Optimization of Friction Stir Welded Aluminium Plates by the New Modified Particle Swarm Optimization

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Abstract. Friction Stir Welding (FSW) is a complex process that needs and trial to reach the optimal properties. In this work deals theoretical consideration done by two ways; first way is conventional Particle Swarm Optimization (PSO) and the second method is new modified Particle Swarm Optimization. The Friction stir welding data were taken from recent studies. The input to the program are nine experiments for different cases and the output is the ultimate stress for each experiment. The artificial neural network is used to relate the relation between input and output to form a cost function. The results show that the modified PSO gives the more accurate optimum result than conventional PSO when compared with other researches with maximum discrepancy 23.5%.

Keywords. Friction stir welding, Particle swarm optimization, Modified PSO.

1. Introduction

There were many benefits of FSW as compared with other welding like the absence of porosity according to very high temperature of fusion welding that leads to more study on FSW parameters that lead to optimum mechanical properties [1]. Mohammad [2] investigated the mechanical (hardness and tensile) and weld microstructural properties of the FSW for AA7075-O to AA5083-O aluminum alloys. Tensile tests showed that the mechanical properties of the welded are higher than the parent metals. The Artificial Neural Network (ANN) model was implemented to develop the relation between the FSW parameters and the mechanical properties. Proposed the hybrid multi-objective evolutionary algorithms that consists of two steps: using MOPSO to generate of a Pareto set, then obtain the best solution by using TOPSIS. Nizar [3] full factorial design of experiment is studied, the experimental data is used as an input to ANN model that is used to relate the input–output parameters of FSW. These characteristics can be optimized using four algorithms: real-coded genetic algorithm GA, binary-coded genetic algorithm GA, particle swarm optimization PSO and differential evolution DE, are coupled with the built ANN models. The results are obtained from the above algorithms and compared to evaluate the best algorithm and it is PSO algorithm with less number of alterations. Murali [4] is built an empirical relation between FSW parameters (welding speed, tool rotation and tilt angle) with yield strength and tensile strength of one pass and multi pass friction stir welded aluminum 6082 butt joints. Taguchi method with particle swarm optimization technique was used for this analyzing with three -factors three level central composite design to determine the optimal conditions. Padmanaban [5] the mathematical model was built using response surface methodology to predict the strength of the AA2024 and AA7075 friction stir welded plates and were optimized using particle
swarm optimization algorithm to find maximum tensile strength. Murali [6] is proposed an integrated WPCA-ANN-PSO approach to perform Multi response Optimization MRO of FSW in a three stage process for two welded plates of AA2024-T4 aluminum. The factors that is considered were tool rotation speed (TRS), D/d ratio and weld speed (WS). The output considered were hardness and ultimate tensile strength (UTS) of the welded plates. Pallavi [7] has been work to characterize the grain structure of friction stir welded (AA 1100) as a function of the different parameters, like plunge depth (PD), rotation speed of the tool (TRS) and speed of welding (WS). PSO has been used to obtain the optimal parameters for maximum strength and ductility with suitable grain size. FSW and FSP are very useful processes; therefore they were studied experimentally and numerically, [8-11] by the authors in order to obtain the best results regarding to the parameters of the welding and processing of the joints. The numerical technique [12-18] is considered as a helpful technique to help the researchers in their work to obtain reliable results, [19-25], but the experimental, [26-32] studies are more reliable for that. Then, the numerical results calculated comparison by experimental, [33-39], or analytical technique, [40-46], to give the discrepancy for results evaluated, [47-53]. The objective of this work is to use new origin modification on PSO method and compared with conventional PSO to get the optimal parameters of welded aluminium plates from [4,6,54] that lead to maximum ultimate stress.

2. Conventional particle swarm optimization

Particle swarm optimization (PSO) is based on the behaviours of a swarm of birds. Each particle has its own intelligence to discover well path to food, remain of the swarm are able to find the good path even they are located far away in the swarm[55]. Each particle in a swarm has two characteristics: the position and the velocity. Each particle ambulates about the design space until the best position is discovered. The simulating model is randomly searched in the design space to find the maximum value of the objective function (target), [55]. The cost function is found by using artificial neural network (ANN) to simulate the relation between input and output. Artificial neural networks (ANN) is similar to physical cellular connect by their ability to store, acquire and use their knowledge to related to the network’s performance [56-60]. Three input that is introduced to the ANN and one output with six hidden layers that is the structure of the feed forward network. Normalized done on input and output to get best result by reduce the space of solution. The function that is used to train the hidden layers is called bipolar continuous activation function (tansig).

\[
f(\text{net}) = \frac{2}{1 - \exp(-\lambda \text{net})} - 1
\]  

(1)

Where, \( \lambda > 0 \). For output layer is used unipolar continuous activation functions (logsig),

\[
f(\text{net}) = \frac{1}{1 - \exp(-\lambda \text{net})}
\]  

(2)

The trained value from ANN is sent to PSO and modified PSO to complete the optimization and find the best input with maximum output. The structure of ANN is shown in figure 1.

![Figure 1. Structure of ANN.](image)
Velocity and position from Conventional PSO is shown below,

\[
V_{ij}^{k+1} = w \times V_{ij}^k + c_1 \times r_1 \times ((\text{Pbest}_{ij}^k - X_{ij}^k) + c_2 \times r_2 \times (\text{Gbest}_{ij}^k - X_{ij}^k)) \\
X_{ij}^{k+1} = X_{ij}^k + V_{ij}^{k+1}
\] (3) (4)

Where; \( \text{Gbest}_{ij}^k \) : global best position, \( \text{Pbest}_{ij}^k \) : local best position, and \( w \) is the inertia.

\[
w = w_{\text{max}} - k \times (w_{\text{max}} - w_{\text{min}}) / \text{MaxIteration}
\] (5)

Where; \( k \) : current alteration, \( \text{MaxIteration} \) : Maximum number of alteration and, \( w_{\text{max}}, w_{\text{min}} \) : maximum and minimum inertia.

But the inertia in conventional PSO program is taken as a constant its value with the other constant are set in the Table (1).

| Table 1. Parameters of conventional PSO. |
|-----------------------------------------|
| Parameter     | Value   |
|----------------|---------|
| No. of alteration | 100     |
| Inertia (w)    | 0.98    |
| C1             | 2       |
| C2             | 2       |
| Swarm size     | 30      |

3. Modified PSO

The original point in this paper is the equation of inertia is modified to below equation,

\[
w = (w_{\text{max}} - \frac{(w_{\text{max}} - w_{\text{min}}) \times \text{iteration}}{\text{MaxIteration}}) \times \beta^{k+1}
\] (6)

Where,

\[
\beta^{k+1} = \mu \times \beta^k \times (1 - \beta^k)
\]

And all other parameters are constant and shown in Table 2. The flow chart of PSO is shown in Fig. 2.

| Table 2. Parameters of modified PSO. |
|--------------------------------------|
| Parameter     | Value   |
|----------------|---------|
| No. of alteration | 100     |
| C1             | 2       |
| C2             | 2       |
| Swarm size     | 30      |
| \( w_{\text{max}} \)    | 2       |
| \( w_{\text{min}} \)    | 1       |
| \( \mu \)             | 4       |
| Initial beta    | 0.3     |
4. Result and discussion

In this paper three different verification are done ref. [4,6,54]. The results of programs shown in table (3). In [4] there are three parameters (inputs) to optimized (rotational speed, title angle and weld speed) with nine experimental tests that are done and each of them have three value. The input to ANN network are the three above parameters and the outputs is ultimate stress. The networks are trained to do the cost function that is used in PSO and modified PSO. The result for PSO is showed good convergence but is less that of modified PSO when is compared according to ultimate stress. The ultimate stress due to modified PSO is higher that the ultimate stress due mentioned in [4] by 8.6% and due to PSO is 5.9% this is due to the inertia is continuously varying in each alteration until the best swarm is specified (the alteration is finished), for information the ref. [4] is used PSO and Taguchi method to optimized, but the input to PSO program is done by using ANOVA method to specify the most influence parameters. Murali [6] is used Taguchi-Weighted Principal Component Analysis (WPCA) approach then Artificial Neural Network (ANN) to develop the relation of factors finally is used Particle Swarm Optimization (PSO). Eight experiment that used in this paper with three input parameters (tool dimension (D/d), welding speed and rotational speed) with two values for each parameters with two outputs (but in the used program in this research only one output ultimate stress). The study is showed that the experimental optimum at (D/d=3.08, w= 936.18 rpm and v= 17 mm/min) is (ultimate stress =108.105 MPa) but the exact maximum that can be seen from table that used for training the network is (85.5MPa). The present study is shown that ultimate stress is found in (w= 1500 rpm, v=20mm/min) with ultimate stress is 276 N/mm2. Some changes done on program to do this case by changing the input matrix to two column instead of three column and the number of parameters to two instead of three parameters. The present study is shown that ultimate stress by PSO
is (274.0154N/mm²) when (w=1002.1 rpm, v=59 mm/min) and for modified PSO, the ultimate stress is (293.497N/mm²) when (w=1600 rpm, v=20 mm/min), the optimum stress that is obtained from modified PSO is higher than the optimum stress that is obtained from paper by 6.3% and for conventional PSO is 7.11%.

### Table 3. The results of programs

| Ref. No | Rotational results | PSO | Modified PSO |
|---------|--------------------|-----|--------------|
| [4]     | Rotational speed= 809.685 (rpm) | Rotational speed= 704 (rpm) | Rotational speed= 703 (rpm) |
|         | Title angle=3°     | Title angle=1°     | Title angle=3°     |
|         | Weld speed= 1.7142 (inch/min) | Weld speed= 1.993 (inch/min) | Weld speed= 1.02 (inch/min) |
|         | Ultimate stress= 197.4239 N/mm² | Ultimate stress= 202 N/mm² | Ultimate stress= 214 N/mm² |
| [6]     | Rotational speed= 936.18 rpm | Rotational speed=1171.5 rpm | Rotational speed=1000 (rpm) |
|         | D/d=3.08,          | D/d =3             | D/d =3              |
|         | Weld speed= 17 (mm/min) | Weld speed= 17.2 (mm/min) | Weld speed= 17(mm/min) |
|         | Ultimate stress= 108.105 N/mm² | Ultimate stress=85.5638 N/mm² | Ultimate stress=105.4051 N/mm² |
| [54]    | Rotational speed= 1500(rpm) | Rotational speed=1002.1(rpm) | Rotational speed=1600 (rpm) |
|         | Weld speed= 20 (mm/min) | Weld speed=59 (mm/min) | Weld speed= 20(mm/min) |
|         | Ultimate stress= 276 N/mm² | Ultimate stress=274.015 N/mm² | Ultimate stress= 293.497N/mm² |

### 5. Conclusion

The new modification method presented was successfully worked based upon the PSO method in changing the inertia in each alteration of solution. The results of the PSO and the modified PSO are compared well with the other researchers work applying different experimental results (different number of input and output), the results show good verifications with these researches. The maximum improvement of modified PSO is 23.3% in ref. [6] with three input parameters (tool dimension (D/d), welding speed and rotational speed) and one output (ultimate stress).

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