Load level prediction system model of friction stir spot welded aluminium alloy using support vector machine

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Abstract. The cost and efficiency of experiment and test are still a major issue in manufacturing especially in welding. In this study, a machine learning technique i.e. support vector machine (SVM) was applied to develop a load level prediction system of friction stir spot welded joint aluminium alloy AA5052-H112. This load level prediction system model was proposed based on three levels of load group of the welded joint. Experimental works in friction stir spot welding was conducted on samples specimens of AA5052-H112 2mm thick overlap joint based on 27 combinations of governed parameters i.e. spindle speed, tool depth, and dwell time. Mechanical testing of tensile shear load was then carried out to those specimens to obtain 27 loads data to form the SVM classifier. These data were required for pattern classification and model development via training and testing the proposed prediction system. The result obtained via training and testing showed the classification of load data produced by the proposed system, matched to the required load level with the 100%. This study proved that the proposed load level prediction system offered a useful tool to predict the load level of friction stir welded joint aluminium alloy AA5052-H112 by using respected parameters without required experiments and tests.

1. Introduction
In automotive industry, reducing weight of a vehicle is a significant way to reduce fuel consumption. This is reflected to application of lightweight materials, which has been rapidly growing since a decades. One of the most applied lightweight materials in industry is aluminium. Aluminium is normally welded using solid state welding process. One of the common solid state joining processes used in automotive is friction stir spot welding (FSSW). FSSW is the variant in friction stir welding (FSW), developed by The Welding Institute in the UK since 1991 [1]. Advantageous of this technique are low distortion, low energy, and avoiding melt related defects [2].

The process of FSSW consists of three main stages i.e. plunging, stirring, and retracting (Figure 1). The process starts with rotating the FSSW tool at a fix angular speed that set beforehand. During rotating, the tool is forced axially onto the workpieces surface. Once the rotating tool reached the workpiece surface, friction is begun to form a weld spot, where heat is then generated around the workpieces. This allows plastic deformation in the workpieces to soften the workpiece material. Subsequently, forging action plunges the rotating tool into the workpiece. The plunging movement of
the tool causes the softened material escape from its original position. However the tool shoulder restricts the softened metal flow to the shoulder position. After plunging, the stirring stage starts when the tool reaches a predetermined depth. In this stage, the tool keeps rotating in the workpieces to generate heat. This heat mainly influenced by two actions, i.e. friction between rotating tool and workpiece, and severe plastic deformation of the workpiece. Thus the materials adjacent to the tool are heated, softened, and mixed in the stirring stage where a solid-state joining will be formed [2]. Material around the tool is softened by friction heating and stirred by the tool to unify between both surfaces [3]. The process is ended at the stage of retracting where the tool is slowly retracted from the workpiece back to the initial position.

![Illustration of FSSW process](image)

**Figure 1.** Illustration of FSSW process applied on two overlapped sheet metals; (a) Plunging process; (b) Stirring process; (c) Retreating process. [4]

### 2. Problem identification

In order to enhance productivity in manufacturing, improvement in the welding process is necessary with consideration of quality of the welded joint. Thus, optimization of FSSW process was needed. A broad of study in optimization of the FSSW process had been noted due to its necessity to define optimal settings of such processes by ascertaining the governed parameters. However, such optimization approaches competed with cost efficiency of experiments and tests, as the price of raw materials and time consuming. In consequence, employing machine learning intelligence systems as an efficient approach to solve engineering problems especially in manufacturing [5-11], and especially in welding [12-16] is considerable to reduce cost and efficiency of experiment and test. Therefore, an approach to optimize the FSSW process without spent the cost and time of experiment and test in the earlier stage was recommended.

Based on the above statement, the purpose of this study was to propose a prediction system model to the mechanical property of friction stir spot welded joint using machine learning technique, support vector machine (SVM). The proposed prediction system model was focused on the load group of the welded joint based on the governing parameters (spindle speed, tool depth, and dwell time). It was planned that the governing parameters will be considered as the input to SVM classifier in the proposed prediction system model to produce information of the coming load group of respected welded joint.

### 3. Methodology

In order to solve the problem statement and fulfilled the objective, a several steps should be took under consideration. First of all was a development of the proposed prediction system model for load group of FSSW welded joint based on SVM, as a technique that overtook artificial neural networks in machine learning popularity. This technique is much simpler methods such as linear classifiers gradually. Subsequently, preliminary laboratory for experiment and mechanical test must be carried out to the workpieces of friction stir spot welded joint. Furthermore, the data obtained from the test were then collected and classified into 3 different groups of loads (high, medium, and low). Those data were then used to train and test the proposed system model. Finally, the proposed system model produced the predicted load groups of friction stir spot welded joints. If the predicted load group was
not fulfilling and match to the actual result of testing, a new proposed system model was necessary to be reformed. The research methodology of this experiment was referring to Creswell [17]. The overview of the methodology could be seen in Figure 2.

![Figure 2. Methodology of the study](image)

The SVM technique was used as pattern classification technique that measured the similarities between input data and the data stored in the database. In this study, the prediction system model had two important phases namely, the training phase and the testing phase. The training phase was the process of development the prediction system model that could be used as the references for the prediction system model. The testing phase was a process to evaluate the prediction system model that
already trained. The algorithm of the whole process of prediction system model is described in schematic diagram shown in Figure 3.

![Schematic diagram of proposed algorithm in SVM technique for prediction system model.](image)

**Figure 3.** Schematic diagram of proposed algorithm in SVM technique for prediction system model.

### 3.1. Support vector machine

The idea of SVM is the mapping of non-linearly training data into higher-dimensional feature space through the kernel function used as pattern classification. SVM constructs a hyper-plane in a high dimensional feature space, which can be used for classification, regression or other tasks [18]. Therefore a good separation is achieved by the hyper-plane that has the largest distance to the nearest training data points of any class (functional margin), since in general the larger the margin the lower the generalization error of the classifier (Figure 4). Hence, in the linear separable case, there exists a separating hyperplane whose function is

$$w^T x + b = 0 \quad w \in R^N, b \in R$$

where $w$ is weight, and $b$ is bias. For optimized linear division, a hyperplane is constructed to separate the two classes [19]. This implies

$$y_i (w^T x + b) \geq 1, i = 1, ..., N$$

**Figure 4.** SVM with linear separable data [18].

By introducing Lagrange multiplier $\alpha_i$, the SVM training procedure aims to solve a convex quadratic problem (QP). The solution is a unique globally optimization result, which has the following property:
where \( \alpha_i \neq 0 \), \( X_i \) is called the support vectors. When SVM is trained, a decision can be obtained by comparing each new example \( X \) with only the support vector \( \{X_i\}, i \in SV \);

\[
y = \text{sign} \left( \sum_{i \in SV} \alpha_i y_i (x_i \cdot x^T) + b \right)
\]

(4)

where \( x^T \) is the testing data and \( SV \) is the support vector data.

3.2. Preliminary laboratory

This session was conducted to prepare the samples for experiment and test on the work pieces of aluminium alloy AA5052-H112. This alloy was commonly used in manufacturing especially in automotive car body [4]. It had a good strength, formability and corrosion resistance [20]. Even though Aluminium alloys have some disadvantages especially for welding. It is well known that this alloy show very poor weld ability compared to fusion welding, due to local high temperature during welding that can produce undesirable deformation of sheet metal [21]. Table 1 shows the chemical composition of AA5052-H112. The dimension of the sample of work piece was 125 x 40 x 2 millimetres (mm) with overlap area of 40 x 40 mm according to the JIS Z3136:1999 standard (Figure 5.a).

Table 1. Chemical composition of AA-5052-H112 (mass fraction, %).

| Cu  | Mg  | Si  | Fe  | Mn  | Z   | C   | Al  |
|-----|-----|-----|-----|-----|-----|-----|-----|
| 0.10| 2.2 | 0.25| 0.4 | 0.10| 0.10| 0.35| Bal |

Material being used for FSSW tool in this study was K100 tool steel with 5mm pin diameter and 2mm pin length of cylindrical pin profile [22]. The shoulder diameter was 12 mm. The geometry of FSSW tool was showed in Figure 5.b).

![Figure 5. Work pieces and tool preparation; a) Geometry of sample AA5052-H112 with overlap joint, b) Geometry of FSSW tool (K100 steel) with cylindrical pin profile.](image)
3.3. Experimental work and tensile shear load test
The welding experiment in FSSW was applied on the vertical head CNC milling machine (FIRST-MCV300) with the position perpendicular to the surface of the work piece as shown in Figure 6. The work piece was firmly clamped to the bed and a FSSW tool was plunged into the spot weld of the work piece for sufficient time in order to plasticize around the pin. The parameter of FSSW process used in this study consisted of spindle speed, tool depth and tool dwell time. The spindle was set in the constant speed of 1000, 1200 and 1400 radian per minutes (rpm) respectively. In every set of spindle speed, the tool depth was arranged at 2.5, 3, and 3.5 mm respectively. Furthermore for every state of tool depth, the tool dwell time was varied from 5, 7, and 9 second (s). From such setting it was formed 27 combinations among those three parameters for FSSW that applied for each sample work piece (Table 2). This was planned in such a way to investigate any changes of load occurred as a result of changes the parameter combination during FSSW.

![Figure 6](image1.png)

**Figure 6.** a) FSSW using vertical head CNC Milling machine with the position of the tool that perpendicular to the work piece surface, b) FSSW sample specimen after welding ready for tensile shear load test, c) Tensile shear load test on a 100 kN Instron universal testing machine.

**Table 2.** Experimental results of tensile shear load test.

| Spindle speed (Rpm) | Tool depth (mm) | Dwell time (second) | Mean tensile shear load (N) |
|--------------------|----------------|---------------------|-----------------------------|
| 1000               | 2.5            | 5                   | 2923                        |
| 1000               | 2.5            | 7                   | 1772                        |
| 1000               | 2.5            | 9                   | 3369                        |
| 1000               | 3              | 5                   | 3179                        |
| 1000               | 3              | 7                   | 3900                        |
| 1000               | 3              | 9                   | 4255                        |
| 1000               | 3.5            | 5                   | 3179                        |
| 1000               | 3.5            | 7                   | 4313                        |
| 1000               | 3.5            | 9                   | 4255                        |
| 1200               | 2.5            | 5                   | 1988                        |
| 1200               | 2.5            | 7                   | 2018                        |
| 1200               | 2.5            | 9                   | 2334                        |
| 1200               | 3              | 5                   | 3852                        |
| 1200               | 3              | 7                   | 3287                        |
| 1200               | 3              | 9                   | 3699                        |
| 1200               | 3.5            | 5                   | 3846                        |
| 1200               | 3.5            | 7                   | 4162                        |
| Spindle speed (Rpm) | Tool depth (mm) | Dwell time (second) | Mean tensile shear load (N) |
|---------------------|----------------|---------------------|---------------------------|
| 1200                | 3.5            | 9                   | 4387                      |
| 1400                | 2.5            | 5                   | 3846                      |
| 1400                | 2.5            | 7                   | 1901                      |
| 1400                | 2.5            | 9                   | 4387                      |
| 1400                | 3              | 5                   | 3365                      |
| 1400                | 3              | 7                   | 3121                      |
| 1400                | 3              | 9                   | 3125                      |
| 1400                | 3.5            | 5                   | 3980                      |
| 1400                | 3.5            | 7                   | 4100                      |

4. Result and discussion
The development of the proposed system model and experimental work, including tensile shear load test of friction stir spot welded joints had been completely done, and would be discussed in this session. First of all, Table 3 showed the data obtained from the tensile shear load test that classified into three different load groups (high, medium, and low) with respect to the input parameters of spindle speed, tool depth, and dwell time. Based on the input parameters, it was expected that the prediction system model would produce output one of those load groups. The group of low load is classified for the loads measured from 1500 to 2500 N. The medium load group was the load measured from 2500 to 4000 N. The high load group is subjected to the loads from 4000 until 5000 N.

Table 3. Classification of three different load groups from the mean tensile shear loads.

| Group Level | Spindle speed (Rpm) | Tool depth (mm) | Dwell time (second) | Mean tensile shear load (N) |
|-------------|---------------------|----------------|---------------------|-----------------------------|
| High        | 1000                | 3              | 9                   | 4255                        |
|             | 1000                | 3.5            | 7                   | 4313                        |
|             | 1000                | 3.5            | 9                   | 4255                        |
|             | 1200                | 3.5            | 7                   | 4164                        |
|             | 1200                | 3.5            | 9                   | 4387                        |
|             | 1400                | 2.5            | 9                   | 4387                        |
|             | 1400                | 3.5            | 7                   | 4100                        |
|             | 1400                | 3.5            | 9                   | 4650                        |
| Medium      | 1000                | 2.5            | 5                   | 2923                        |
|             | 1000                | 2.5            | 9                   | 3369                        |
|             | 1000                | 3              | 5                   | 3179                        |
|             | 1000                | 3              | 7                   | 3900                        |
|             | 1000                | 3.5            | 5                   | 3179                        |
|             | 1200                | 3              | 5                   | 3852                        |
|             | 1200                | 3              | 7                   | 3287                        |
|             | 1200                | 3              | 9                   | 3699                        |
|             | 1200                | 3.5            | 5                   | 3846                        |
|             | 1400                | 2.5            | 5                   | 3846                        |
|             | 1400                | 3              | 5                   | 3365                        |
|             | 1400                | 3              | 7                   | 3121                        |
|             | 1400                | 3              | 9                   | 3125                        |
|             | 1400                | 3.5            | 5                   | 3980                        |
| Low         | 1000                | 2.5            | 7                   | 1772                        |
|             | 1200                | 2.5            | 5                   | 1988                        |
|             | 1200                | 2.5            | 7                   | 2018                        |
|             | 1200                | 2.5            | 9                   | 2334                        |
Furthermore, the load data from these three groups were used to train and test the proposed system model. The load data of three groups were divided into two parts. First part for the data training (Table 4), and second part for the data testing (Table 5). In this training stage, the system model learned the characteristic of significant change of governing parameters to the data training for pattern classification. Subsequently, the proposed system model that had been trained, had to be tested by using data testing in order to validate and evaluate the performance of the proposed system model.

Table 4. A list of data used for training the system model.

| Group Level | Spindle speed (Rpm) | Tool depth (mm) | Dwell time (second) | Mean tensile shear load (N) |
|-------------|---------------------|-----------------|---------------------|-----------------------------|
| high        | 1000                | 3               | 9                   | 4255                        |
|            | 1000                | 3.5             | 7                   | 4313                        |
|            | 1000                | 3.5             | 9                   | 4255                        |
|            | 1200                | 3.5             | 7                   | 4164                        |
| medium      | 1000                | 2.5             | 5                   | 2923                        |
|            | 1000                | 2.5             | 9                   | 3369                        |
|            | 1000                | 3               | 5                   | 3179                        |
|            | 1000                | 3.5             | 7                   | 3900                        |
|            | 1200                | 3               | 5                   | 3852                        |
|            | 1200                | 3               | 7                   | 3287                        |
| Low         | 1000                | 2.5             | 7                   | 1772                        |
|            | 1200                | 2.5             | 5                   | 1988                        |
|            | 1200                | 2.5             | 7                   | 2018                        |

Table 5. A list of data used for testing the system model.

| Group Level | Spindle speed (Rpm) | Tool depth (mm) | Dwell time (second) | Mean tensile shear load (N) |
|-------------|---------------------|-----------------|---------------------|-----------------------------|
| High        | 1200                | 3.5             | 9                   | 4387                        |
|            | 1400                | 2.5             | 9                   | 4387                        |
|            | 1400                | 3.5             | 7                   | 4100                        |
|            | 1400                | 3.5             | 9                   | 4650                        |
| Medium      | 1200                | 3               | 9                   | 3699                        |
|            | 1200                | 3.5             | 5                   | 3846                        |
|            | 1400                | 2.5             | 5                   | 3846                        |
|            | 1400                | 3               | 5                   | 3365                        |
|            | 1400                | 3               | 7                   | 3121                        |
|            | 1400                | 3               | 9                   | 3125                        |
|            | 1400                | 3.5             | 5                   | 3980                        |
| Low         | 1200                | 2.5             | 9                   | 2334                        |
|            | 1400                | 2.5             | 7                   | 1901                        |

The completed training and testing process of the proposed system model was shown with 100% accuracy. This means, the proposed algorithm for the proposed prediction system model was fully accurate to determine the level of tensile shear load of friction stir spot welded joint AA5052-H112.
Table 6. Training and testing accuracy of the proposed system model.

| Output group level | Training accuracy (%) | Testing accuracy (%) |
|--------------------|-----------------------|----------------------|
| High               | 100                   | 100                  |
| Medium             | 100                   | 100                  |
| Low                | 100                   | 100                  |

5. Conclusion
The load level prediction system of friction stir welded joint of aluminium alloy AA5052-H112 had been developed in this work. This prediction system aimed to obtain the useful information of the welded joint being made based on the governed parameters especially in the earlier stage in the design requirement. Therefore such experiment and test, that spent cost and time consuming, could be avoided in order to enhance productivity. In the development of the proposed system model, such algorithm was created based on the support vector machine (SVM) classifier. Such experimental work and mechanical test on tensile shear load of sample specimens of friction stir welded joints were performed under JIS Z3136:1999 standard to obtain load data. The data obtained were classified into three different load groups (high, medium, and low) with respect to the input parameters of spindle speed, tool depth, and dwell time. The load group of high was classified from 4100 N to 4650 N. The load group of medium was measured from 2923 N to 3980 N. The low loads were grouped from 1772 N to 2334 N. The load data from these three groups were used to train and test the proposed system model. The completed training and testing process of the proposed system model was shown with the accuracy of 100%. This means, the proposed algorithm for the proposed prediction system was accurate perfectly to determine the level of tensile shear load of friction stir spot welded joint of AA5052-H112.

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