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MATLAB Graphical User Interface (GUI) for Prediction of Optimum Asphalt Content That Satisfies Marshall Parameters of HRS-Base Hot Mixture Asphalt by Using Artificial Neural Networks

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Abstract: *Marshall test is the most common standard laboratory test method for hot mixture asphalt used in Indonesia. The Marshall test method aims to measure the stability of aggregate and asphalt mixtures against plastic deformation (flow), as well as to analyze the density and voids of the compacted mixture. The optimum asphalt content of the mixture is usually obtained from the mean value of the optimum asphalt content range at a desired density that satisfies all Marshall parameters (VMA, VIM, VFB, Marshall Stability, Flow, and Marshall Quotient). This study aims to predict the optimum asphalt content of HRS-Base hot mixture asphalt by using Artificial Neural Networks (ANN) and to design a graphical user interface that enables users to perform interactive work. The optimum asphalt content of mixture was determined by using ANN optimization method with MATLAB R2016a 9.0 software. Graphical User Interface (GUI) command to find the optimum asphalt content of HRS-Base hotmix asphalt was given based on the empirical formula that already obtained from previous ANN modeling. The selected learning algorithm was backpropagation with training function Levenberg-Marquardt (trainlm). The selected network architecture was found to give optimum results where the predicted value is same with the target value.*

Keywords: *Artificial neural networks, backpropagation, hot mixture asphalt, HRS-Base, Marshall, optimum asphalt content, MATLAB, GUI*

1. Introduction

The durability of a pavement layer is generally related to how long the road construction can withstand vertical load (vehicle load) and horizontal load (brake force) according to the age of service life. Hot Rolled Sheet (HRS) is one type of flexible pavement that is most often used in the roadway pavement in Indonesia. HRS is an upper layer of pavement that consists of a mixture of aggregate of gap graded, filler and harder asphalt cement with lower penetration, with a certain ratio, and which is mixed and compacted in a hot state. The HRS mixture developed based on the mixture concept of Hot Rolled Asphalt (HRA) originating from the UK, then modified in accordance with the conditions in Indonesia[1].

The quality and quantity of asphalt in the hot mixture greatly affects the performance of the pavement mixed in receiving the traffic load. Low asphalt content in a mixture will cause pavement layers durability and would affecting cracking. Likewise, excessive asphalt content will make the pavement layer have bleeding. Therefore, the required asphalt content in a pavement layer mixture is the optimum asphalt content, so it needs to be optimized in order to obtain the optimum asphalt content which provides the suitable stability in the pavement layer.

Artificial Neural Networks (ANN) is a massively and parallelly distributed data processing system, which has a natural tendency to store knowledge based on experience and to recall that stored knowledge (Haykin, 1999)[2]. The operation of ANN is inspired by the knowledge of biological neurons of the human brain that always try to stimulate the learning process in the human brain. The ANN program is one of optimization program contained in the MATLAB software program.

2. Literature Review

Marshall's stability is the ability of an asphalt mixture to resist load until a flow exists, expressed in kilograms, whereas flow is a state of deformation of an asphalt mixture that occurs as a result of loading, expressed in mm. Stability of the specimen is the maximum load resistance of the specimen at temperature of 60 °C (140 °F). Flow is a change of shape of an asphalt mixture that occurs on the specimen from zero loading up to the maximum loading given during the stability test[3].

Marshall mix design method is one of the common methods used in some countries to design hot mixture asphalt[4]. There are two main design parameters considered in this method, namely Marshall Stability and Flow. These parameters depend on several factors including aggregate gradation and cement asphalt content.

In the scope of hot mixture asphalt, research with ANN application have been increasingly in demand. A study modeling the value of Marshall Stability on asphalt concrete in various temperatures, time variations and physical properties was conducted[5]. The use of ANN can also be applied to modified hot mixture asphalt with Levenberg Marquardt Back Propagation (LMBP) algorithm training, transfer function of sigmoid Hyperbolic tangent and sigmoid log to predict Marshall test result of modified hot mixture asphalt with polypropylene fiber (PP)[6]. ANN modeling was carried out by using the Marshall standard physical properties of the specimens such as PP fiber type, PP fiber content, asphalt content, specimen's height, unit weight, void in aggregate minerals (VMA), asphalt void (VFA), and air void to predict Marshall's Stability, Flow, and Marshall Quotient.

Similar study was conducted by using ANN and least square support vector machines (LS-SVM) to predict Marshall parameters obtained from Marshall testing modified asphalt mixtures with Polyethylene (PE) waste from utilized milk packets[7]. The used of ANN in the study also carried out by modifying the asphalt mixture using Polyparaphenylene Terephtalamide (PTF) fiber[8]. The test specimens were prepared based on the gradation limit, the optimum binder content, and different PTF contents. Non-destructive testing was also carried out by using nuclear density gauges and light weight deflectometer (LWD). Non-destructive testing data such as force, pressure, pulse, deflection, elastic modulus, wet density, humidity, humidity, Marshall, and air content were determined as input variables, while Marshall stability as output variables[9].

3. Theoretical Basis

Hot Rolled Sheet (HRS) has been widely used as a surface layer on road pavement in Indonesia, due to its water-resistant properties. HRS-Base mixture is gap-graded which means there is an aggregate fraction that is not available (absent) or very small in number. HRS-Base gap-graded requires greater amount of fine aggregate than AC-Base. Since fine aggregates are usually relatively difficult to obtain, the cost required to create HRS-Base mixture is usually greater than AC-Base. In order to make HRS-Base mixture can meet the required pavement service life as planned, it requires a handling using a relatively resistant additive material to delay premature deterioration in the asphalt pavement layer.

3.1. Hot Mixture Asphalt Materials

Asphalt mixture is a mixed combination of aggregate and asphalt. In hot mixture asphalt, asphalt acts as a binder between aggregate particles, and the aggregate acts as a reinforcement. The mechanical properties of asphalt in the asphalt mixture are obtained from the friction and cohesion of the constituents. Aggregate friction is obtained from interlocking, and its strength depends on the gradation, surface texture, grain shape, and maximum aggregate size used. While the cohesion properties obtained from the properties of asphalt used.

Before carrying Marshall testing out, total percent of asphalt binder content (Pb) needs to be determined, which is the middle or ideal asphalt content. To obtain percent asphalt binder content, formula as in Equation (1) is used.

$$Pb = 0{,}035(\%CA) + 0{,}045(\%FA) + 0{,}18(\%FF) + K \quad (1)$$

where:

Pb = total percent of asphalt binder content, percent to the weight of the mixture (rounded to closest 0.5%)

CA = percent of coarse aggregate, retained on sieve No. 8

FA = percent of fine aggregate, passes sieve No. 8 and retained on sieve No. 200

FF = percent of aggregate at least 75% passes No. 200

K = a constanta, 0.5 to 1.0 for AC and 2.0 - 3.0 for HRS

3.2. Determination of Optimum Asphalt Content

To get the optimum asphalt content (OAC or Pbo), 15 units of specimen were made, each 3 sample units with 5 variations of asphalt content. If the total percent asphalt content (Pb) obtained is a%, then the specimens made for laboratory Marshall testing have asphalt contents (a–1)%, (a–0,5)%, a%, (a + 0,5)% and (a + 1)%.

4. Methodology Research

Sample data was taken from Marshall's testing laboratory data carried out in the Asphalt and Concrete Laboratory of Materials Quality Testing Center of Public Works and Spatial Planning of Central Kalimantan Province. Sample data consists of 315 Marshall test datum of HRS-Base hot mixture asphalt using aggregate from various quarry (both local and outside of Central Kalimantan).

Data obtained from laboratory testing were then grouped into input data and output data, and optimization process was carried out by using Artificial Neural Network (ANN) optimization method with MATLAB R2016a 9.0 software. Backpropagation method with Levenberg-Marquardt (trainlm) training function was chosen because it is the fastest algorithm for feedforward neural network training with large data (up to hundreds of weight), although this learning function takes up considerable storage space. There were 12 input variables, including aggregate properties, asphalt content and asphalt absorption, volumetric properties (VMA, VIM, and VFB), Marshall parameters (Stability, Flow, MQ) and effective asphalt content. The optimum asphalt content (Pbo) was used as the output variable. The hyperbolic tangent sigmoid activation function (tansig) was selected for transfer from input to hidden layer, and a linear activation function (purelin) was selected for transfer from hidden layer to output.

Normalization of data was carried out to put input data and target output data in a certain range. In ANN, the input data and the output data are normalized by using the mean and standard deviation values in order that the range between the input data and the output does not vary much so that it will produce a prediction value close to the target output value.

In MATLAB, normalization of data with the help of the mean and standard deviation will bring data into the normal form (mean = 0, standard deviation = 1). Commands for normalization of data in MATLAB is and 'mapstd' or 'prestd' ((normalization of inputs and targets with mean = 0, standard deviation = 1). The normalized data will be returned to its original form by using Equation (2):

$$Y = meanT_k + \left(netY_k \times S.devT_k\right) \quad (2)$$

5. Results and Analysis

The result of normalization of data with the aid of mean and standard deviation or known as 'mapstd' (normalization of input and target with mean = 0, standard deviation = 1) for input and output variables can be seen in Table 1.

After the training, the final weights from the input layer to the hidden layer (*Vji*), and the weights from the hidden layer to the output layer (W_{kj}) can be obtained.

The mathematical expression for the output of the hidden layer (Z_j) is calculated by Equation (3).

$$net\ Z_j = V_{j0} + \sum_{j=1}^{2} X_i V_{ji} \quad (3)$$

The mathematical expression for the output layer output (Y_k) is calculated by the Equation (4).

$$net\ Y_k = W_{k0} + \sum_{j=1}^{k} X_i W_{kj} = netY \quad (4)$$

The mathematical calculation to find Y_k as follows:

$$netY_k = 0.0000023966 - 0.9999Z_j \quad (5)$$

The value of the predicted output of optimum asphalt content of hot mixture asphalt can be written as follows:

$$Y = 6.225 + \left(0{,}025 \times netY_k\right) \quad (6)$$

TABLE I: Mean Value and Standard Deviation of Input Variable Data

	X**1**	***X*****2**	***X*****3**	***X*****4**	***X*****5**	***X*****6**	***X*****7**	***X*****8**
Mean	-2.3724	-0.0818	-0.6933	1.7724	2.2951	-1.2955	-0.5860	1.3723
St.dev	-10.0095	-2.1007	0.5238	5.3739	13.4502	0.6935	-4.8327	5.5056
	X_9	X_{10}	X_{11}	X_{12}	T_k			
Mean	0.3836	-0.4099	0.0870	-0.3975	6.225			
St.dev	0.4986	0.6157	0.4938	-1.1136	0.025			

where:

X_1 = asphalt absorption, percent by total aggregate dry weight basis, Pba (%)
X_2 = asphalt, percent by total weight of mixture, Pb (%)
X_3 = specimen volume (cm³)
X_4 = bulk specific gravity of compacted mixture, Gmb
X_5 = theoretical maximum specific gravity of mixture, Gmm theoretical
X_6 = void in mineral of aggregate, VMA (%)
X_7 = void in mixture, VIM or Va (%)
X_8 = void filled with bitumen, VFB or void filled with asphalt, Vfa (%)
X_9 = Marshall Stability (kg)
X_{10} = Flow (mm)
X_{11} = Marshall Quotient (kg/mm)
X_{12} = effective asphalt content, Pbe (%)
T_k = target optimum asphalt content, Pbo (%)

The network architecture that gave optimum results in predicting the optimum asphalt content of hot mixture asphalt is shown in Figure 1. A summary of the results of backpropagation algorithm processing with Levenberg-Marquardt training method can be seen in Figure 2, where obtained correlation coefficient R equals to 1 (Figure 3).

6. Discussion

The quality of the mixed material (aggregate and asphalt) used and the characteristics of the HRS-Base hot mixture asphalt must comply with the requirements of the General Specification of Hot Mixtures Asphalt, Section 6.3 (Directorate General of Highways 2010). Designing of the HRS-Base hot mixture asphalt is not fixely decided with a certain target value, as long as it meets the 3-6% VIM Marshall requirements range, VIM at minimum refusal density of 2%, and meets the volumetric characteristic values (VMA, VFB), and other

Marshall parameters. If the characteristics of the hot mixture asphalt do not meet the requirements, the aggregate gradation and the proportion of the combined materials should be changed. Obviously this is done along with the cost of material needs in the site, so it needs to be optimized.

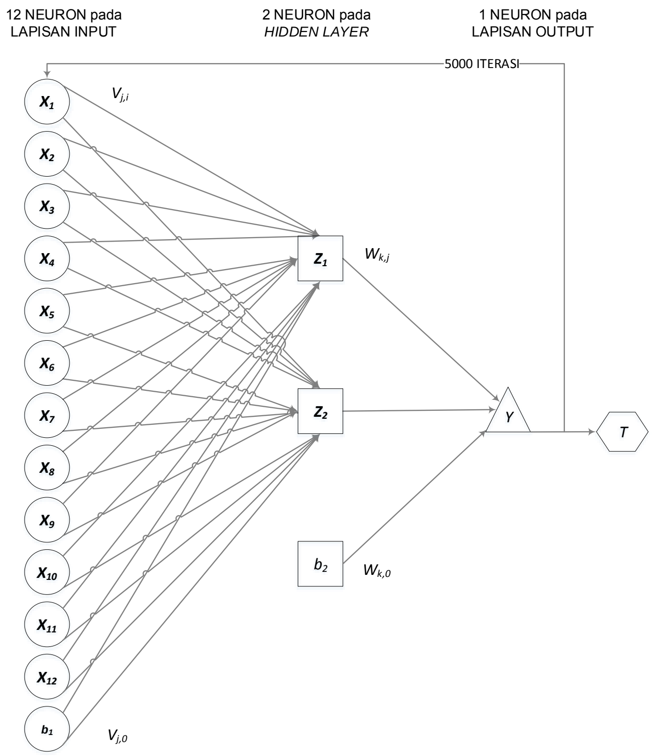

Fig. 1: network architecture that gave optimum results in predicting the optimum asphalt content of hot mixture asphalt

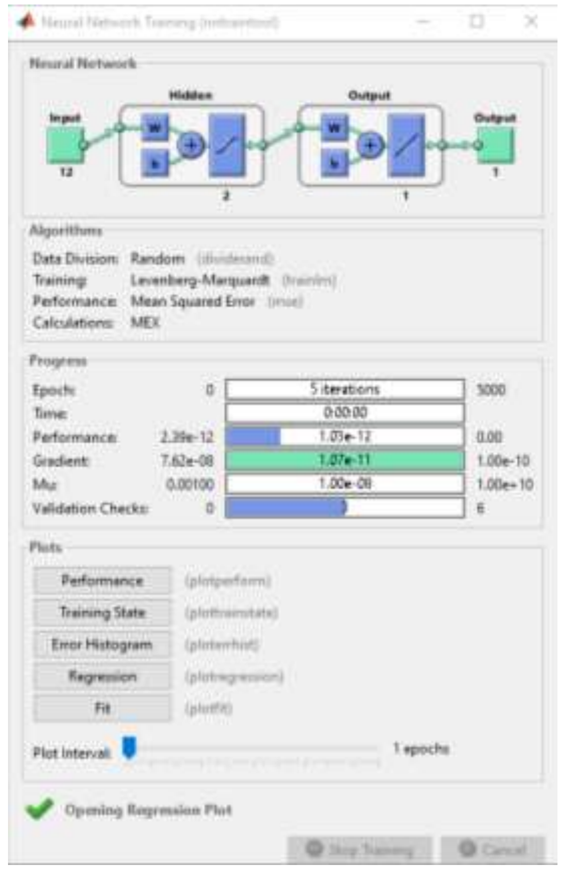

Fig. 2: summary of the results of backpropagation algorithm processing with Levenberg-Marquardt training method

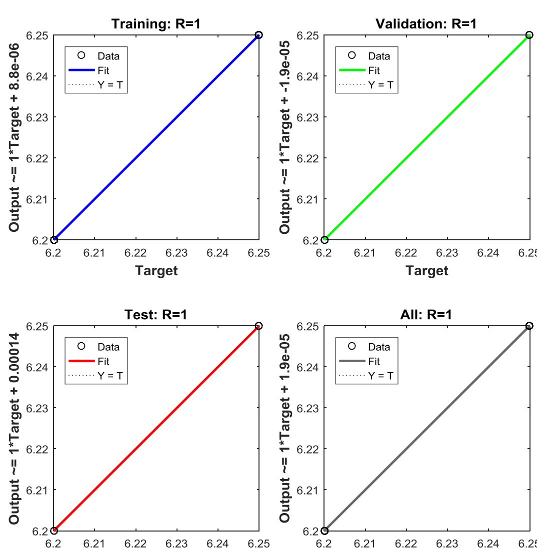

Fig. 3: Regression graph of training data, validation and testing

Stopping criteria set if on 5000 epoch iteration, failure occurred as much as 6 times or error reaches 1×10^{-10}. Of the 5000 epoch maximum set, the iteration stopped at the 6th iteration within 0.134 seconds.

The predicted results given are very satisfactory. Figure 4 shows the ANN can predict exactly the optimum asphalt content of HRS-Base hot mixture asphalt considering the input variable is complete enough (12 variables) so that these whole variables affect the network performance during the training process.so that the learning process conducted by artificial neural networks is effective in receiving and processing the information provided, so the results can be surely tested and validated.

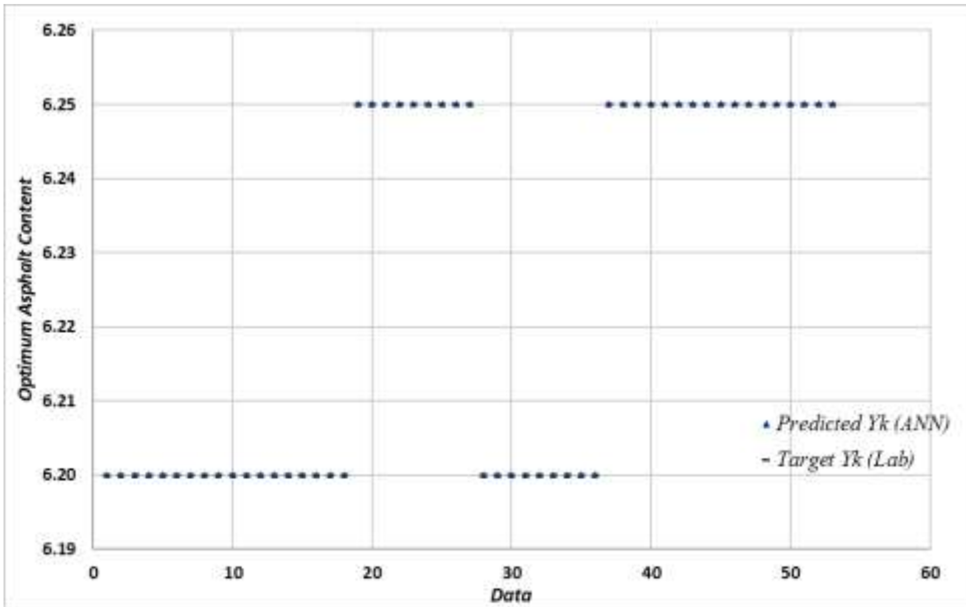

Fig. 4: Comparison of optimum bitumen content (Pbo) between laboratory test result and ANN prediction result

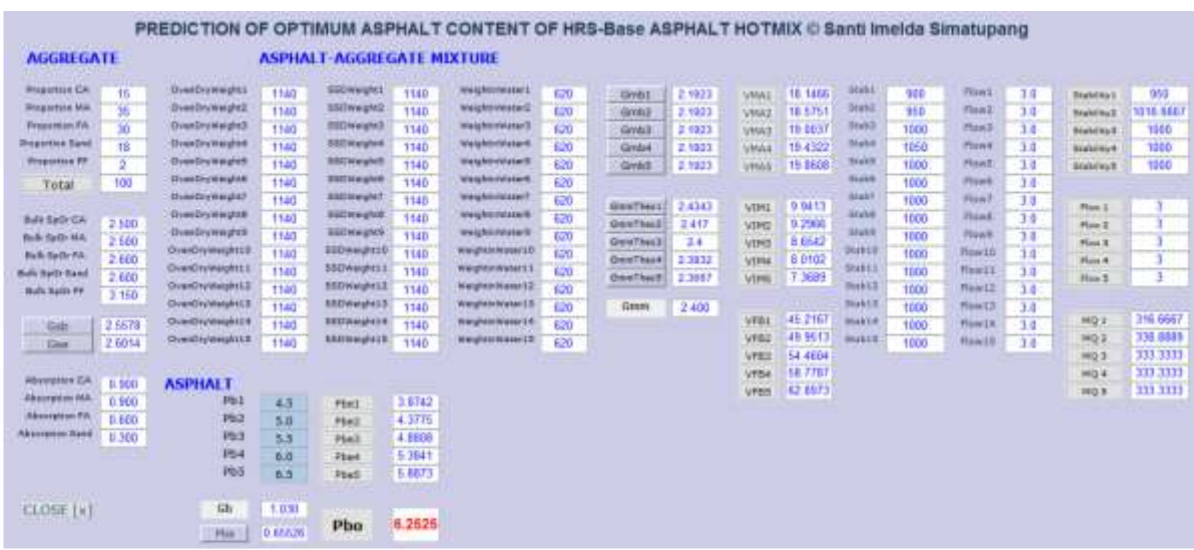

Fig. 5: GUI window area of predicting optimum asphalt content of HRS-Base asphalt hotmix

The Graphical User Interface (GUI) is the interface of an operating system in the form of a graphical display using icons, menus and mouse that enable users to perform interactive work. The main elements of the GUI can be summarized in the WIMP concept (window, icon, menu, and pointing device). MATLAB R2016a 9.0 also features the GUIDE Matlab (GUI Matlab) which allows the user to create an interface display and execute calculation commands based on given mathematical formulas.

In this study, a number of callback commands were given to a window area containing all the labels and values of each associated input variables and output variables in the prediction of optimum asphalt content of HRS-Base asphalt hotmix. String in the form of text converted into numeric numbers by using str2double script.

```
Stability = str2double(get(editStability,'String'));
Flow = str2double(get(editFlow,'String'));
MQ = str2double(get(editMQ,'String'));
```

To obtain the optimum asphalt content at the end of the calculation program, use the script:

```
set(editPbo,'String',num2str(Pbo));
get(editPbo,'Value');
```

With this GUI, prediction of optimum asphalt content of HRS-Base asphalt hotmix by using ANN optimization method is considered highly effective and efficient. It is effective because the obtained empirical equation model is able to give the result of output prediction value equal to the target output value of optimum asphalt content of HRS-Base asphalt hotmix. It is also efficient because the backpropagation algorithm with the Levenberg-Marquardt training method is able to predict the optimum asphalt content of HRS-Base asphalt hotmix in just a very short time, only 2-3 seconds. This method can save time to predict the optimum asphalt content of HRS-Base asphalt hotmix which usually takes several working days in the laboratory.

7. Conclusion

The selection of good network architecture, proper training algorithms and learning functions, as well as an appropriate activation function can make the ANN method provide good predictive results on the optimum asphalt content of the HRS-Base hot mixture asphalt with low mean square of error. With learning function Levenberg-Marquardt (trainlm) as well as tansig and purelin activation function, the obtained empirical equation model is able to give the result of output prediction value equal to the target output value of optimum asphalt content of HRS-Base hot mixture asphalt.

8. References

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