Prediction Model of Tensile Strength Property in Friction Stir Welding Using Artificial Neural Network (ANNs)

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Abstract

For years, manufacturing industry faced challenges in conserving high cost and efficiency in research and development of products especially in relation to welding structure. To handle this problem, this research conducts an effort to develop methods to determine tensile strength properties of Friction Stir Welding (FSW) in Aluminum alloy using prediction model. An artificial intelligent technique, i.e. Artificial Neural Network (ANNs) is used to develop the prediction model. Initial work involves FSW welding experiment and testing of subsequent result to analyze the tensile strength properties of the welding structure based on process parameter input. Prediction model is developed based on Back Propagation (BP) of error to predict tensile strength of the FSW structure. Input parameters for the model is tool rotational speed and travel speed while output of the model is the tensile strength of FSW welded structures. Proposed prediction model is then trained with experiment data. Testing of the proposed prediction model was then conducted using unused experiment data from the training. Research result shows that proposed prediction model is aligned with experiment data. This shows that average error value from the training and testing is 0.010286 or very small (close to zero) which means that the desired output of the prediction model for the training and testing is close to each other. Result from regression graph for training and testing shows matching linear regression between output and target when compared to dash line of the ideal result. This shows an absolute linear relationship where R equals to 0.9 or close to 1. This proves good compatibility the prediction model.

Keywords
Friction stir welding, artificial neural network, tensile strength.

1. Introduction
Friction stir welding as a welding technique has been applied for the past several years in the engineering field especially in manufacturing. Compared with conventional welding technique especially for lower melting material such as Aluminium alloys which is normally susceptible to hot cracking, FSW promises high quality welding with high durability as well as some other advantages due to its nature of not reaching the melting temperature during welding. Introduced by The Welding Institute (TWI) in 1991, FSW is considered as a green technology that emphasizes on environmentally friendly process that does not need material filler. FSW is known as one of solid state welding processes that relies on heat energy produced from mechanical friction. Technically, this welding technique works based on a combination of two main processes associated by parameter to tool motion, i.e. rotational speed and travel speed respectively [Nandan]. As described in Figure 1, the tool rotates in a specific speed in Revolutions Per-Minute (RPM) and this tool moves in a specific speed along the welding path in millimetre per minute (mm / min) speed unit.

This technique has the advantage to be able to join similar and dissimilar materials which are not normally considered bondable (or "incompatible"), like Aluminum with Steel, Copper with Aluminum, Titanium with Copper and Titanium with Stainless Steel and nickel alloy to be Steel [Huseyin]. Other significant advantage from this technique is shorter welding time with small amount of heat energy thus it is an efficient energy usage. Currently FSW welding is a more popular option especially for manufacturing industry like automotive, plane, train and ship as well as spaceship and space station, oil and gas and construction.

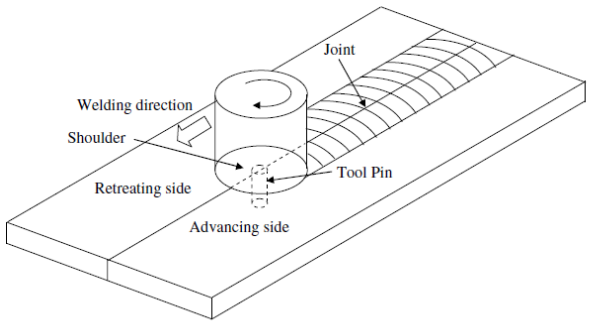

Figure 1. Friction Stir Welding process [Nandan]

Newest issue in manufacturing industry is that a welding process needs to be quick and accurate to improve performance and strength of the welding structure. Thus a study and test to optimize FSW process is needed as this has become a concern due the needs to determine optimal settings of such processes through adjusted parameter. However, optimization approach competes for testing with cost efficiency demand, especially in terms of the use of testing material and execution time. One of heuristic approaches to be considered is to use machine learning intelligence system as an efficient approach to solve technical issues especially in the manufacturing field [Niyeti, Maleki, Jinhua], and particularly welding [Hasan, Maleki].

One of the most popular machine learning techniques is Artificial Neural Network (ANNs) which is also used in predicting and obtaining optimum parameter in manufacturing process. The biggest difference is in neural network input and output which are already considered as training and testing network. Previous study about this approach can be found in [Okuyucu, Shojaeefard, Yousif].

2. Implementation of Artificial Neural Network

Artificial neural network (ANNs) is a computation model implemented in numerous application in the area of optimization and prediction problems. Adopted from the nervous system and applied on human's brain system, it is capable as machine learning as well as pattern recognition [Chen]. ANNs consists of causality relationship between factors influencing the process to produce corresponding result. Artificial Neural Network is designed in such a way to be able to determine resulting output from alteration inputs accurately. Expected output in this research is welding structure mechanical character which is the tensile strength that is influenced by input parameter, rotational speed and travel speed respectively. This machine learning technique is expected to be used to replace testing work and tests to save costs and time.

Basically, network can be described mathematically as f function of x towards y distribution ($f: x \rightarrow y$). Network may consist of input layer, output layer and one or more intermediate later called hidden layer. Network must be trained first through functions with trial and error of given ANNs architecture and proposed algorithm to obtain the best result and solution. Training is implemented through multiplication of weight and addition of bias before entering neuron.

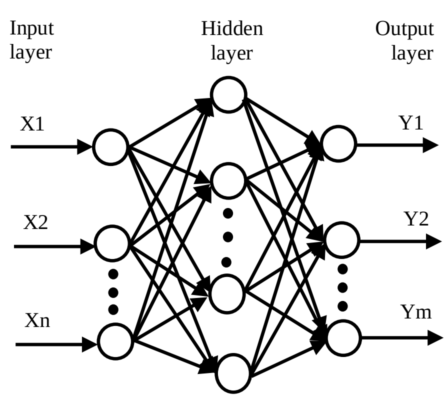

Figure 2. Basic Structure of Neural Network [Thanapong].

In this research, the sigmoid tangent (Tansig) (x) and linear χ(x) are used as back propagation (BP) function. Figure 2 is the basic structure of BP neural network as the gradient descent method that minimizes the sum of squared errors between the target value and the output of the neural network. Neural network process is in the amount of layer and neuron where time is a problem for such complex structure of the network [Maleki, Wackerly].

In the network, back propagation algorithm involved are two processes, i.e. forward process and backward process. Forward process spread input vectors through network to produce output on the output layer and the backward process spread error values back to the network to determine weight change during training. A unit in hidden layer will send activation to each unit in output layer during forward process spread. During the spread, backward process unit in hidden layer will receive error signal from each unit in the output layer [Yousif].

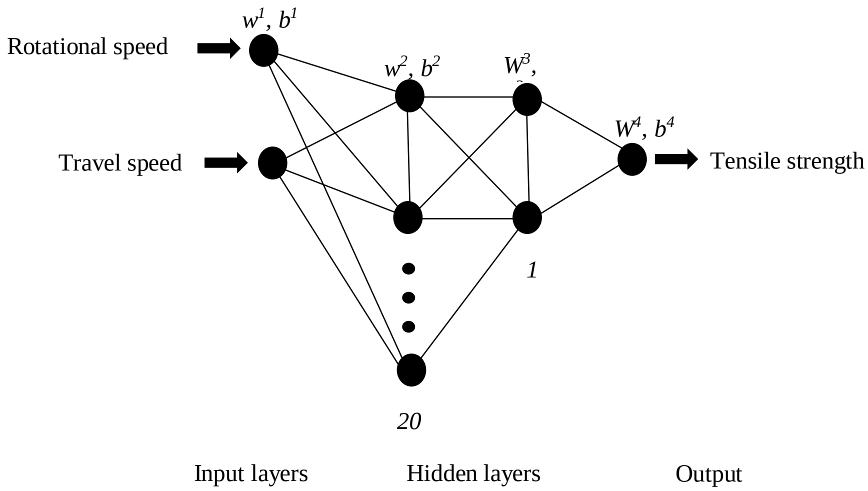

Figure 3. Structure for a network of the proposed study.

In this paper, forward movement speed and rotational speed of welding is the input of ANNs model and tensile strength is the output of ANNs model. Conceptual structure for the proposed ANNs model is shown in Figure 3. Two parameter inputs enter the input layer to determine an output. The statistic of performance evaluation used to train ANNs model in this research is Mean Square Error (MSE). MSE predictor, estimator MSE (θ), the sum of the variance of the estimator and the squared bias of the estimator are each defined in (1), (2) and (3) [Wackerly], which are as follow:

$$MSE = \frac{1}{n}\sum_{i=1}^{n}\left(\hat{Y}_i - Y_i\right)^2 \quad (1)$$

$$MSE\left(\hat{\theta}\right) = E\left[\left(\hat{\theta} - \theta\right)^2\right] \quad (2)$$

$$MSE\left(\hat{\theta}\right) = Var\left(\hat{\theta}\right) + Bias\left(\hat{\theta}, \theta\right)^2 \quad (3)$$

3. Experimental work

To develop a prediction model, some work needs to be done in advance, such as FSW experiment work followed by mechanical testing of FSW structure. In the experimental work stage, conventional milling machine with FSW tool, spin to connect workpieces from 6mm thick plate in the Aluminum AA6061-T651 alloy as seen in Figure 4. The rotating speed and travel speed of the FSW tool vary according to Table 1. The next stage is mechanical testing. This testing was conducted on FSW structure to obtain its mechanical character through tensile test.

Tensile test was conducted with cross head speed of 5 mm / minute according to EN-895-200 standard where tensile specimen dimension is shown in Figure 5. Tensile test of FSW structure was conducted in room temperature using universal testing machine 250KN. During the uniaxial tensile test, high resolution extensometer was also used. Chosen parameter combinations are tabulated in table 1.

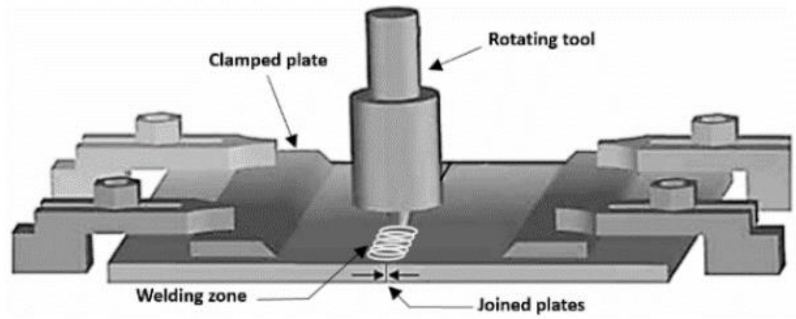

Figure 4. The position of the clamps fixed relative to the surface of the sheet.

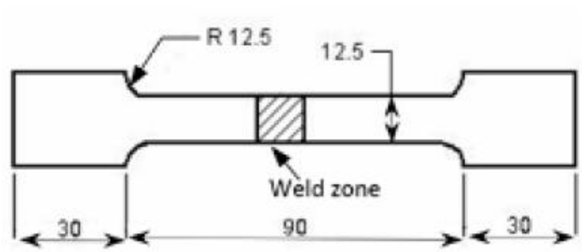

Figure 5. Dimensions of flat tensile specimen.

Table 1. Combination of governing parameter and the of tensile test measurement

Rotation speed (Rpm)	**Travel speed (mm/s)**	**Tensile Strength (MPa)**			**Mean Tensile Strength (MPa)**
		1rst Specimen	2nd Specimen	3rd Specimen	
350	0.80	149.2	149.3	148.2	148.9
350	1.42	169.4	169.3	169.3	170.0
350	2.38	167.1	169.8	169.8	169.0
350	3.33	187.7	189.9	189.9	188.7
350	4.55	190.6	191.0	191.0	188.9
650	0.80	142.7	150.7	152.0	148.5
650	1.42	174.0	175.6	175.7	175.1
650	2.38	194.5	192.5	192.8	193.3
650	3.33	189.8	188.5	188.5	188.9
650	4.55	196.4	196.3	198.7	197.2
950	0.80	135.0	144.1	143.0	140.7
950	1.42	166.2	167.7	161.0	165.0
950	2.38	172.9	191.8	182.5	182.4
950	3.33	187.8	181.1	178.8	182.6
950	4.55	204.5	209.3	207.2	207.0
1400	0.80	168.2	172.6	164.5	168.4
1400	1.42	59.6	70.5	67.3	65.8
1400	2.38	110.3	108.4	100.5	106.4
1400	3.33	143.6	145.4	153.7	147.6
1400	4.55	30.6	27.1	30.3	29.3

4. Model Development and Discussion

The purpose of this research is to propose a prediction model based on artificial neural network technique in predicting mechanical character of FSW welding structure that focuses on tensile strength. Chosen parameter will be considered as an input that will be included in the proposed network model. This network model is packed of several neurons arranged in different layers which are also connected through variable weight. This weight is calculated with iterative method during training process, when network is given a large amount of data for training as bait and when there is input and output matches representing pattern to be modelled.

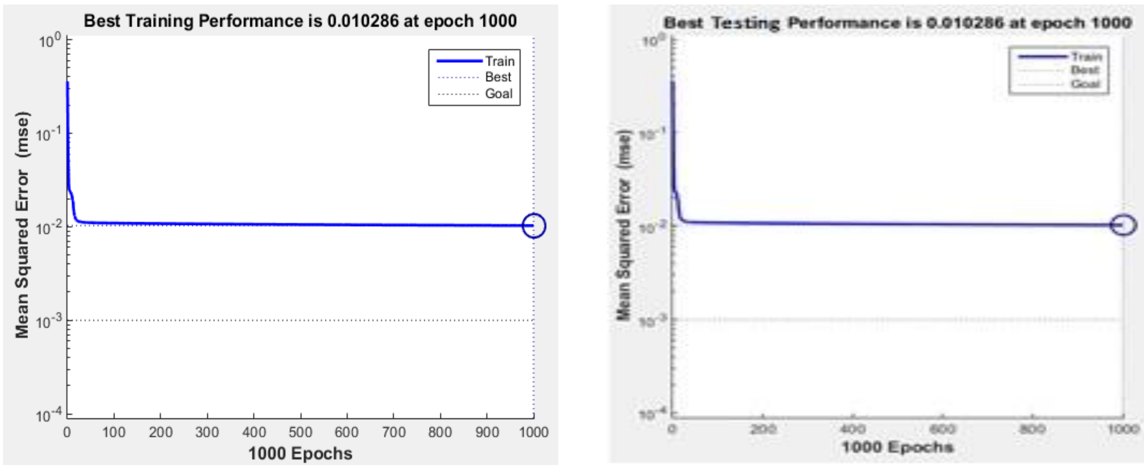

Figure 6. Performance analysis of trained and tested networks.

In this research, BP Algorithm (backpropagation) is used with 2 hidden layers. MATLAB platform is used to train and test proposed ANNs model. In the training, 20 neurons are installed in the first hidden layer and similarly 1 neuron in the second hidden layer which will be used to improve output accuracy. The first ANNs layer is related to the process parameter like rotational speed of FSW tool and travel speed of FSW tool. After training network, testing was conducted by using known testing data. Model of Artificial Neural Network explained in this research is used to predict tensile strength from the welded structure. Statistical method is used to compare results from network and to increase output accuracy. The first layer of ANNs network is aligned with the chosen process parameter which are rotational speed and travel speed of FSW tool. After training network, testing network was conducted using known testing data. ANN's model explained in this research is used to predict FSW tensile strength through training process. Statistical method is used to compare results from network.

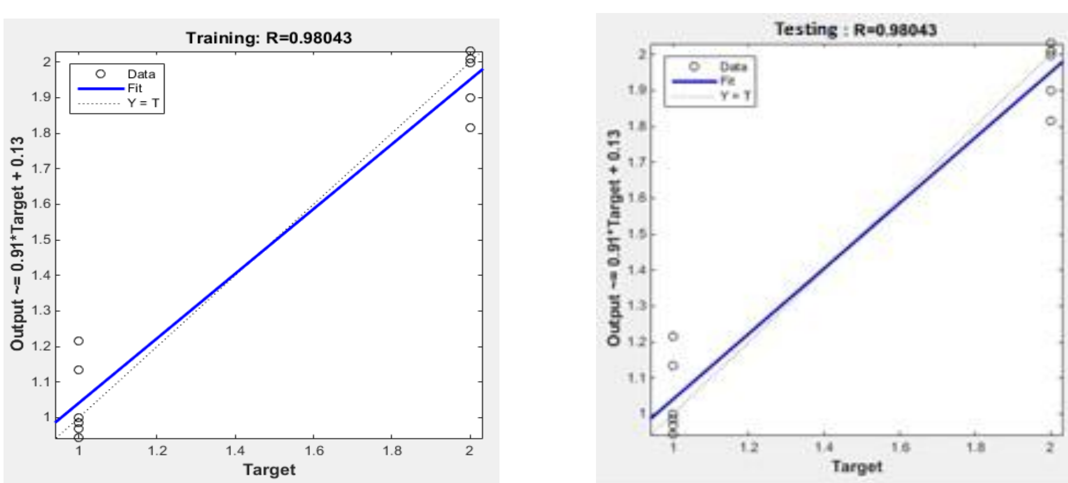

Figure 7. Regression analysis of trained and tested networks.

As shown by figure 6, the final mean-square error is small. Both training and testing network with their linear regression between output network and corresponding target show similar graph. The figure shows that the Mean Square Error (MSE) of ANNs model declines. Well trained ANNs have to have very low MSE at the end of the training which, in this research, equals to 0.010286. This result shows that the MSE is very small (close to zero) where desired ANNs output and resulting ANNs output for the training set are close.

According to the result obtained from the regression graphs of training and testing (Figure 7), the best fit of linear regression line between output and target shows the right linear relationship when compared with the dash line of ideal result. This is based on the R value that is equal to 0.9 or very close to 1 which indicates a good fit.

5. Conclusion

In this research, Artificial Neural Network (ANNs) is used to predict FSW welding parameter in Aluminum 6061-T6 alloy. Rotational speed and travel speed tools are considered to be ANN's model inputs. An effective parameter from the FSW process for tensile strength is modelled. MSE value from training and testing is 0.010286 or very small (close to zero) which means that the desired output and ANN's output for training set and testing become very close to each other. On the other hand, results derived from the regression graphs of training and testing show that the linear regression line between output and target compared to dash line of perfect result (ideal condition) have the right linear relationship where the R value equals to 0.9 or very close to 1. This shows a good fit.

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