MULTI OBJECTIVE OPTIMIZATION OF FSW PROCESS PARAMETERS USING GENETIC ALGORITHM AND TLBO ALGORITHM

Lam Suvarna Raju¹, Venu Borigorla²

¹,²VFSTR Dept., Mechanical Engineering, Guntur, AP-522213, India
¹drlsraju@gmail.com, ²venuborigorla@gmail.com

Corresponding Author: Venu Borigorla

Abstract

AA2014 has been extensively used in manufacture of light weight fabricated components similar to commercial automobile components, which requires high strength with minimal weight and along with decent corrosion effect. The traditional welding of this Aluminium alloyed materials generally encounter solidification problems like hot cracking. Friction Stir Welding (FSW) is an ecofriendly joining process where in the actual melting of material and recasting will not happen. Many of the researchers carried out sufficient experiments for optimizing process parameters and to establish empirical relationships in order to predict better mechanical properties. In the present investigation, a comparative study of FSW between experimentation and optimization of process parameters such as tool rotation speed and weld speed, to attain maximum mechanical properties using Genetic Algorithm (GA) and Teaching Learning Based Optimization (TLBO) algorithm. From the results it shows that the TLBO gives the better combinations of process parameters which give superior mechanical properties compared to experimental results as well as other optimization techniques.

Keywords : FSW; Process Parameters; Mechanical Properties; Genetic Algorithm; TLBO

I. Introduction

FSW is a noteworthy alteration of conventional welding process, emerged in 1991 and patented by TWI, UK [I]. In the past two decades, it has seen a meaningful growth in metal joining applications and in particular aerospace industry witnessed huge application of this. Previous studies proved that the number of process parameters effects weldment of FSW of aluminum alloys specially in microstructure and mechanical properties [III]. Majority of the studies focused on the flow of material from front to rear of the tool pin as sound mixing of material is of more importance [II]. The effect of process parameters is investigated in order to obtain superiority weldments with enhanced mechanical properties [X].
As it is primarily determined by the main parameters of FSW, good joints are prepared by the proper selection of process parameters improper amalgamation generates defects in joints [IV]. Recent researchers identified that tool geometry is a critical factor which influences the heat and stirring required to join the plates effectively. In addition to that, process parameters play a vital role in producing quality weldments aiding in generating sufficient amount of heat required for solid-state welding which in turn helps in fine grains at weld zone [IV-V]. More researchers are obtained better mechanical properties using optimization techniques like RSM, grey relation analysis, Taguchi, PSO, ant colony algorithm, honey bee algorithm, GA, TLBO algorithm, Multi-objective biogeography based optimization algorithm in FSW [VI-XII].

The optimization of process parameters using above said algorithm are required algorithm special control parameter [XIII-XV]. To mitigate these troubles using TLBO and compared the results with GA. The current work focuses on the improvement of scientific models using GA and TLBO to forecast the good mechanical properties of AA2014-T651 weldments. Along with optimization studies, the experiments are also conducted to validate the optimum parameters. It observed that TLBO produced better results compared to experimental studies as well as GA.

II. Experimental Procedure

The weldments of AA 2014- T651 plates of 140 X 80 X 6 mm were performed using FSW. The schematic sketch, as publicized in Figure 1. The experimentations were conducted as per the DOE (L9) by taking two factors and three levels of input variables using plain taper tool pin as presented in Fig.1. The Tool Rotation Speed (TRS), Welding Speed (WS) used as input variables where as other factors remained constant.

The weldments are fabricated by using different tool rotation speeds like 700, 900, 1100 rpm, with WS of 40, 50, 60 mm/min and tilt angle (TA) of 1.5°. The defect free friction stir weldments are shown in Fig.2.

Fig. 1: A) FSW Process B) Plain taper tool pin profile
The friction stir weldments are cross-sectioned slanting to the welding direction as per ASTM E8 and A370 standards using wire cut EDM machine. Samples were polished at the surface and edges for avoiding stress concentration [XVII] to examine mechanical properties. The illustration of tensile and impact specimens are presented in Fig. 3.

Digital micro hardness tester (HVS-100B model) was used to measure the micro hardness in the weld zone. The tensile test was performed using the universal testing machine (UTM-Model TUE-CU-1000) of 100KN capacity at room temperature. Impact tests were performed. Impact strength of the weld is measured using Izod impact test equipment (Model KI-1.4). The mechanical properties of weldments and corresponding input parameters are presented in Table 1.

![Figure 2: Friction stir weldments with plain taper cylindrical tool pin.](image)

![Figure 3: Sketch of Tensile and Impact sample.](image)
Table 1: Input parameters and experimental results.

| Tool Type               | TRS (rpm) | WS (mm/min) | TS (Mpa) | YS (Mpa) | EL (%) | IS (J) | H (HV) |
|------------------------|-----------|-------------|----------|----------|--------|--------|--------|
| Plain taper cylindrical tool | 700       | 40          | 297      | 243      | 8.2    | 7.28   | 103    |
|                        | 700       | 50          | 282      | 240      | 7.67   | 6.54   | 100    |
|                        | 700       | 60          | 267      | 237      | 7.13   | 5.81   | 98     |
|                        | 900       | 40          | 310      | 244      | 8.19   | 7.38   | 106    |
|                        | 900       | 50          | 295      | 241      | 7.68   | 6.65   | 104    |
|                        | 900       | 60          | 280      | 239      | 7.17   | 5.92   | 101    |
|                        | 1100      | 40          | 322      | 245      | 8.23   | 7.5    | 109    |
|                        | 1100      | 50          | 307      | 243      | 7.76   | 6.78   | 107    |
|                        | 1100      | 60          | 292      | 240      | 7.22   | 6.05   | 105    |

III. Results and Discussion

Present era manufacturing process adopt various optimization algorithms to obtain best results. The present study focused on maximization of mechanical properties with best combinations of process parameters with GA and TLBO algorithm. Effect of WS and TRS on the Hardness (H), Percentage of Elongation (EL), Impact Strength (IS), Tensile Strength (TS) and Yield Strength (YS) were studied. The two operating process parameters considered will affect the heat generation and thus effects flow of the material. It is noticed that combinations of process parameters that create low or high frictional heat will majorly effect material flow and this in turn affect mechanical properties. Objective functions for the TS, YS, EL, IS, and H were generated using MINITAB17 as shown in the equations (1-5) for plain taper tool pin.

Maximization:

Plain Taper Cylindrical Tool Pin Profile:

\[
\begin{align*}
TS &= 313.417 + 0.062500 \times \text{TRS} - 1.5000 \times \text{WS} \\
YS &= 248.667 + 0.006667 \times \text{TRS} - 0.2667 \times \text{WS} \\
EL &= 10.1203 + 0.000175 \times \text{TRS} - 0.051667 \times \text{WS} \\
IS &= 9.7817 + 0.000583 \times \text{TRS} - 0.073000 \times \text{WS} \\
H &= 100.333 + 0.016667 \times \text{TRS} - 0.2333 \times \text{WS}
\end{align*}
\]

Constraints:

\[ZTS = TS \leq 483\]
ZYS = YS ≤ 414 \hspace{1cm} (7)
ZEL = EL ≤ 13 \hspace{1cm} (8)
ZIS = IS ≤ 9 \hspace{1cm} (9)
ZH = H ≤ 155 \hspace{1cm} (10)

Parameter Bounds:
Tool rotation speed: 700 ≤ TRS ≤ 1100 \hspace{1cm} (11)
Weld speed: 40 ≤ WS ≤ 60 \hspace{1cm} (12)

Optimization of Process Parameters by using Genetic Algorithm:
Several traditional methods like dynamic programming have been used in the past to optimize the parameters in FSW of Al alloy, but still there is a need for a multipurpose algorithm to solve diverse optimization problems. This paper uses a Genetic Algorithm to solve the problems which have been a problem to traditional optimization and which gives better results compared to existing techniques. The optimization process was done for plain taper cylindrical tool pin. The procedural program was written and executed in MATLAB GA TOOLBOX using regression equations; from these equations, the functions were developed to find the optimal value.

**Fitness.m.file**
Function \( y = \text{vignan\_fitness}(x) \)
\[
Y(1) = 313.417 + 0.062500 \times x(1) - 1.5000 \times x(2);
Y(2) = 248.667 + 0.006667 \times x(1) - 0.2667 \times x(2);
Y(3) = 10.1203 + 0.000175 \times x(1) - 0.051667 \times x(2);
Y(4) = 9.7817 + 0.000583 \times x(1) - 0.073000 \times x(2);
Y(5) = 100.333 + 0.016667 \times x(1) - 0.2333 \times x(2);
\]

**Constraint.m.file**
Function \([c, ceq] = \text{vignan\_constraint}(x)\]
\[
c(1) = [483 - (313.417 + 0.062500 \times x(1) - 1.5000 \times x(2))];
c(2) = [414 - (248.667 + 0.006667 \times x(1) - 0.2667 \times x(2))];
c(3) = [13 - (10.1203 + 0.000175 \times x(1) - 0.051667 \times x(2))];
c(4) = [9 - (9.7817 + 0.000583 \times x(1) - 0.073000 \times x(2))];
c(5) = [155 - (100.333 + 0.016667 \times x(1) - 0.2333 \times x(2))];
ceq = [];
\]

**Optimization of Tool Box:**
Solver = ga_genetic algorithm

*Copyright reserved © J. Mech. Cont.& Math. Sci.*
*Lam Suvarna Raju et al*
Fitness function = @fitness
No. of variables = 2
Bounds = [700 40], [1100 60]

Table 2: Optimized process parameters and Mechanical properties from GA

| S.N | TRS (rpm) | WS (mm/min) | TS (Mpa) | YS (Mpa) | EL (%) | IS (J) | H (HV) |
|-----|-----------|-------------|----------|----------|--------|--------|--------|
| 1   | 1098      | 39.6        | 321.25   | 243.15   | 7.98   | 7.05   | 105.89 |

Multi-Response Optimization of TLBO Algorithm:

The TLBO technique is used to optimize TRS and WS to obtaining better mechanical properties. Along with optimization studies, the experiments are also conducted to validate the optimum parameters. It observed that TLBO produced better results compared to experimental studies and GA.

The size of the primary population consists of 9 experiments as presented in Table 1. Individual constraints for TS, YS, EL, IS, and H, were deliberate using the relations (6-10). Based on the overall constraints ($Z_1$) the objective function was framed.

$$Z_1 = \left( \frac{Z_{TS}}{Z_{TS_{\text{max}}}} \right) + \left( \frac{Z_{YS}}{Z_{YS_{\text{max}}}} \right) + \left( \frac{Z_{EL}}{Z_{EL_{\text{max}}}} \right) + \left( \frac{Z_{IS}}{Z_{IS_{\text{max}}}} \right) + \left( \frac{Z_{H}}{Z_{H_{\text{max}}}} \right)$$

The primary population and updated population values are presented in Table 3 to Table 11. From the experimentation and optimization, the TRS and WS are optimized using GA and TLBO and the results are presented in Table 12.

Table 3: Initial population

| S.N | TRS (rpm) | WS (mm/min) | TS (Mpa) | YS (Mpa) | EL (%) | IS (J) | H (HV) | $Z_1$ |
|-----|-----------|-------------|----------|----------|--------|--------|--------|-------|
| 1   | 700       | 40          | 297.17   | 242.67   | 8.1    | 7.2    | 102.67 | 48.2  |
| 2   | 700       | 50          | 282.17   | 240.00   | 7.6    | 6.5    | 100.33 | 85.83 |
| 3   | 700       | 60          | 267.17   | 237.33   | 7.1    | 5.8    | 98.00  | 15.21 |
| 4   | 900       | 40          | 309.67   | 244.00   | 8.2    | 7.3    | 106.00 | 47.9  |

Copyright reserved © J. Mech. Cont.& Math. Sci.
Lam Suvarna Raju et al
Table 4: Teachers Phase (New values of the variables, objective functions, constraints, and violations) (R-0.74; 0.84)

| S. No | Di ff-1 | Di ff-2 | TR S (rpm) | WS (mm/min) | TS (MPa) | YS (MPa) | E L (%) | IS (J) | H (HV) | ZTS | ZYS | ZEL | ZIS | ZH | Z1 |
|-------|---------|---------|------------|-------------|----------|----------|---------|-------|--------|-----|-----|-----|-----|----|----|
| 1     | 17-4    | 7.4     | 700        | 40          | 297.17   | 242.67   | 8.18    | 7.27  | 102.67 | 185.83 | 171.33 | 4.82 | 1.73 | 52.33 | 4.11 |
| 2     | 17-4    | 7.4     | 700        | 42.6        | 282.17   | 240.00   | 7.66    | 6.54  | 100.33 | 200.83 | 174.00 | 5.34 | 2.46 | 54.67 | 4.56 |
| 3     | 17-4    | 7.4     | 700        | 52.6        | 267.17   | 237.33   | 7.14    | 5.81  | 98.00  | 215.83 | 176.67 | 5.86 | 3.19 | 57.00 | 5.00 |
| 4     | 17-4    | 7.4     | 726        | 40          | 309.67   | 244.00   | 8.21    | 7.39  | 106.00 | 173.33 | 170.00 | 4.79 | 1.61 | 49.00 | 3.95 |
| 5     | 17-4    | 7.4     | 726        | 42.6        | 294.67   | 241.33   | 7.69    | 6.66  | 103.67 | 188.33 | 172.67 | 5.31 | 2.34 | 51.33 | 4.39 |
| 6     | 17-4    | 7.4     | 726        | 52.6        | 279.38   | 238.00   | 7.5     | 5.10  | 203.75 | 175.53 | 5.3   | 3.53 | 4.39 | 4.39 |

As per new variables

Optimized Values

Copyright reserved © J. Mech. Cont. & Math. Sci.
Lam Suvarna Raju et al
Table 5: combined population (Teachers Phase)

| S.N. O | TRS (rpm) | WS (mm/min) | TS (MPa) | YS (MPa) | E L (%) | IS (J) | H (HV) | ZTS | ZYS | ZL | ZS | ZH | Rank |
|--------|-----------|-------------|----------|----------|---------|--------|--------|-----|-----|----|----|----|------|
| 4      | 700       | 40          | 297.17   | 242.67   | 8.18    | 7.27   | 102.67 | 185.83 | 171.33 | 4.82 | 1.73 | 52.33 | 4.11 |
| 5      | 700       | 50          | 282.17   | 240.00   | 7.66    | 6.54   | 100.33 | 200.83 | 174.00 | 5.34 | 2.46 | 54.67 | 4.56 |
| 6      | 700       | 60          | 267.33   | 237.33   | 7.14    | 5.81   | 98.00  | 215.83 | 176.67 | 5.86 | 3.19 | 57.00 | 5.00 |
| 7      | 900       | 40          | 309.67   | 244.00   | 8.21    | 7.39   | 106.00 | 173.33 | 170.00 | 4.79 | 1.61 | 49.00 | 3.95 |
| 8      | 900       | 50          | 294.67   | 241.33   | 7.69    | 6.66   | 103.67 | 188.33 | 172.67 | 5.31 | 2.34 | 51.33 | 4.39 |
| 9      | 900       | 60          | 279.67   | 238.67   | 7.18    | 5.93   | 101.34 | 203.33 | 175.33 | 5.82 | 3.07 | 53.66 | 4.83 |

Note: Yellow color indicates values are replaced by their bounds accordingly

Mean 700 40 Maximum 215.83 176.67 5.86 3.19 57

Copyright reserved © J. Mech. Cont.& Math. Sci.
Lam Suvarna Raju et al
### Table 6: Candidate solution based on non-dominance rank and crowding distance (Teacher Phase)

| S.N | TRS (rpm) | WS (mm/min) | TS (Mpa) | YS (Mpa) | EL (%) | IS (%) | H (HV) | ZTS | ZYS | ZE | ZL | ZS | ZH | Z² | Rank |
|-----|-----------|-------------|----------|----------|--------|-------|-------|------|------|----|----|----|----|----|-----|
| 7   | 110       | 50          | 307.17   | 242.67   | 7.73   | 6.77  | 107.00 | 175.83 | 171.33 | 5.27 | 2.23 | 48.00 | 4.22 | 8   |
| 8   | 110       | 60          | 292.00   | 240.00   | 7.21   | 6.04  | 104.67 | 190.83 | 174.00 | 5.79 | 2.96 | 50.33 | 4.67 | 14  |
| 9   | 700       | 40          | 297.17   | 242.67   | 8.18   | 7.27  | 102.67 | 185.83 | 171.33 | 4.82 | 1.73 | 52.33 | 4.11 | 6   |
| 10  | 700       | 42.6        | 282.17   | 240.00   | 7.66   | 6.54  | 100.33 | 200.83 | 174.00 | 5.34 | 2.46 | 54.67 | 4.56 | 9   |
| 11  | 700       | 52.6        | 267.17   | 237.33   | 7.14   | 5.81  | 98.00  | 215.83 | 176.67 | 5.86 | 3.19 | 57.00 | 5.00 | 15  |
| 12  | 726       | 40          | 309.67   | 244.00   | 8.21   | 7.39  | 106.00 | 173.33 | 170.00 | 4.79 | 1.61 | 49.00 | 3.95 | 5   |
| 13  | 726       | 42.6        | 294.67   | 241.33   | 7.69   | 6.66  | 103.67 | 188.33 | 172.67 | 5.31 | 2.34 | 51.33 | 4.29 | 7   |
| 14  | 726       | 52.6        | 279.67   | 238.67   | 7.18   | 5.93  | 101.34 | 203.33 | 175.33 | 5.82 | 3.07 | 53.66 | 4.83 | 13  |
| 15  | 926       | 40          | 322.17   | 245.33   | 8.25   | 7.50  | 109.33 | 160.83 | 168.67 | 4.75 | 1.50 | 45.67 | 3.78 | 2   |
| 16  | 926       | 42.6        | 307.17   | 242.67   | 7.73   | 6.77  | 107.00 | 175.83 | 171.33 | 5.27 | 2.23 | 48.00 | 4.22 | 4   |
| 17  | 926       | 52.6        | 292.17   | 240.00   | 7.21   | 6.04  | 104.67 | 190.83 | 174.00 | 5.79 | 2.96 | 50.33 | 4.67 | 11  |

Best ranked values from Table 5

| S.N | TRS (rpm) | WS (mm/min) | TS (Mpa) | YS (Mpa) | EL (%) | IS (%) | H (HV) | ZTS | ZYS | ZE | ZL | ZS | ZH | Z² | Rank |
|-----|-----------|-------------|----------|----------|--------|-------|-------|------|------|----|----|----|----|----|-----|
| 7   | 110       | 40          | 322.17   | 245.33   | 8.25   | 7.50  | 109.33 | 160.83 | 168.67 | 4.75 | 1.50 | 45.67 | 3.78 | 1   |
| 16  | 926       | 40          | 322.17   | 245.33   | 8.25   | 7.50  | 109.33 | 160.83 | 168.67 | 4.75 | 1.50 | 45.67 | 3.78 | 2   |

Copyright reserved © J. Mech. Cont.& Math. Sci.
Lam Suvarna Raju et al
Table 7: New values of the variables, objective functions, constraints, and violations (Learner Phase)

| S. NO | TR (rp m) | TS (mm/min) | YS (Mpa) | E L (%) | IS (J) | H (HV) | Z TS | Z YS | Z E L | Z IS | Z H | Interaction |
|-------|-----------|-------------|----------|---------|--------|---------|------|------|-------|------|-----|-------------|
| 1     | 110    0  40 | 322.17     | 245.33   | 8.25    | 7.50  | 109.33  | 160.83 | 168.67 | 4.75  | 1.50 | 45.67 | 3.78 | 1 and 9   |
| 2     | 110    0  40 | 322.17     | 245.33   | 8.25    | 7.50  | 109.33  | 160.83 | 168.67 | 4.75  | 1.50 | 45.67 | 3.78 | 2 and 8   |
| 3     | 107    6  40 | 320.67     | 245.17   | 8.24    | 7.49  | 108.93  | 162.33 | 168.83 | 4.76  | 1.51 | 46.07 | 3.80 | 3 and 7   |
| 4     | 110    0  44.03| 316.12    | 244.26   | 8.04    | 7.21  | 108.39  | 166.88 | 169.74 | 4.96  | 1.79 | 46.61 | 3.96 | 4 and 6   |
| 5     | 700    0  40 | 297.17     | 242.67   | 8.18    | 7.27  | 102.67  | 185.83 | 171.33 | 4.82  | 1.73 | 52.33 | 4.11 | 5 and 1   |

Copyright reserved © J. Mech. Cont.& Math. Sci.
Lam Suvarna Raju et al
| S. No | TR (rpm) | WS (mm/min) | TS (MPa) | YS (MPa) | E (%) | IS (J) | H (HV) | Z<sub>TS</sub> | Z<sub>YS</sub> | Z<sub>S</sub> | Z<sub>H</sub> | Rank |
|-------|----------|-------------|----------|----------|-------|--------|--------|-------------|-------------|-----------|-----------|------|
| 1     | 110      | 40          | 322.17   | 245.33   | 8.25  | 7.50   | 109.33 | 160.83      | 168.67      | 4.75      | 1.50     | 45.67 | 3.78 |
| 2     | 926      | 40          | 322.17   | 245.33   | 8.25  | 7.50   | 109.33 | 160.83      | 168.67      | 4.75      | 1.50     | 45.67 | 3.78 |
| 3     | 900      | 40          | 309.67   | 244.00   | 8.21  | 7.39   | 106.00 | 173.33      | 170.00      | 4.67      | 1.61     | 49.00 | 3.95 |
| 4     | 926      | 42.6        | 307.17   | 242.67   | 7.73  | 6.77   | 107.00 | 175.83      | 171.33      | 5.27      | 2.23     | 48.00 | 4.22 |
| 5     | 726      | 40          | 309.67   | 244.00   | 8.21  | 7.39   | 106.00 | 173.33      | 170.00      | 4.67      | 1.61     | 49.00 | 3.95 |
| 6     | 700      | 40          | 297.17   | 242.67   | 8.18  | 7.27   | 102.67 | 185.83      | 171.33      | 4.82      | 1.73     | 52.33 | 4.11 |
| 7     | 700      | 40          | 297.17   | 242.67   | 8.18  | 7.27   | 102.67 | 185.83      | 171.33      | 4.82      | 1.73     | 52.33 | 4.11 |
| 8     | 726      | 42.6        | 294.67   | 241.33   | 7.69  | 6.66   | 103.67 | 188.33      | 172.67      | 5.31      | 2.34     | 51.33 | 4.39 |
| 9     | 110      | 50          | 307.17   | 242.67   | 7.73  | 6.77   | 107.00 | 175.83      | 171.33      | 5.27      | 2.23     | 48.00 | 4.22 |
| 10    | 110      | 40          | 322.17   | 245.33   | 8.25  | 7.50   | 109.33 | 160.83      | 168.67      | 4.75      | 1.50     | 45.67 | 3.78 |
Table 9: Collect all rank 1 solutions from Table 8

| S.N.O | TRS (rpm) | WS (mm/min) | TS (MPa) | YS (MPa) | E L (%) | IS (J) | H (HV) | Z_TS | Z_YS | Z_E L | Z_s | Z_H | Z| Rank |
|-------|-----------|-------------|----------|----------|---------|--------|--------|------|------|-------|-----|-----|---|------|
| 0     | 110       | 40          | 322.17   | 245.33   | 8.25    | 7.50   | 109.33 | 160.83| 168.67| 4.75  | 1.50 | 45.67| 3.78 | 1 |
| 12    | 107       | 40          | 320.67   | 245.17   | 8.24    | 7.49   | 108.93 | 162.33| 168.83| 4.76  | 1.51 | 46.07| 3.80 | 4 |
| 13    | 110       | 44.03       | 316.12   | 244.26   | 8.04    | 7.21   | 108.39 | 166.88| 169.74| 4.96  | 1.79 | 46.61| 3.96 | 7 |
| 14    | 700       | 40          | 297.17   | 242.67   | 8.18    | 7.27   | 102.67 | 185.83| 171.33| 4.82  | 1.73 | 52.33| 4.11 | 10 |
| 15    | 700       | 40          | 297.17   | 242.67   | 8.18    | 7.27   | 102.67 | 185.83| 171.33| 4.82  | 1.73 | 52.33| 4.11 | 10 |
| 16    | 700       | 40          | 297.17   | 242.67   | 8.18    | 7.27   | 102.67 | 185.83| 171.33| 4.82  | 1.73 | 52.33| 4.11 | 10 |
| 17    | 700       | 42.6        | 293.27   | 241.97   | 8.04    | 7.08   | 102.06 | 189.73| 172.03| 4.96  | 1.92 | 52.94| 4.23 | 17 |
| 18    | 110       | 55.5        | 298.92   | 241.20   | 7.45    | 6.37   | 105.72 | 184.08| 172.80| 5.55  | 2.63 | 49.28| 4.47 | 18 |

Copyright reserved © J. Mech. Cont. & Math. Sci.
Lam Suvarna Raju et al
Table 10: Collect all max and min values of objective functions from Table 8

| S.NO | Objective functions |
|------|---------------------|
|      | TS (Mpa) | YS (Mpa) | EL (%) | IS (J) | H (HV) |
|      | Max | Min | Max | Min | Max | Min | Max | Min | Max | Min |
| 1   | 322.16 7 | 293.26 7 | 245.33 3 | 241.19 9 | 8.24612 2 | 7.4452 8 | 7.50 3 | 6.371 5 | 109.33 4 | 102.06 | 1 |

Table 11: Calculation of crowding distances from Table 9 & 10

| S.NO | TRS (rpm) | WS (mm/min) | TS (Mpa) | YS (Mpa) | EL (%) | IS (J) | H (HV) | Rank1 | CD |
|------|------------|-------------|----------|----------|--------|--------|--------|-------|----|
| 1    | 1100       | 40          | 322.167  | 245.333  | 8.24612| 7.503  | 109.335| 1     | ∞  |
| 2    | 1100       | 40          | 322.167  | 245.333  | 8.24612| 7.503  | 109.335| 1     | 1  |
| 3    | 1100       | 40          | 322.167  | 245.333  | 8.24612| 7.503  | 109.335| 1     | ∞  |

Table 12: Optimal Process parameters and Mechanical Properties

| S.NO | Technique Used | Process parameters | Mechanical properties |
|------|----------------|---------------------|-----------------------|
|      |                | TRS (rpm) | WS (mm/min) | TS (Mpa) | YS (Mpa) | EL (%) | IS (J) | H (HV) |
| 1    | Experimental   | 1100  | 40          | 321  | 244   | 8    | 7.14   | 100    |
| 2    | GA             | 1098  | 39.6        | 321.25 | 243.15 | 7.98  | 7.05   | 105.89 |
| 3    | TLBO           | 1100  | 40          | 322.16 | 245.33 | 8.24  | 7.50   | 109.33 |

IV. Conclusion

From this study, the following conclusions are drawn:

- Defect free welds are obtained using FSW.
- The TLBO suggested best combination of process parameters as TRS of 1100 rpm and WS of 40 mm/min.

Copyright reserved © J. Mech. Cont.& Math. Sci.
Lam Suvarna Raju et al
The optimization was confirmed by experimental results. Experimental values of Mechanical properties were having good relation with optimized values.

Acknowledgment

The authors are very much thankful to the authorities (DST-SERB), Ref.No. SERB/F/11385/2018-2019 for granting fund to this project, Vignan’s deemed to be university for extending the facilities to complete the current work.

References

I. W, M, Thomas, E, D, Nicholas, J, C, Needham, M, G, Murch, P, Temple Smith, and C, J, Dawas, Int. Patent Appl.No.PCT/GB92/02203 and GB patent Appl: No 9125978.8, Dec 1991, U.S. Patent Appl.No.5460317, Oct 1995.

II. R, Nandan, T, Deb Roy, and H, K, D, H, Bhadeshia, “Recent Advances in Friction-Stir Welding: process, weldment structure and properties”, Prog.Mater.Sci., vol.53, pp.980-1023, 2008

III. R, S, Mishra and Z, Y, Ma, “Friction Stir Welding and Processing”, Mater. Sci. Eng. R, vol.50, pp.1-78, 2005.

IV. Anton Savio Lewise, K and Edwin Raja Dhas, J, “A Review of Friction Stir Welding of Aluminium alloys”, International journal of Advanced Chemical Science and applications, vol.5, no.3, pp.28-32, 2017.

V. Thirupathi reddy, G, Syed Rabbani Bash, “Effect of weld speed on tool pin profile using friction stir welding”, IJSRM, vol.3, no.1, pp.1892-1896, 2015.

VI. Indira Rani, M, Marpu, RN and Kumar, ACS, “A study of process parameters of friction stir welded AA6061 aluminium alloy in O and T6 conditions”, ARPN J Eng Appl Sci, vol.6, pp.2006–2011, 2011.

VII. Khalid Hussain, A and Pasha Quadri, S, “A evaluations of parameters of friction stir welding for aluminum AA6351 alloy”, Int J Eng Sci Technol, vol.2, pp.5977–5984, 2010.

VIII. Morteza Ghaffarpour, Ahmad Aziz and Taha-Hossein Hejazi, “Optimization of friction stir welding parameters using multiple response surface methodology”, Proceedings of the Institution of Mechanical Engineers, Part L: Journal of Materials: Design and Applications, vol.231, no.7, pp.571–583, 2017.

IX. Ghaffarpour, M, Mollaei Dariani, B and Kokabi, AH et al, “Friction stir welding parameters optimization of heterogeneous tailored welded blank sheets of aluminium alloys 6061 and 5083 using response surface methodology”, J Eng Manuf, vol.44 no.A, pp.2013–2022, 2012.
X. Yousif, YK, Daws, KM and Kazem, BI, “Prediction of friction stir welding characteristic using neural network”, Jordan J Mech Ind Eng, vol.2, pp.151–155, 2008.

XI. Vidal, C, Infante, V, and Pec, as P, et al, “Assessment of improvement techniques effect on fatigue behavior of friction stir welded aerospace aluminium alloys” Procedia Eng, vol.2, pp.1605–1616, 2010.

XII. Shahrabi, J and Hejazi, TH, “A new mathematical program based on principal component analysis for multiple response optimization”, IEEE International Conference on Quality and Reliability, vol.42, pp. 445–450, 2011.

XIII. Venkata Rao, R, Kalyankar, VD, multi-pass turning process parameter optimization using teaching-learned-based optimization algorithm, Scientia Iranica E, vol.20, no.3, pp. 967-974, 2013.

XIV. Venkata Rao, K, Murthy PBGSN and Vidhu KP, “Assignment of weightage to machining characteristics to improve overall performance of machining using GTMA and utility concept”. CIRP, Journal Manufacturing Science and Technology, vol. 18, pp.152–158, 2017.

XV. Cheema, MS, Dwivedi, A, and Sharma, AK, “A Hybrid approach to multicriteria optimization based on user’s preference rating”. Proceedings of I Mech E Part B: Journal of Engineering Manufacture, vol.227, no.11, pp.1733-1742, 2013.

XVI. Kadaganchi, R, Gankidi, M.R and Gokhale, H, “Optimization of process parameters of aluminum alloy AA 2014-T6 friction stir welds by response surface methodology”. Def. Technol, vol.11, pp.209–219, 2015.

XVII. Kumar, A and Suvarna Raju, L, “Influence of Tool Pin Profiles on Friction Stir Welding of Copper”. Materials and Manufacturing Processes, vol.27, no.12, pp.1414-1418, 2012.