Prediction of physical and Mechanical Properties of aluminum metal matrix composite Using Artificial Neural Networks

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ABSTRACT: Aluminum metal matrix composites (AMCs) are advanced engineering metal that used for many applications. In this work AMCs consist of aluminum 7075 and silicon carbide (SiC) were manufactured by stir casting for different weight ratio. AMCs were tested to find mechanical and physical properties such as young modulus, ultimate stress, maximum elongation, hardness, density. These properties are trained using artificial neural network to predict the property for different weight ratio. The main point in this research is using ANN with small number of data (only ten) that reducing the cost manufacture, testing and getting better results of prediction. The maximum increasing percentages of young modulus due to adding SiC is 72.8% at weight ratio 1% and the all other properties is became less than AL7075 because of the form of brittle phase aluminum carbide due to manufacturing process.

KEYWORDS: Aluminum metal matrix composites, ANN, silicon carbide

INTRODUCTION

Two or more homogeneous material (phases) are mixed together to form a composite material. These materials that are bonded together may be polymer, metal and ceramic. These phases are distinguished by the naked eyes [1]. Artificial neural network was used to predict fatigue crack growth of Al7020T7 and Al2024T3 alloys under the different of load ratio, the results are good agreement with the experimental result for six sets of data (R = 0, 0.2, 0.4, 0.6, 0.7 and 0.8) for the two alloys. Also, ANN was applied on the unknown data of R = 0.5 to predict crack growth [2]. The manufacture and testing of metal matrix composite is high cost thus the using of method to predict the property of composite material is needed. For this purpose, Artificial Neural Networks (ANN) are used to predict the property of AMCs. Back propagation learning algorithm was used to training, testing and validation for modeling alloy that was contained Cu, Mg and Zn as matrix with 1-15% Al2O3 particles as a reinforced material, results for training give small error about range of 2-7% done by Muhammad [3]. The optimization by using ANN model in conjunction with the application of Taguchi method for modeling in turning cutting force are studied. The ANN training and specified parameters were arranged in orthogonal array (L18) and using the proposed equation for predicting the performance of ANN model and has shown high prediction accuracy to avoid the long procedure of trial and error done by Miloš J. Madić [4].

Reddy studied the application of ANN in predicting the natural frequency of laminated composite plates under clamped boundary condition by varying the fiber orientations, –45°, 0°, 45° and 90°. These natural frequencies were found by using finite element software. The result of ANN showed that good prediction of the natural frequency [5]. Noorunnisa made the prediction of the chemical and physical properties (thermal conductivity, degradation temperature, crystallization temperature and tensile strength) of Composites made from low density polyethylene reinforced with graphene nanoplatelets (of weight ratio 1, 2, 4, 6, 8, and 10 %) that were extruded in a twin screw for three speeds (50, 100, and 150 rpm) by using ANN [6]. To reduce time and cost by using prediction obtained from ANN model for the micro-hardness, tensile extension, yield strength, ultimate strength, young modulus, fracture time, tenacity, electrical conductivity for aluminum metal matrix with different weight ratio of silicon carbide made them by Philip [7]. Ho Hwi Chie tried to achieve low cost and efficiency in welding process, Artificial Neural Network is used to predict tensile strength of Friction Stir Welded Plate Aluminum alloy. The Prediction is progressing based on Back Propagation to find tensile strength of the FSW plate and trained with experimental data. The Input data for the predicted model is travel speed and tool rotational speed.
and the output data is the tensile strength of welded structures. The result shows that value of average error from the training and testing is 0.010286 which means that the output of the network is close to desired output. [8]

The objective of this work is manufacturing an aluminum metal matrix composite by stir casting and tested for several properties such as (density, ultimate stress, young modulus and maximum elongation) for different weight ratios of silicon carbide SiC. Then artificial neural network (ANN) model is designed to predict the properties of AMMCs materials for different weight ratios in order to predict the best ratio used to manufacture the plate in purpose to reduce the cost of manufactured process by manufacturing small number of plates and obtained the property for large numbers of weight ratio in this range.

EXPERIMENTAL PROCEDURE
The Modeling of aluminum metal matrix composites material in artificial neural network needs suitable number of data. However, a suitable number of weight ratio of silicon carbide in aluminum 7075 as a matrix is selected in range of (0.1% to 15%) manufactured by stir casting method. The manufactured procedure is described here.

First, aluminum 7075 is heated to a temperature of 750 °C and the heated silicon carbide (which particle size is 50-100 micron with flake shape) with specified weight ratio is added to the aluminum and then blending it by 200-250 rotational speed for 15 min by stirrer made of steel coated by ceramic and then poured to mold made of steel until the complete solidification. Then the plates are heated into 480 °C for a period of five hours then quenching in water then aging process is done at 150 °C for twelve hours. The manufactured plates are cut by wire made from molybdenum with diameter 0.18 mm to sample of tensile, hardness and density according to their standards.

**Tensile Test**
For the tensile tests, a Universal Testing Machine (Zwick/ roel Z250 made in Germany with maximum capacity 250 KN) was used for all samples according to standard ASTM E8M-04. Tensile tests were done at speed of 0.04mm/s at room temperature.

**Brinell hardness test**
Brinell hardness Testing Machine at 30 KN load for 10 sec was used for the hardness test according to standard E10 -00. Three readings of each sample (in HBW) were taken and the average value was listed for each sample.

**Density Test**
The density of the sample is done using Archimedes law .Three reading are taken for each sample and then the average of these reading are considered.

**ARTIFICIAL NEURAL NETWORK METHODOLOGY**
The new kind of computational intelligence systems artificial neural network (ANN), is used to handle many complicated problems with ability to learn by many known inputs. In recent years, ANN finds its application in the training and modeling in various applications in the area of prediction and optimization problems. Among the various classifications, multi-layer back propagation algorithm is the most popular ANN architecture because it has a desired target as well as minimization error technique. Many nonlinear activation functions such as tanh, sigmoidal and or radial can be used to model the activity of neuron [2]. The ability of ANN to predict the output is came from the training of many inputs that have known output. The mathematical modelling of ANN can be described as function (f) of input (x) towards output (y) (f: x → y). ANN may consist of input layer, hidden layer (may be a number of layer) and output layer as shown in figure 1. [8]
Training

The artificial neural network is created to predict the property of aluminum metal matrix composite material with different weight ratios of silicon carbide. For maximum performance 1000 epochs target time steps have been taken and allowed for validation and testing. The number of hidden layers are (15). The training of program is automatically stopped when the target is reached with decreasing in MSE of the validation samples.

Learning and testing

The artificial neural network test and learn itself using the given data set and creates a simple Simulink model upon successful completion of the MatLab program.

RESULTS AND DISCUSSION

Experimental Results

From the experimental work result, it can be found that the density (as shown is fig. 2) is decreased when the weight ratio is increased because that the porosity is increased related to adding silicon carbide to the poured aluminum, this property is very useful to reduce the weight of aluminum for the application that need low weight but also this porosity is decreased the mechanical properties such as ultimate stress.

![Figure 2. Density with various weight ratio of silicon carbide of (AMMCS)](image)

The Brinell hardness of AMMCs (fig. 3) is increased when the weight ratio is increased because of presence of silicon carbide that prevent the movement of dislocations. Also, it can be seen that it is less than the AL7075 because this aluminum alloy is suffered from melting in high temperature and then adding SiC that lead to form aluminum carbide, Al$_4$C$_3$ which is very brittle, that lead to degrade the mechanical properties of the composite (this the same reason of decreasing ultimate stress when the weight ratio increase) (fig. 4). But in some ratios when the SiC increases to 5% the hardness became larger than aluminum without reinforcement by 2.9% because the presence of SiC. The young modulus (fig. 5) is increased when the weight ratio increased because silicon carbide has high young modulus.
**Figure 3.** Hardness with various weight ratio of silicon carbide of (AMMCS)

The maximum strain shown (in fig.5) is decreased by increasing the weight fraction of reinforcement particles. This decreasing because of the decreasing of ductility due to the silicon carbide which resist the plastic flow of aluminum matrix material and the form aluminum carbide is brittle.

![Figure 3](image)

**Figure 4.** Ultimate stress with various weight ratio of silicon carbide of (AMMCS)

![Figure 4](image)

**Figure 5.** Young modulus with various weight ratio of silicon carbide of (AMMCS)

![Figure 5](image)

**Figure 6.** Maximum strain with various weight ratio of silicon carbide of (AMMCS)

![Figure 6](image)

**ANN Results**

In this research five programs are made, each of them has one input (weight ratio %) and each program has one output (density, young modulus, ultimate stress, hardness, maximum elongation) and the sixth program is collecting the output of all five programs and predict the output of new selected input. A total number of ten data samples are the input of each program. The input used is the weight ratio of silicon carbide of AMMCs and the output is the mechanical and physical property shown in table.1. The result of training and learning shown in figs.
The five programs of artificial neural network (one for each property) give their purpose of learning and training of the neuron cell and the network is ready for prediction of the properties for the other ratios that they are not done in experimental work by making sixth program that combines all outputs of fifth programs and generate new outputs for new inputs (only for good weight ratio that lead to improvement the properties). See table

**Table 1. Experimental results that used as input for ANN program**

<table>
<thead>
<tr>
<th>Weight ratio (%)</th>
<th>Density g/cm³</th>
<th>Hardness</th>
<th>Young modulus (GPa)</th>
<th>Ultimate stress (MPa)</th>
<th>Maximum Strain (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>2.7567</td>
<td>161</td>
<td>81.172</td>
<td>545.45</td>
<td>13.119</td>
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<tr>
<td>0.1</td>
<td>2.9</td>
<td>130</td>
<td>120.4157</td>
<td>145.382</td>
<td>1.2488</td>
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<td>0.5</td>
<td>2.72</td>
<td>134</td>
<td>167.601</td>
<td>130.1285</td>
<td>0.20885</td>
</tr>
<tr>
<td>1</td>
<td>2.75</td>
<td>146</td>
<td>140</td>
<td>125.7294</td>
<td>0.186</td>
</tr>
<tr>
<td>2</td>
<td>2.75</td>
<td>148</td>
<td>114.6467</td>
<td>120.7567</td>
<td>0.13263</td>
</tr>
<tr>
<td>3</td>
<td>2.6267</td>
<td>155</td>
<td>89.818</td>
<td>115.01</td>
<td>0.1298</td>
</tr>
<tr>
<td>5</td>
<td>2.6833</td>
<td>165.667</td>
<td>62.027</td>
<td>110.0305</td>
<td>0.1223</td>
</tr>
<tr>
<td>7</td>
<td>2.54</td>
<td>124.6</td>
<td>40.109</td>
<td>101.63</td>
<td>0.117</td>
</tr>
<tr>
<td>10</td>
<td>2.36</td>
<td>110</td>
<td>32.796</td>
<td>37.94</td>
<td>0.11196</td>
</tr>
<tr>
<td>15</td>
<td>2.35</td>
<td>103.3</td>
<td>30.6796</td>
<td>25.34</td>
<td>0.11025</td>
</tr>
</tbody>
</table>

**Table 2. The predicted properties for different weight ratio**

<table>
<thead>
<tr>
<th>ratio</th>
<th>Density (g/cm³)</th>
<th>Hardness</th>
<th>Young modulus (GPa)</th>
<th>Ultimate stress (MPa)</th>
<th>Maximum Strain (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.2</td>
<td>2.9000</td>
<td>126.6904</td>
<td>138.7337</td>
<td>147.0490</td>
<td>0.9076</td>
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<tr>
<td>0.3</td>
<td>2.8100</td>
<td>132.0000</td>
<td>151.0612</td>
<td>137.7555</td>
<td>0.7288</td>
</tr>
<tr>
<td>0.4</td>
<td>2.7233</td>
<td>133.7537</td>
<td>157.6960</td>
<td>132.1042</td>
<td>0.3129</td>
</tr>
<tr>
<td>0.6</td>
<td>2.7225</td>
<td>135.0879</td>
<td>163.4117</td>
<td>129.1879</td>
<td>0.1991</td>
</tr>
<tr>
<td>0.7</td>
<td>2.7297</td>
<td>138.0581</td>
<td>163.9265</td>
<td>128.3630</td>
<td>0.1969</td>
</tr>
<tr>
<td>0.8</td>
<td>2.7403</td>
<td>141.8775</td>
<td>130.9918</td>
<td>127.4702</td>
<td>0.1948</td>
</tr>
<tr>
<td>0.9</td>
<td>2.7472</td>
<td>144.6413</td>
<td>134.2364</td>
<td>126.5619</td>
<td>0.1920</td>
</tr>
<tr>
<td>1.1</td>
<td>2.7502</td>
<td>146.5524</td>
<td>144.2620</td>
<td>125.0500</td>
<td>0.1835</td>
</tr>
<tr>
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<td>2.7504</td>
<td>146.7684</td>
<td>147.2017</td>
<td>124.4941</td>
<td>0.1778</td>
</tr>
<tr>
<td>1.3</td>
<td>2.7504</td>
<td>146.8656</td>
<td>148.1850</td>
<td>124.0300</td>
<td>0.1713</td>
</tr>
<tr>
<td>1.4</td>
<td>2.7504</td>
<td>146.9309</td>
<td>143.6533</td>
<td>123.6138</td>
<td>0.1644</td>
</tr>
</tbody>
</table>
Prediction of physical and Mechanical Properties of aluminum metal matrix composite Using Artificial Neural Network

Figure 7. ANN training
AMMCs which is consist of AL7075 and different weight ratio of SiC is manufactured by stir casting method and then calculate the physical and mechanical properties of these plates. The density is reduced because of the porosity that is formed due to adding this material to melted aluminum. The hardness is decreased when adding SiC to the melted aluminum but when the weight ratio is increased the hardness is also increased until the weight ratio became 5% then it decreased because of large amount of Sic Young modulus is increased due to the addition of SiC.
of the SiC until it reaches to the maximum increasing of enhancement with a percentage of 72.8% at weight ratio 1% because of the high young modulus of SiC, but the young modulus is decreased until it reaches the maximum decreasing percentage of 62.9% at weight ratio of 15% due to that the large amount of SiC may be weakened the material because of this aluminum alloy is suffered from melting in high temperature and then adding SiC that lead to form aluminum carbide, Al₄C₃ which is very brittle that leads to weakened the material. Ultimate stress is decreased when adding SiC to AL7075 because of the porosity in addition to form silicon carbide during the manufacturing process this brittle phase that weakened the metal with percentage of 73.4%. The maximum strain is decreased by 90.7% due to adding SiC because it is brittle material. Artificial Neural network is very good intelligent method to predict the properties to reduce the cost of manufacturing by select tested small number of weight ratio at specified range and then made them as input to ANN, finally it can be predicted the property of any weight ratio in this input range. For this research only is needed ten sample to make this prediction and make other samples with new results.

REFERENCES