms. The coefficient of determination (R^2) signifies the goodness of the suitability of the model. In all the responses, the value of R^2 is above 95%, and it means the predicted data are more compatible with the experimental data. Table VII represented the R^2 factors for each response.

Table VI. ANOVA table for output response surface model.

Response 1: Ultimate Tensile Strength

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	610.65	9	67.85	22.49	0.0016	significant
A-RS	4.50	1	4.50	1.49	0.2764	
B-TS	50.00	1	50.00	16.57	0.0096	
C-SD	40.50	1	40.50	13.43	0.0145	
RS*TS	0.7500	1	0.7500	0.2486	0.6392	
RS*SD	0.0833	1	0.0833	0.0276	0.8745	
TS*SD	6.75	1	6.75	2.24	0.1949	
RS^2	128.15	1	128.15	42.48	0.0013	
TS^2	188.96	1	188.96	62.64	0.0005	
SD^2	94.15	1	94.15	31.21	0.0025	
Residual	15.08	5	3.02			
Lack of Fit	0.2833	1	0.2833	0.0766	0.7957	not significant
Pure Error	14.80	4	3.70			
Cor Total	625.73	14				

Response 2: Yield Strength

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	569.87	9	63.32	23.54	0.0014	significant
A-RS	40.50	1	40.50	15.05	0.0116	
B-TS	74.42	1	74.42	27.66	0.0033	
C-SD	112.50	1	112.50	41.82	0.0013	
AB	48.00	1	48.00	17.84	0.0083	
AC	0.0133	1	0.0133	0.0050	0.9466	
BC	16.33	1	16.33	6.07	0.0569	
A^2	70.24	1	70.24	26.11	0.0037	
B^2	143.90	1	143.90	53.49	0.0007	
C^2	26.49	1	26.49	9.85	0.0257	
Residual	13.45	5	2.69			
Lack of Fit	0.2510	1	0.2510	0.0761	0.7964	not significant
Pure Error	13.20	4	3.30			
Cor Total	583.32	14				

Response 3: Total Elongation

Retrieval Number: E3205039520/2020©BEIESP
DOI: 10.35940/ijitee.E3205.039520
Journal Website: www.ijitee.org

Published By:
Blue Eyes Intelligence Engineering & Sciences Publication

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	1.39	9	0.1542	16.59	0.0032	significant
A-RS	0.0012	1	0.0012	0.1345	0.7288	
B-TS	0.0061	1	0.0061	0.6509	0.4564	
C-SD	0.0613	1	0.0613	6.59	0.0502	
AB	0.0280	1	0.0280	3.02	0.1430	
AC	0.2028	1	0.2028	21.82	0.0055	
BC	0.0300	1	0.0300	3.23	0.1324	
A^2	0.1677	1	0.1677	18.04	0.0081	
B^2	0.0643	1	0.0643	6.91	0.0466	
C^2	0.0697	1	0.0697	7.50	0.0409	
Residual	0.0465	5	0.0093			
Lack of Fit	0.0016	1	0.0016	0.1386	0.7286	not significant
Pure Error	0.0449	4	0.0112			
Cor Total	1.43	14				

Response 4: Dome Height

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	40.75	9	4.53	14.04	0.0048	significant
A-RS	0.1250	1	0.1250	0.3875	0.5609	
B-TS	0.5000	1	0.5000	1.55	0.2683	
C-SD	4.50	1	4.50	13.95	0.0135	
AB	0.0008	1	0.0008	0.0026	0.9614	
AC	6.60	1	6.60	20.46	0.0063	
BC	0.3675	1	0.3675	1.14	0.3346	
A^2	6.74	1	6.74	20.91	0.0060	
B^2	3.42	1	3.42	10.61	0.0225	
C^2	1.92	1	1.92	5.94	0.0589	
Residual	1.61	5	0.3226			
Lack of Fit	0.0008	1	0.0008	0.0020	0.9667	not significant
Pure Error	1.61	4	0.4030			
Cor Total	42.36	14				

Response 5: Microhardness

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	340.85	9	37.87	35.24	0.0005	significant
A-RS	12.00	1	12.00	11.17	0.0205	
B-TS	9.25	1	9.25	8.60	0.0325	
C-SD	12.50	1	12.50	11.63	0.0190	
AB	0.3008	1	0.3008	0.2800	0.6194	
AC	4.44	1	4.44	4.13	0.0977	
BC	6.60	1	6.60	6.14	0.0559	
A^2	154.83	1	154.83	144.09	0.0001	
B^2	114.13	1	114.13	106.21	0.0001	
C^2	36.66	1	36.66	34.12	0.0021	
Residual	5.37	5	1.07			
Lack of Fit	0.1208	1	0.1208	0.0920	0.7768	not significant
Pure Error	5.25	4	1.31			
Cor Total	346.22	14				

B. Effect of process parameters on UTS, YS, TE, DH, µH

The three-dimensional (3D) plot for effect of shoulder diameter on each response such as UTS, YS, TE, DH, and µH of the FSWed joint is illustrated in Fig.3. In Fig. 3 represents the influence of any two parameters on each response where the remaining parameter lies on the center value. It is observed that the increase of shoulder diameter results in an increase of the UTS, YS, TE, and DH of the FSWed joint up to maximum value. There is an increase in the shoulder diameter from 12 mm to 14 mm. The microhardness decreases, then shoulder diameter increases from 14 mm to 16mm, then microhardness increases. It is due to the plastic flow of the material at the weld nugget zone that results in complete recrystallization occurs. The optimum frictional heat was generated in between the FSWed joint. It results in the proper mixing of material and great bonding created to make the strengthen joint. At the increasing of shoulder diameter, there is a contact surface increased of welded surface and tool pin. The 3D plot for the effect of rotational speed and travel speed on each response is illustrated in Fig.4. The increases of rotation speed result in them decreases all response values such as UTS, YS, TE, µH, and DH of the FSW joints. It produces more amount of heat, and it affects the flowability of the material in the WNZ area. There is further rotational speed reached to a maximum value; the responses were increased. There also observed that the travel speed has very less effect on the responses.

Table VII: Coefficient of determination values.

Response / Coefficient	UTS	YS	TE	DH	µH
UTS	1.74	1.64	0.0964	0.5679	1.04
Mean	123.13	111.85	2.53	16.18	83.58
C.V. %	1.41	1.47	3.81	3.51	1.24
R^2	0.9759	0.9769	0.9676	0.9619	0.9845
Adjusted R^2	0.9325	0.9354	0.9093	0.8934	0.9565
Predicted R^2	0.8664	0.8729	0.7140	0.9447	0.9012
Adeq Precision	18.5102	18.0705	16.6412	15.0667	22.3302

Retrieval Number: E3205039520/2020©BEIESP
DOI: 10.35940/ijitee.E3205.039520
Journal Website: www.ijitee.org

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication

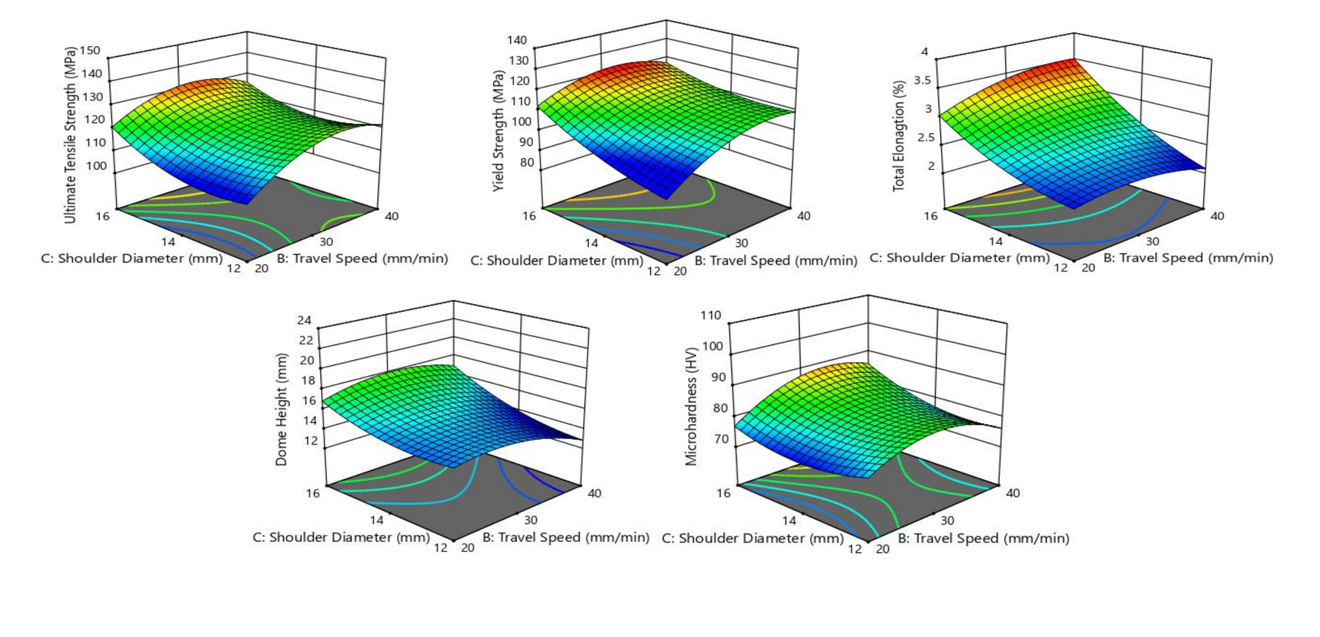

Fig.3. Effect of shoulder diameter and travel speed on responses.

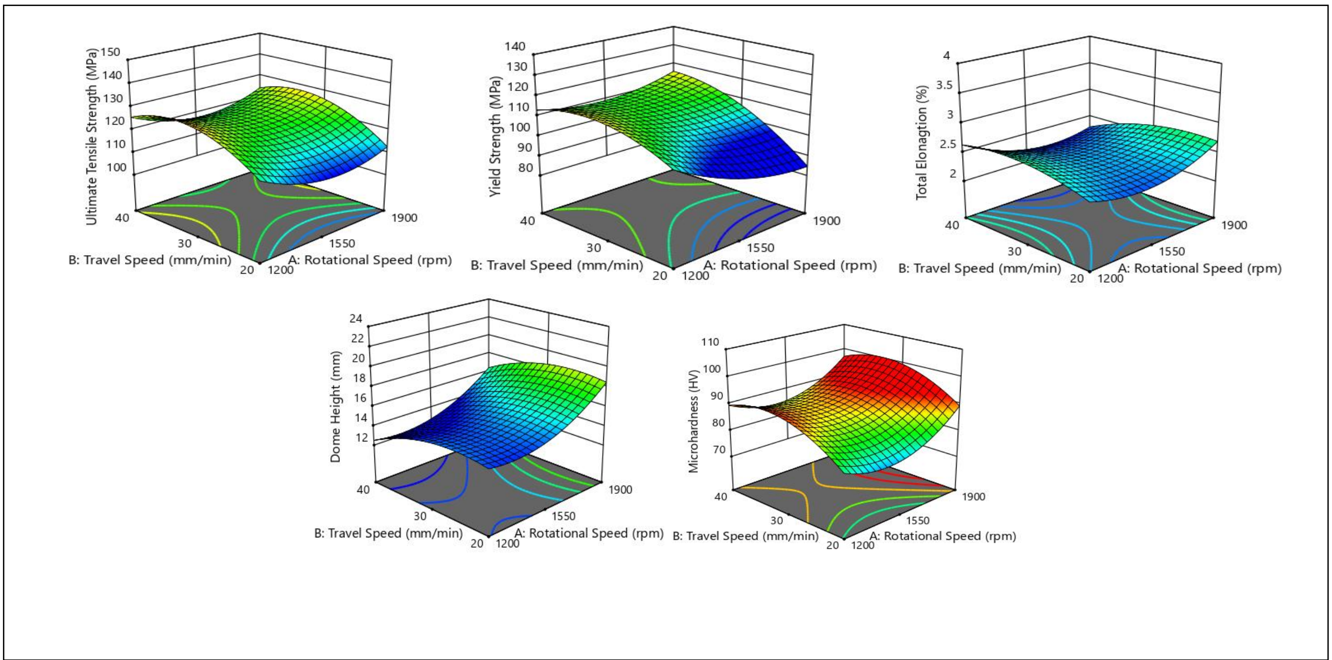

Fig.4. Effect of rotational speed and travel speed on responses.

C. Optimized parameters

Optimization of the input process parameter to maximize the output response such as UTS, YS, TE, DH, and µH were carried out. Optimization was performed based on the effect of the process parameters on the output responses. It was observed that the best-predicted input process parameter is 1644 rpm of rotational speed, 28 mm/min of travel speed,13 mm of shoulder diameter as presentd in Table VIII.

Table VIII: Optimized parameter and response value

Input parameter			Output responses					
RS	TS	SD	UTS	YS	TE	DH	µH	Desirability
1644	28	13	120	108	2.5	15	82	1.000

IV. CONCLUSION

In this present study, the effect of SD, RS, TS on output responses UTS, YS, TE, DH, and µH of joint were investigated. The following conclusions can be concluded:

- The SD and RS have a more influenced parameter on the formation of the FSWed joint.
- As per the ANOVA result, the adequacy of the developed model is found satisfactory with more than 95% of confidence level.
- With the combination of these parameters, the weld joint had crack free and sound weld formation.

- A maximum UTS of 120 MPa, YS of 108 MPa, TE of 2.5%, DH of 15mm, and 82 HV was exhibited by the FSW joint fabricated with the optimized parameters of RS of 1644 rpm, TS of 28 mm/min, and SD of 13mm respectively.

REFERENCES

1. Murr LE, Murr LE, Paso E. A Review of FSW Research on Dissimilar Metal and Alloy Systems. 2010;19(November):1071–89.
2. Al C, Cu C, Wt F, Wt C, Wt C, Zn ST, et al. Aluminum 6061 - T6 ; 6061 - T651 Subcategory : 6000 Series Aluminum Alloy ; Aluminum Alloy ; Metal ; Nonferrous Metal Close Analogs : Composition Notes : Aluminum content reported is calculated as remainder . Composition information provided by the Alumin. 2015;1–2.
3. Ng C-H, Yahaya SN., Majid AA. Reviews on aluminum alloy series and its applications. Acad J Sci Res. 2017;5(December):708–16.
4. Rai R, Bhadeshia HKDH, Debroy T. Review : friction stir welding tools. 2011;16(4):325–42.
5. Shah LH, Othman NH, Gerlich A. Review of research progress on aluminium–magnesium dissimilar friction stir welding. Sci Technol Weld Join [Internet]. 2018;23(3):256–70. Available from: http://dx.doi.org/10.1080/13621718.2017.1370193
6. Padmanaban G, Balasubramanian V. Selection of FSW tool pin profile , shoulder diameter and material for joining AZ31B magnesium alloy – An experimental approach. Mater Des [Internet]. 2009;30(7):2647–56. Available from: http://dx.doi.org/10.1016/j.matdes.2008.10.021
7. Palanivel R, Mathews PK, Murugan N, Dinaharan I. Effect of tool rotational speed and pin profile on microstructure and tensile strength of dissimilar friction stir welded AA5083-H111 and AA6351-T6 aluminum alloys. Mater Des [Internet]. 2012;40:7–16. Available from: http://dx.doi.org/10.1016/j.matdes.2012.03.027
8. Elangovan K, Balasubramanian V. Materials & Design Influences of tool pin profile and tool shoulder diameter on the formation of friction stir processing zone in AA6061 aluminium alloy. 2008;29:362–73.
9. Mallieswaran K, Padmanabhan R, Balasubramanian V. Friction stir welding parameters optimization for tailored welded blank sheets of AA1100 with AA6061 dissimilar alloy using response surface methodology. Adv Mater Process Technol [Internet]. 2018;4(1):142–57. Available from: https://doi.org/10.1080/2374068X.2017.1410690
10. Ghaffarpour M, Aziz A, Hejazi TH. Optimization of friction stir welding parameters using multiple response surface methodology. Proc Inst Mech Eng Part L J Mater Des Appl. 2017;231(7):571–83.
11. SHANAVAS S, EDWIN RAJA DHAS J. Parametric optimization of friction stir welding parameters of marine grade aluminium alloy using response surface methodology. Trans Nonferrous Met Soc China (English Ed [Internet]. 2017;27(11):2334–44. Available from: http://dx.doi.org/10.1016/S1003-6326(17)60259-0
12. Ma XW, Wang F, Zhao GQ. The Limiting Dome Height Tests and Formability of Magnesium Alloy Sheet AZ31B. Appl Mech Mater. 2013;302:140–5.
13. Zadpoor AA, Sinke J, Benedictus R. Theoretical prediction of failure in forming of friction stir welded blanks. 2008;305–8.
14. Shao Z, Bai Q, Li N, Lin J, Shi Z, Stanton M, et al. Experimental investigation of forming limit curves and deformation features in warm forming of an aluminium alloy. Proc Inst Mech Eng Part B J Eng Manuf. 2018;232(3):465–74.
15. Rodrigues DM, Loureiro A, Leitao C, Leal RM, Chaparro BM, Vilaça P. Influence of friction stir welding parameters on the microstructural and mechanical properties of AA 6016-T4 thin welds. Mater Des [Internet]. 2009;30(6):1913–21. Available from: http://dx.doi.org/10.1016/j.matdes.2008.09.016
16. Gungor B, Kaluc E, Taban E, Sik A. Mechanical, fatigue and microstructural properties of friction stir welded 5083-H111 and 6082-T651 aluminum alloys. Mater Des. 2014;56:84–90.
17. Ma ZY, Feng AH, Chen DL, Shen J. Recent Advances in Friction Stir Welding/Processing of Aluminum Alloys: Microstructural Evolution and Mechanical Properties. Crit Rev Solid State Mater Sci. 2018;43(4):269–333.
18. Xu W, Liu J, Zhu H, Fu L. Influence of welding parameters and tool pin profile on microstructure and mechanical properties along the thickness in a friction stir welded aluminum alloy. 2013;47:599–606.

AUTHORS PROFILE

Praveen Kumar is presently working as an Assistant professor at Delhi Institute of Tool Engineering, Govt. of NCT of Delhi. He is a Ph.D. research scholar at Gautam Buddha University, Greater Noida. He completed B.Tech. in Mechanical and Automation Engineering in 2004. He completed a Masters in Engineering (MTech.) in production engineering. His research Area is Production engineering, metal forming, and welding processes. He has more than four years of industrial experience and approximately seven years of teaching experience and especially teaching production engineering, press tool design, manufacturing science, Engineering drawing, etc. He has published more than 20 research papers in various National and International conferences and journals. He has membership in the IFERP organization.

Dr. Satpal Sharma is presently working as an Assistant professor at Gautam Buddha University, Greater Noida. He completed B.Tech. in Mechanical Engineering in 1997. He completed a Masters in Engineering (M.E.) in production engineering. He completed a PhD from IIT Roorkee. His research Area is a composite material, production engineering, material science etc. He has more than 2 years of industrial experience and approximately 27 years of teaching experience. He has published more than 100 research papers in various National and International conferences and journals. He has membership in various mechanical organizations. He has many govt-funded projects and one patent.