Jurnal Kejuruteraan 34(4) 2022: 719-727
https://doi.org/10.17576/jkukm-2022-34(4)-19

Short-Term Aging Performance and Simulation of Modified Binders Using Adaptive Neuro-Fuzzy Inference System

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Received 4 October 2021, Received in revised form 15 November 2021
Accepted 15 December 2021, Available online 30 July 2022

ABSTRACT

The influence of polymer/nanocomposites (Acrylete-Styrene-Acrylonitrile (ASA)/ Nanosilica (Si)) asphalt binder aging and performance characteristics was investigated. ASA was used at 5% while nanosilcia was blended in 3, 5 and 7% concentrations by the weight of asphalt. Temperature sensitivity, aging resistance and viscoelastic properties of the asphalt binders were evaluated by conducting physical and dynamic shear rheometer (DSR) testing procedures. The tests were performed under unaged and short-term aged conditions by simulating the aging of asphalt in a Rolling thin film oven (RTFO). Additionally, the Adaptive Neuro-Fuzzy Inference System (ANFIS) modelling technique was adopted to predict the short-term aged behaviour of asphalt binders by using the viscoelastic properties of asphalt in an unaged state. The experimental outcomes from the DSR tests showed that the complex modulus (G) was increased and the phase angle (δ) was reduced for the modified binders, indicating an improvement in the viscoelastic properties compared to the control asphalt binder. Furthermore, the considerably small difference in the G* and δ between the binders in unaged and RTFO aged states indicated that the modifiers had a positive effect in terms of improving the aging resistance of the asphalt binders. Moreover, the ANFIS model prediction capacity, which was assessed by the Coefficient of Determination (R2) and Mean Squared Error (MSE) and Mean Average Percentage Error (MAPE) was shown to be capable of accurately predicting the short term-aging behaviour of asphalt binders from the asphalt binder viscoelastic properties in an unaged state with an R2 value of 0.977, MSE of 0.00032 and MAPE of 0.286.*

Keywords: Polymer nanocomposite; acrylete-styrene-acrylonitrile; nanosilica; dynamic shear rheometer; short-term aging; artificial intelligence

INTRODUCTION

Asphalt binders possess valuable engineering properties that can resist dynamic vehicular loading and extreme climatic conditions due to their viscoelastic nature, and hence, are commonly used in flexible pavement design (Sotiriadis 2016). However, according to previous reports of field observations and the research conducted in the literature, it has been acknowledged that neat asphalt binder used for paving applications may not always ensure sufficient stability, durability and desired performance characteristics. In efforts to enhance the performance of asphalt binders and mixtures, numerous investigations have been concentrated on asphalt modification with polymers, nanomaterials and polymer nanocomposites due to their versatile properties, which are needed to design superior performing asphalt pavements (Behnood & Gharehveran 2019; Yang & Tighe 2013). However, it should be noted that there is not a superior modifier in terms of improving the durability (aging resistance and moisture susceptibility) and all performance characteristics (high temperature and low temperature characteristics) of asphalt. Often, enhancements made to a specific characteristic of asphalt are at the expense of another one. On this basis, polymer nanocomposite modifiers have recently become popular among researchers since they combine the rewarding properties of certain additives and/or minimize the drawbacks of additives in the same asphalt blend (Polacco et al. 2015).

Acrylete-Styrene-Acrylonitrile (ASA) and nanosilica, which were the two additives used in the current study, have been previously utilized as sole additives to modify base asphalt and they are known to be capable of enhancing the high and low temperature performance characteristics as well as improving the durability of neat asphalt (Ali et al. 2015; Bhat & Mir, 2019). Along with the positive effects of these materials on the performance of asphalt binders, it has been reported in numerous studies that they have been limited to address multiple concerns at the same time when used as sole additives. Albrka et al. (2016) studied the performance properties of ASA modified binders and mixtures and found that adding 5% ASA by the weight of asphalt improved the rutting resistance up to 36%. The findings from a study conducted by (Mubaraki, 2020) also showed that significant enhancements in rutting and fatigue resistance parameters were achieved by adding 4% ASA in the asphalt matrix, indicating that ASA can improve both high and low temperature performance characteristics of asphalt binders. Numerous types of nanosilica have also been investigated extensively in the literature. In almost all studies, favourable effects of nanosilica on the asphalt binders were reported regarding the high temperature performance and resistance to oxidative aging (Bhat & Mir, 2019). On the other hand, although the nanosilica modification of asphalt binders was noted to have a positive effect on the intermediate and low temperature performance characteristics in a number of studies, a significant amount of researchers have reported that the influence of nanosilica on asphalt binders was insignificant or adverse (Crucho et al. 2018; Yao et al. 2013; You et al. 2011). The aforementioned researchers have mainly focused on the laboratory investigations for asphalt binders in fresh conditions; however, evaluating the performance of asphalt binders under aged conditions is equally significant to make reliable engineering evaluations regarding the performance of asphalt binders in the field.

Aging of asphalt cement is an irreversible process that reduces its durability, causing early deterioration of asphalt pavement, and hence, increasing the maintenance cost to restore and maintain its service life (Wang et al. 2020). Therefore, laboratory simulations of aging conditions are crucial to understand the as-laid properties of asphalt binders since there could be significant differences in the properties of aged and unaged asphalt cement. It should be noted that, until now, there have been no tests yet invented to directly measure the aging of asphalt cement. However, the aging effects can be evaluated by conducting physical, morphological and rheological tests in unaged and short-term conditions by using a rolling thin film oven (RTFO) under laboratory conditions in order to observe the changes in properties of asphalt cement (Wang et al. 2020).

However, the RTFO conditioning of samples and repeating the experimental procedures for RTFO conditioned samples that were conducted for the unaged conditioned asphalt binders is not a practical and a cost-effective method. Therefore, a number of researchers have presented studies regarding the modelling of asphalt binder's short-term aged properties by using statistical and computational techniques. (Zhang et al. 2019) developed a short- term aging model for asphalt binders by using viscosity and rheological activation energy. (Hamzah et al. 2015) evaluated the effects of short-term aging on the viscoelastic characteristics of asphalt binders at intermediate temperatures using the response surface method. (Lin et al. 2016) conducted investigations on the physical and chemical properties of asphalt binders by using component analysis and functional group analysis to predict long-term aging of asphalt binders in the field. In this study, the author developed an Artificial Intelligence based model by adopting Adaptive Neuro-Fuzzy Inference System (ANFIS) to model the short-term aged viscoelastic properties of asphalt binders by using the critical viscoelastic parameters, G* and δ, of the asphalt in a fresh state. The primary objective of the current research is to investigate the performance characteristics of asphalt binders modified with ASA/Si and to develop an ANFIS model to predict the behaviour of Polymer Nanocomposite (PNC) modified asphalt binders under short-term aging conditions.

EXPERIMENTAL METHODS

MATERIALS AND SAMPLE PREPARATION

The virgin asphalt that was used as the base binder (also referred to as the control sample) was 80/100 penetration grade and it was obtained from Petronas Petroleum/ Malaysia. The type of polymer used in the modification process was an elastomeric polymer named Acrylate-Styrene-Acrylonitrile (ASA) and it was used at 5% concentration by the weight of base binder since research conducted previously in the literature reported this finding as the optimum polymer content to modify virgin asphalt (Ali et al. 2015; Mubaraki, 2019). Nano silica particles at 3, 5 and 7% by the weight of ASA 5% modified asphalt binder were further added to the asphalt blend gradually to form polymer/nanocomposite modified asphalt binders (PNCMAB). The specific gravity of the ASA used in the current study was 1.04-1.07 and the size was 2mm. The physical and chemical properties of the nanosilica particles were also given in Table 1.

A high shear mixer was used to blend the polymer nanocomposite (PNC) modified asphalt binders at 5000 rotations per minute (rpm) at 165°C ± 3°C for 60 minutes. The shear rate, duration and temperature at which the blending process was performed were selected according to softening point analysis. The samples were taken every 20 minutes during the blending process and the ring and ball softening point test was applied. Once the softening point test results were stabilised, it was assumed that the particles were dispersed evenly in the blend and the blending process was completed.

TABLE 1. Physical and chemical properties of the Nano silica particles

Properties	Nano-Silica
Formula	SiO_2
Molecular Weight	6.3-6.49
Colour and Odour	White
Form	Nano powder
Purity	0.9999
Average nanoparticle size (nm)	30- 50
Bulk Density (g/cm^3)	N/A
Melting Point (°C)	1600
Solubility in Water	Insoluble

CONVENTIONAL PHYSICAL TESTS

The penetration and ring and ball softening point tests were conducted as specified in the ASTM D5-05 and ASTM D36-06 testing procedures, respectively. The test results were indicative for the consistency, hardness and elasticity of the control and modified samples. Based on the test results, temperature susceptibility of the asphalt binders, referred to as the Penetration Index (PI), was computed by using Equation 1.

$$\mathrm{PI} = \frac{1952 - 500\log(\mathrm{Pen25}) - 20\mathrm{S.P}}{50\log(\mathrm{Pen25}) - \mathrm{S.P} - 120} \quad (1)$$

STORAGE STABILITY TEST

The storage stability test was utilized to assess the integrity and homogeneity of AC. The test procedure was followed by emptying prepared samples into the aluminium foil tubes which had a diameter of 3cm and a height of 16cm. Top of the aluminium tubes were closed and rested in an oven at ±163 °C for 2 days in vertical position. After removing the tubes from the oven, the tubes were cooled down at room temperature and were split into 3 equal sections which the upper and lower third sections were taken for the softening point investigation.

ROTATIONAL VISCOSITY

ASTM D4402 – 06 was utilized to measure the rotational viscosity (RV) of the asphalt binders. The RV test was used to determine the range of temperatures which the asphalt is anticipated to undergo during the manufacturing and construction processes. Although the test is generally conducted at 135°C and 165°C for unmodified asphalt binders, in this study, the tests were conducted at various temperatures with 15°C increments from 120°C to 180°C in order to observe the variations in viscosity at elevated temperatures and to be able to plot a smooth viscosity-temperature curve. In addition, the RV tests were conducted on unaged and short-term aged samples to assess the aging index for the control and modified asphalt binders by using Equation 2.

$$\text{RV Aging index} = \frac{\mathrm{S_{RTFO}} - \mathrm{S_{unaged}}}{\mathrm{S_{RTFO}}} \quad (2)$$

SHORT-TERM AGING OF THE ASPHALT BINDERS

Short-term aging is referred to the condition when bituminous binders undergo irreversible property changes due to the effects of heat and air during the mixing and paving operations (Lolly et al. 2017). A rolling thin film oven (RTFO) was used to simulate the short-term ageing behaviour of the asphalt binders. The RTFO procedures were conducted by following the standards in ASTM D 2872 – 04.

FREQUENCY SWEEP TEST

A dynamic shear rheometer (DSR) was used to conduct the frequency sweep tests. The significance of the test is that it reveals the fundamental rheological properties of the asphalt binders. The tests were performed under strain-controlled conditions within a linear viscoelastic region by applying stress in sinusoidal wave form, which created a shearing action with oscillatory movements of fixed (bottom) and oscillating (top) plates of the DSR. The test was software controlled and run between 46°C - 82°C with a 25mm spindle diameter and 1mm sample thickness. A range of frequencies between 0.159 Hz and 15.92 Hz were used to test the asphalt binder samples. The tests were conducted on unaged and RTFO aged samples to investigate the influence of aging on the rheological properties of the asphalt binders.

ANFIS MODELLING

ANFIS is an artificial intelligence based technique that is able to solve complex non-linear problems that require human-thinking like expertise (Cüneyt et al. 2006). ANFIS adopts a hybrid learning algorithm that combines the Artificial Neural Network's (ANN) data driven and fuzzy inference system's (FIS) knowledge-based abilities to maximise the accuracy of the prediction model. The learning phase in ANFIS was in two phases, which were the forward and backward passes. The former was performed until layer 4 (illustrated in Figure 1), where the premise parameters were trained using the least squares method, and the latter involved the adjustment of consequent parameters by using the Gradient Descent (GD) method (Orouskhani et al. 2013). ANFIS Model development was performed by using a Sugeno type fuzzy inference algorithm. The first order Sugeno type modelling involved a set of fuzzy if then rules as expressed in Equation 3 and Equation 4.

Rule (1): if μ(x) is A1 and μ(y) is B1;
then f1 = p1x + q1y + r1 (3)

Rule (2): if μ(x) is A2 and μ(y) is B2;
then f2 = p2x + q2y + r2 (4)

For given inputs x and y, the membership functions are indicated as A_1, B_1, A_2, B_2 and the outlet functions' parameters are p_1, q_1, r_1, p_2, q_2, r_2.

The structural formula and arrangement of the 5 layer ANFIS is illustrated in Figure 1 and explained by Equations 5, 6,7, 8 and 9. (Nourani et al. 2018).

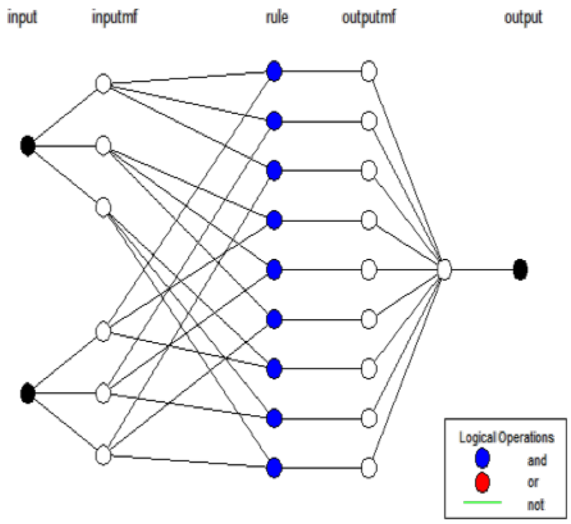

FIGURE 1. The general structure of ANFIS

Layer 1: The layer was responsible for fuzzification of the premise parameters,

$$Q_i^1 = \mu_{Ai}(x) \text{ for } i = 1,2 \text{ or } Q_i^1 = \mu_{Bi}(x) \text{ for } i = 3,4 \quad (5)$$

$Q^1{}_i$ stands for the membership grade for x and y inputs. The selected membership function was a Gaussian membership function since it reduces the error in the prediction process.

Layer 2: The layer calculated the firing strength of the i^{th} rule using T-norm fuzzy operations including the AND and OR operators.

$$Q^2{}_i = w_i = \mu_{Ai}(x).\ \mu_{Bi}(y) \text{ for } i = 1,2 \quad (6)$$

Layer 3: This layer, also denoted as the normalisation layer, calculated the ratio of the i^{th} rule to all rules.

$$Q_i^3 = \overline{w}_i = \frac{w_i}{w_1 + w_2} \qquad i=1, 2 \quad (7)$$

Layer 4: In this layer, each node i performed the subsequence rules as an adaptive node.

$$Q_i^4 = \overline{w}_i(p_i x + q_i y + r_i) = \overline{w}_i f_i \quad (8)$$

p_1, q_1, r_1 were the irregular parameters referred to as the consequent parameters.

Layer 5: This layer was responsible for defuzzification. Summation of all incoming signals from previous node and results were generated in a crisp value.

$$Q_i^5 = \overline{w_i}(p_i x + q_i y + r_i) = \sum_i \overline{w_i} f_i = \frac{\sum_i w_i f_i}{\sum_i w_i} \quad (9)$$

RESULTS AND DISCUSSION

PHYSICAL PROPERTIES

Penetration and softening point tests were conducted as a measure of consistency of the control and ASA/Si modified asphalt binders. As can be observed in Figure 2, the penetration values for the modified binders decreased drastically for the modified binders, while the softening point values increased, indicating that the modification process applied a stiffening effect to the base binder. Additionally, by using the outcomes from the penetration and softening point tests, the Penetration Index, which is associated with the temperature sensitivity of the asphalt binders, was computed. A PI ranges from -3 to +7 where a higher index indicates enhanced temperature susceptibility and vice versa. As deducted from Table 2, the PI values increased as the modifier content in the blend was increased, indicating improved temperature susceptibility for the modified binders.

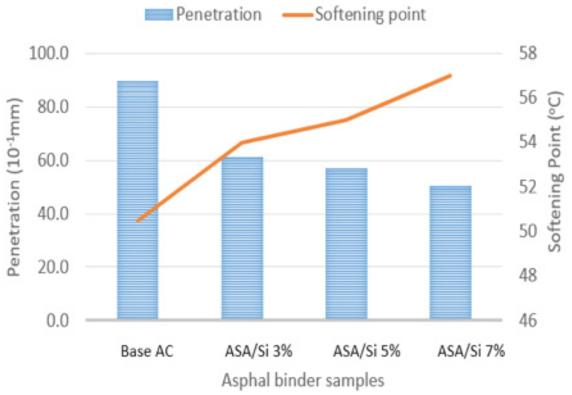

FIGURE 2. Penetration and Softening Point of Control and ASA/Si modified Binders

TABLE 2. Penetration Index

PI	Base AC	ASA/Si 3%	ASA/Si 5%	ASA/Si 7%
	0.469	0.458	0.479	0.571

STORAGE STABILITY

Since asphalt cement is a composite material, because of the different chemical composition, solubility and density of the polymer, nanomaterials and virgin asphalt and its constituents, the lighter components rise to the top portion. Eventually, instability of modified binders leads to phase separation and unreliable performance of asphalt pavements (Yin & Moraes, 2018). The disparity between the softening point of the upper and lower sections of the asphalt samples extracted from the aluminium foil tubes was measured to analyse the storage stability. The results of the storage stability test was illustrated in Figure 3.

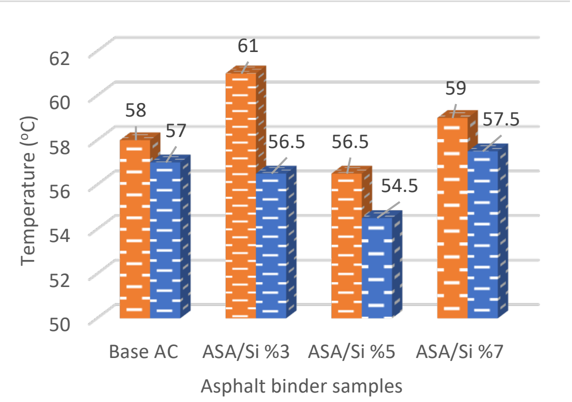

FIGURE 3. Storage Stability of Control and ASA/Si modified Binders

According to the literature, although a difference of up to 4°C-4.5°C, between the top to bottom parts of the conditioned samples was considered within acceptable limits, the common perception among the researchers is that in order to classify AC as storage stable, the difference in softening points should not exceed 2.5°C (Bala et al. 2017). From Figure 3, it was observed that, the storage stabilities for the ASA/Si samples were improved as the modifier to asphalt concentration was increased. It was observed that, the softening point of the sample extracted from the top part of the conditioned sample was not higher than 2.5°C for 5% and 7% ASA/Si modified AC, while at 3% ASA/Si concentration, the difference in softening points was 4.5°C.

ROTATIONAL VISCOSITY

The Rotational Viscosity (RV) test results are critical for the asphalt mixture design, regarding the determination of the mixing and compaction temperatures. Higher viscosities yield a less workable HMA due to increased stiffness, which results in higher energy consumption in the production plant because of increased mixing temperatures and it also requires more effort to compact the asphalt mix in the construction field. The RV testing procedures were applied under fresh and short-term aging conditions for the base and Polymer Nanocomposite (PNC) modified asphalt binders at a range of temperatures from 120°C to 180°C by 15°C increments and the results are illustrated in Figure 4. As deducted from Figure 4, the viscosities for the modified binders increased compared to the base asphalt binders. This result was convenient since a number of researchers have previously reported similar findings that modified binders commonly possess more viscous properties than neat asphalt (Aflaki & Tabatabaee 2009; Abdelaziz & Rehan 2010).

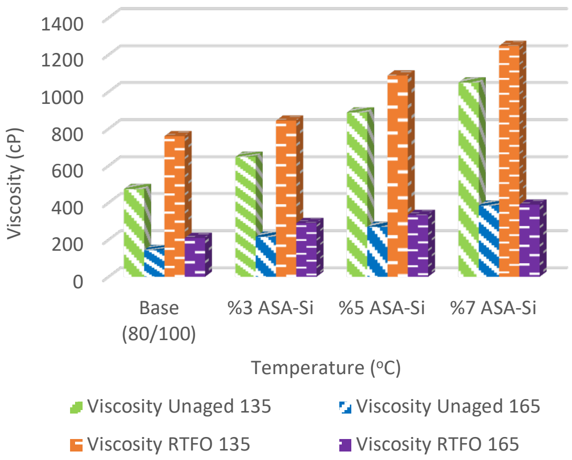

FIGURE 4. Rotational Viscosity of Control and PNC modified asphalt binders in unaged and RTFO aged conditions

Moreover, conducting the tests under fresh and short-term aging conditions enabled the computation of the Viscosity Aging Index (VAI). The aging of asphalt binders during the production stage and over the service course is a major durability concern because it causes hardening of the AC, which alters its physical properties and rheological behaviour. As a result of the age hardening, the asphalt becomes stiffer and more brittle due to increased viscosity, which makes it vulnerable to cracking. The aging occurs due to oxygenation, volatilization and polymerisation or it may occur due to the thixotropic nature of the asphalt material. The aging that occurs during the production and construction stage is referred to as short-term aging. A lower VAI is favourable because it indicates that the asphalt binder possesses better aging resistance since the difference in viscosities between unaged and RTFO aged binders is less remarkable. VAI for the control and PNC modified asphalt binders were computed at 135°C and 165°C and the mean VAI values are presented in Figure 5. It can be observed from Figure 5 that the VAI for the base binder was triple the amount of the VAI observed with the ASA/Si 7% modified asphalt binders, which indicated that after the modification process, the resistance to aging increased up to three times compared to the base binder. In a study conducted by (Abutalib et al. 2015), which investigated the effects of the application of silica fume to reduce asphalt oxidative aging, an increase of up to 8% in the aging index was achieved, which indicated that the addition of ASA/Si modifier in the blend was significantly effective in improving the aging resistance of asphalt binders.

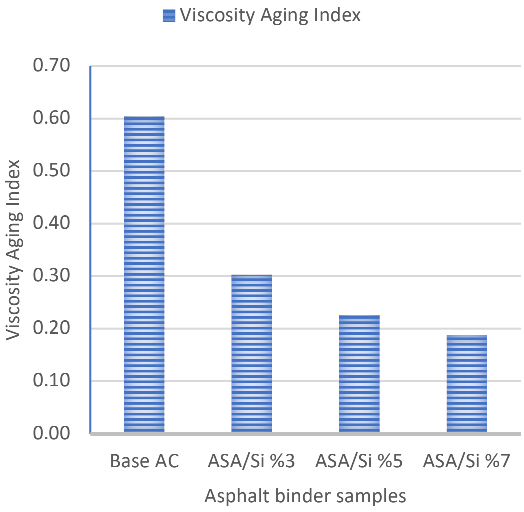

FIGURE 5. The RV Aging Index for control and PNC modified asphalt binders

VISCOELASTIC PROPERTIES

The frequency sweep test was performed by using a DSR machine. The maximum shear strain was set to 12.5% and the frequency sweep testing procedures were applied under various temperatures (46, 52^{+6} up to 82^{o}C) at a range of frequencies from 0.159 Hz to 15.92 Hz to evaluate the viscoelastic properties of the samples. The most significant outcomes from the frequency sweep test were the complex modulus (G*) and the phase angle (δ). These output parameters enabled the graphical representation of the performance characteristics of the base and PNC modified asphalt binders in isothermal plots and rheological master curves. The master curves plotted in Figure 6 display the time dependency of G* and δ at intermediate and high temperatures and at different frequencies, while isothermal plots shown in Figure 7 and Figure 8 illustrate the viscoelastic features of the control and PNC modified asphalt binders at 0.159 Hz and 15.92 Hz.

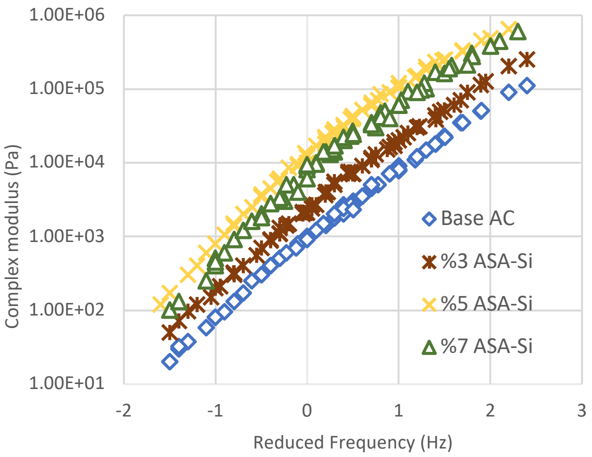

FIGURE 6. Master Curves for control and PNC modified asphalt binders

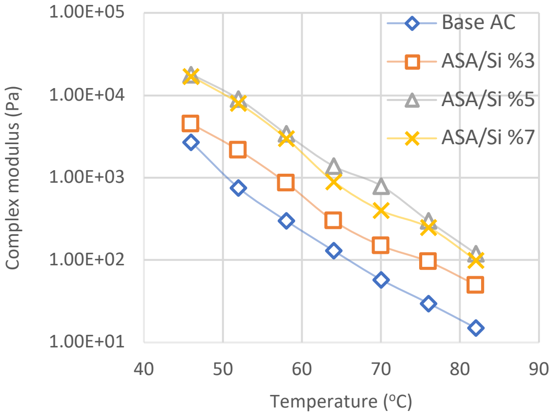

FIGURE 7. Isothermal plots at 0.152 Hz

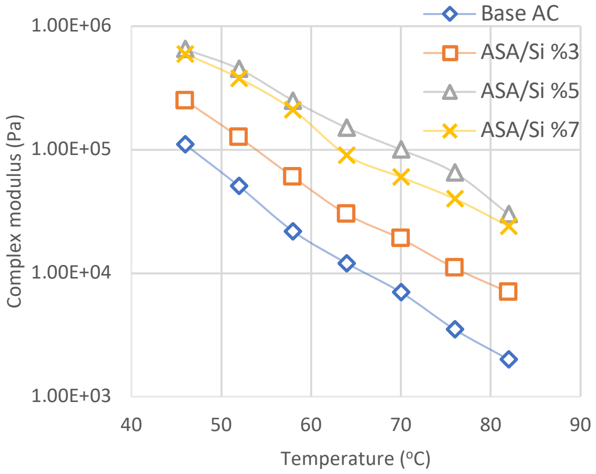

FIGURE 8. Isothermal plots at 15.92 Hz

According to the frequency sweep test results, an increase in the G* was observed up to 5% addition of ASA/Si modifier in the asphalt blend. Beyond this concentration, the asphalt binder exhibited different behaviour. The main reason for the change in behaviour is assumed to be the incompatibility issue between the modifier materials and the asphalt. A similar result was reported in a study conducted by (Ali et al. 2015), in which ASA was utilized as the sole modifier to base asphalt. The phase separation was considered to be the main factor for incompatibility, which resulted in a reduction in the enhancement of rheological properties beyond a certain dosage of ASA polymer. Additionally in another study conducted by (Alhamali et al. 2016), Nano silica was utilized in SBS modified Asphalt binder and similar results were observed, indicating that the utilization of nano silica in polymer modified asphalt can enhance the rheological properties of asphalt binders, but it is not very efficient in solving the incompatibility problem.

Furthermore, the outcomes from the DSR tests were used in the computation of the rutting resistance parameter. The rutting resistance is the ability of asphalt binder to resist permanent deformation at high temperatures. Rutting resistance is defined as the ratio of the viscous and the elastic portions of an asphalt binder and it is denoted by the formula G*/sin δ. According to Superpave standards, at a loading rate of 1.592 Hz, a minimum of 1 kPa and 2.2 kPa are allowable requirements for unaged and RTFO aged binders, respectively. The rutting resistance parameter was evaluated at a range of temperatures from 46ºC- 82ºC at a loading rate of 1.592 Hz by using the G* and δ outcomes from the frequency sweep test results. As illustrated in Figure 9, G*/sinδ was the lowest for base AC. Binders containing ASA/Si composites up to 5% by the weight of bitumen demonstrated the highest G*/sinδ value, while the addition of ASA/Si composites above 5% concentration led to reduced G*/sinδ. The compatibility problem between the polymer nanocomposite and the asphalt was considered to be the factor leading to the reduction in enhancement of the rutting resistance parameter at 7% ASA/Si concentration. As illustrated in Figure 9, the rutting parameter at 64 ºC was found to be as high as 1.00 E+045 for ASA/Si 5%. In a similar study conducted by (Mubaraki et al. 2016), Nano aluminium oxide was utilized to modify ASA modified asphalt binder and a considerable improvement in the rutting resistance parameter was reported.

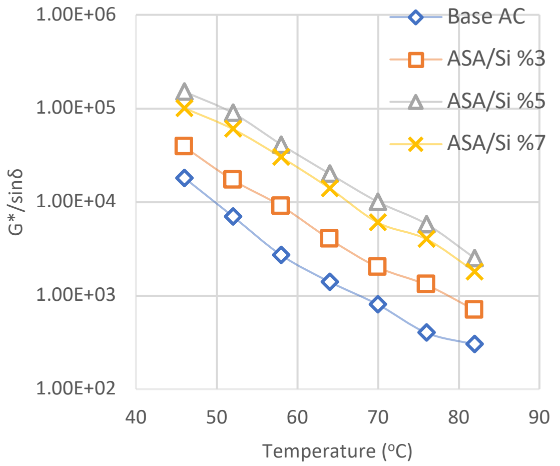

FIGURE 9. The rutting resistance parameter for the control and PNC modified binders

ANFIS MODEL RESULTS

ANFIS, which belongs to a branch of adaptable Feed Forward Multi-Layer Perceptron (FFMLP), consisted of two input parameters (unaged G* and δ) and an output variable (RTFO aged G*) which were connected by a Sugeno-type if then rules-based fuzzy reasoning mechanism. Conceptually, each G* data point in RTFO condition was predicted by using the respective G* and δ data points in unaged condition. A total of 759 data points were used to develop the ANFIS model. The datasets were divided into training and testing parts. 70% of the data points were used for testing, while the remaining data points were used for testing the efficiency of the model's prediction capacity. Statistical indicator metrics, namely the coefficient of determination (R^2), Mean Squared Error (MSE) and Mean Absolute Percentage Error (MAPE) as expressed in Equation 10, Equation 11 and Equation 12, were used to evaluate the prediction capacity of the models.

$$R^2 = 1 - \frac{RSS}{TSS} \tag{10}$$

$$MSE = \frac{1}{n}\sum_{i=1}^{n}(Y_i - \bar{Y}_\iota)^2 \tag{11}$$

$$MAPE = \frac{1}{n}\sum_{i=1}^{n}\left|\frac{A_t - F_t}{A_t}\right| \tag{12}$$

Where R^2 is the coefficient of determination, RSS is the sum of squares of the residuals, TSS is the total sum of squares, Y_i is the actual data point measured, Y_i is the predicted data point A_t is the actual value and F_t is the forecast value.

Statistically, R^2 values close to 1.0 indicate that the model prediction capacity is accurate, while small MSE values are indicative of negligible error between the actual and the predicted data points in the model. Similar to MSE results, MAPE results was also utilized as a measure of prediction accuracy. The R^2 values for the training and testing datasets should be close in order to conclude that the model does not suffer from the overfitting phenomenon and that the model can be relied on to predict data points with untrained datasets. As illustrated in Figure 10, the R^2 for the ANFIS model developed with the testing dataset was 0.977, which is significantly above the acceptable accuracy level of 0.800 as suggested in a number of earlier studies (Alas & Ali, 2019). The MSE analysis results showed that the sum of the errors between the actual and the predicted data points was negligible at 0.00032. Additionally MAPE results for the testing dataset was 0.286 which indicated that the model has high accuracy to forecasting the experimental outcomes.

On the basis of the statistical indicator metrics, it can be considered that the ANFIS modelling technique with a two input and one output structure is an efficient way of predicting the short-term aged properties of asphalt binders by using the properties of the asphalt binders in unaged condition.

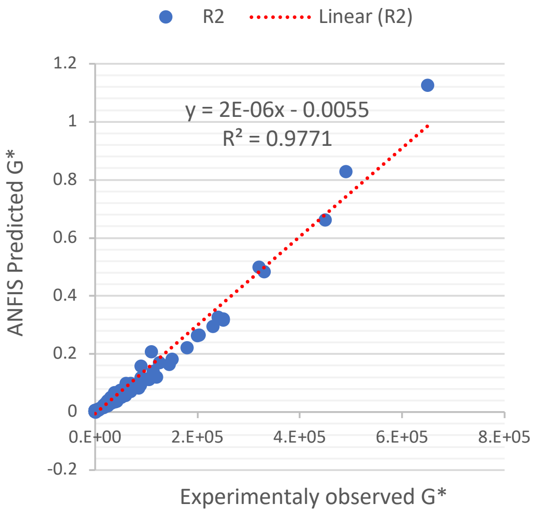

FIGURE 10. ANFIS model prediction capacity based on R^2

CONCLUSION

The influence of ASA/Si polymer nanocomposite modifiers was evaluated under unaged and RTFO aged conditions with respect to physical and rheological properties at the binder level. Additionally, a heuristic modelling technique, ANFIS, was implemented to develop an artificial intelligence model that can estimate the aging behaviour of asphalt binders by using two significant parameters, G* and δ, in an unaged state to predict G* in a short-term aged state.

Based on the experimental outcomes and the ANFIS model analysis, the viscoelastic behaviour of asphalt binders was enhanced up to 5% addition of ASA/Si composite in the base asphalt binder. Beyond this composition, the performance of PNC modified asphalt binder demonstrated less enhancement in the viscoelastic properties, which is assumed to be due to the agglomeration of nanoparticles in the asphalt matrix.

The stiffness of the PNC modified asphalt binders was found to increase after the RTFO aging due to exposure to high pressure and temperature. It was observed that the addition of modifiers improved the aging resistance of the base asphalt binder.

The ANFIS model was able to predict the aging behaviour of base and PNC modified binders with high accuracy as demonstrated by the R^2 values close to 1.0 as well as the low MSE results obtained.

ACKNOWLEDGEMENT

The author appreciates the assistance and continuous support of his supervisor Assoc. Prof. Dr. Shaban Ismail Albrka and Dr. Nasradeen Ali Khalifa for facilitating the equipment and laboratory facilities to conduct the experimental work.

DECLARATION OF COMPETING INTEREST

None

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