PREDICTION OF THE WEATHERING (TEMPERATURE & RAINFALL) EFFECTS ON ASPHALT BINDERS MODIFIED WITH ENR USING ADAPTIVE NEURO-FUZZY INFERENCE SYSTEM

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I hereby declare that all information in this document has been obtained and presented in accordance with academic rules and ethical conduct. I also declare that, as required by these rules and conduct, I have fully cited and referenced all material and results that are not original to this work.

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To my parents…

ABSTRACT

The weathering (temperature and rainfall) effects are the critical factors to determine the durability of asphalt binders in their service of life by making an impact on the performance characters of chemical, physical, and rheological properties. In these studies, we investigated to predict the weathering effects on natural rubber modified asphalt binders by analyzing the G* and δ using ANFIS modeling. For the analysis system modeling the inputs implement as the experimental datasets of G* and δ collected from the DSR machine of taken samples for un-aged, rolling thin film oven RTFO and pressure aging vessel PAV of asphalt binders within defined weathering effects factors like temperature and frequency. Thus, asphalt binders are composites of epoxidized natural rubber at 0% and 6% concentration percentage, where RTFO + PAV signifies for weathering effects during short term aging and for long term aging. The experimentally observed data normalized and formulated for ANFIS modeling to analysis the prediction using the Sugeno inference system algorithm. The evaluation for achieved from experimental based on rheological viscoelastic properties: isochronal of G* and δ, black diagram curve and rutting resistance and for attained from ANFIS modeling of predicted of G* and δ based on the performance of statics indictors R^2, RMSE and R. This studies, found that in the experimental the modified asphalt binders type RTFO + PAV together has better performance of rheological properties than all other binders to resist the extreme weathering effects of heat and cold wave hazards, earthquake, and storm flow; the selected modeling for testing value were achieved that R^2 0.912, RMSE 0.052 and R 0.955, which is more accurate and good model predict of G*.

Keywords: Adaptive Neuro-fuzzy Inference System; Dynamic Shear Rheometer; Epoxidized Natural; Modified Asphalt binder; Rheological Property

ÖZET

Ayrışma etkileri, kimyasal, fiziksel ve reolojik özelliklerin performans karakterlerini etkileyerek asfalt bağlayıcıların kullanım ömründeki dayanıklılığını belirleyen kritik faktörlerdir. Bu çalışmalarda, ANFIS modellemesi kullanarak G * ve analy analizlerini yaparak doğal kauçuk modifiye asfalt bağlayıcıları üzerindeki hava koşullarının etkilerini tahmin etmek için araştırma yaptık. Analiz sistemi modellemesi için girdiler, yaşlandırılmamış, yuvarlanan ince film fırın RTFO ve alınan asfalt bağlayıcıların basınçlı yaşlanma kabı PAV'ının tanımlanmış yıpranma ince tabakalı fırın RTFO'su için alınan numunelerin DSR makinesinden toplanan G * ve da deney verileri olarak uygulanır. ve sıklık. Bu nedenle, asfalt bağlayıcılar,% 0 ve% 6 konsantrasyon yüzdesinde epoksitlenmiş doğal kauçuktan oluşan kompozitlerdir; burada RTFO + PAV, kısa süreli yaşlanma ve uzun süreli yaşlanma sırasında ayrışma etkilerini gösterir. Deneysel olarak gözlemlenen veriler, Sugeno çıkarım sistemi algoritmasını kullanarak tahminin analiz edilmesi için ANFIS modellemesi için normalleştirildi ve formüle edildi. Reolojik viskoelastik özelliklere dayanarak deneysel olarak elde edilen değerlendirme: G * ve iso izolasyonu, siyah diyagram eğrisi ve rutting direnci ve G * ve δ tahminlerinin ANFIS modellemesinden elde edilenler için statik göstergelerin R2, RMSE ve R'nin performansına dayalı Bu çalışmalar, deneyde RTFO + PAV tipindeki modifiye asfalt bağlayıcıların birlikte, sıcak ve soğuk dalga tehlikelerinin, deprem ve fırtına akışının aşırı yıpranma etkilerine karşı koymak için tüm diğer bağlayıcılardan daha iyi reolojik özelliklere sahip olduklarını; Test değeri için seçilen modelleme, G * in daha doğru ve iyi bir model öngörüsü olan R^2 0.912, RMSE 0.052 ve R 0.955'e ulaşmıştır.

Anahtar Kelimeler: Uyarlanabilir Nöro-bulanık Çıkarım Sistemi; Dinamik Kesme Reometresi; Epoksitlenmiş Doğal; Modifiye Asfalt Bağlayıcısı; Reolojik Özellik

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LIST OF ABBREVIATIONS

ENR: Epoxidize Natural Rubber

ASTM: American Society for Testing and Materials

RTFO: Rolling thin film Oven

PAV: Pressure Aging Vessel

G*: Complex modulus

δ: Phase angle

DSR: Dynamic shear rheometer

ANN: Artificial Neural Network

ANFIS: Adaptive Neuro-Fuzzy Inference System

MF: Membership Function

R^2: Coefficient of determination

COV: Covariance

RMSE: Root Mean Squared Error

R: Correlation factors

6 ENR: 6% Epoxidize Natural Rubber

CHAPTER 1

INTRODUCTION

1.1 Introduction

It is an incredible fact that, to have a suitable economic for a good quality of life providing an efficient transport system especial roads. In the early century after more vehicles were starts to used roads researchers try to investigate to improve the pavement materials. At the beginning of the 20^{th} century, well known material calls asphaltic was investigated, however the refined petroleum of bitumen most commonly applicable in the field of pavement (Taherkhani, 2006). Overall, roads constructed to provide sustainable development by carried out safely traffic flow within economic growth in their design life of the structure.

In the structure construction of pavement depending on the use of material, we have rigid (constructed with concrete slab), flexible (constructed with bituminous asphaltic) and composite (a combination of both) pavement. Flexible pavement from those types, mostly applicable due to the binder course from the layers of surface course, binders, and the base course are made to bring a satisfactory performance of transportation by making leveling layers for suitability of surface course in order to properly distribution of vehicle loads to the bottom of pavement structure sub-layer. And in order to repel the fails of the pavement due to cracking of fatigue and rutting in constantly as traffic loads factors also, binder course is more capable to make flexible pavement more longer service life due to making composite with modifiers to provide the satisfactory performance of properties. In general, the pavement layers provided in the construction of transportation for comfortable movement of traffic flow having a smooth surface, clean dry and repel slid due to different exerting force.

In the basis of (EN, 1297), bitumen is the material complex properties made from unpolished lubricant and/or with natural asphalt in the manner of at all or closest to solubility, solid in weather-based temperature as effectively waterproofed, glue and violate (European comments specification EN 12597, 2000). And it is Bitumen is, a dark brown colored hydrocarbon obtained as a byproduct of the distillation of crude oil, is mostly used in pavement construction due to its viscoelastic and

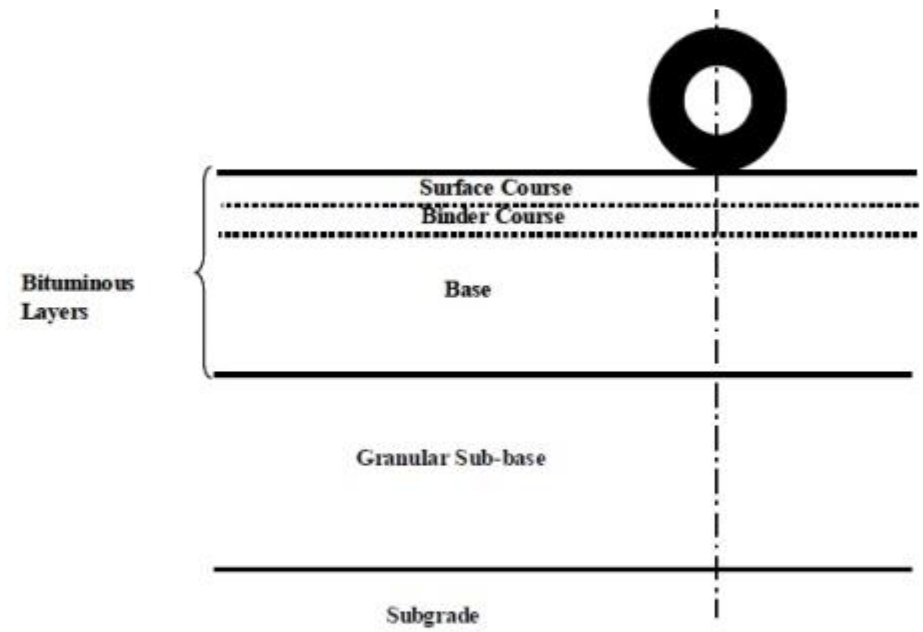


Figure 1.1: A Pavement of typical Flexible structure (Taherkhani, 2006)

adhesive properties, (Kok, Yilmaz, Sengoz, Sengur, & Avci, 2010), Bitumen is made of complex mixtures of aromatic, aliphatic and naphthenic hydrocarbons with a small amount of metallorganic and other organic. In order to provide better performance characteristics and properties of bitumen to implementing in a good manner in the practical site and to facing the problems happens regarding maintenance if disjointedness in layers, and incompatibility with the modifier (Paliukait et al. 2014; Read, J. Witheoak, D. 2003). On this basis to providing an understanding of getting bitumen properties taking consideration from its self-procedure of the production process and from unpolished lubricant characters in which more content of lubricant will determine higher bitumen characters.

The construction pavement will be checked in the laboratory by accelerated weathering system features, for good composite and high-quality performance analysis in service life. In this context, this is the case why the rheological characters keep critical in the implementation of asphalt in order to repel the weathering effects and extreme damage due to disaster effects and overloading of traffic (Lesueur, D., 2009; D'Melo, D., Taylor, R., 2015; Olli-Ville, L., 2015). Even if, an application as biological materials applied to over changing the physical and rheological characters of bitumen it might not suitable due to weathering effects throughout the aging process for a good manner of performance. Also, the properties of asphalt become enough fluid at high temperatures ≈160^{o}C and stiff at confined temperature ≈60^{o}C with stable at the intermediate temperature as soft and elastics, which keep it to repel resisting cracking. However, as the result of the performance properties of bitumen dependent within the limitation of temperature the addition of modifiers will bring for controlling this limitation to provide enhancement bitumen properties.

Thus, in earlier studies, many researchers were investigated for improvement of asphalt performance by the addition of different modifiers. From those modifiers polymers are the most popular; it is properties determined from the organic reaction of macromolecule in order to produce a sequence of long. As polymers composite with asphalt to produce modified asphalt, which has both properties of asphaltenic and polymeric matrix phase character's used for long service life within cost-effective and energy, time-saving. This preformed is for the impacts of the method of mixture bitumen with the modifier, and effects of rheological properties (R. A. Al Mansob et al., 2016). The most common bitumen polymer used modifiers found in literature as described on table 1.1

Now a day, natural rubber modifier applied for many technology of modified asphalt binder, which is the chemical production of natural rubber and acidic formic of proxy within the facilitated properties in order to providing repelling lubricant, adequate strength due to strain compression to the direction of temperature increased, and makes stable the viscous-elasticity as stiffness and elastic relation with decreasing of vulnerability temperature. However, in this technology, the physical and rheological properties of asphalt binder as a mixture stage and in practice on the site of road construction during the beginning, decay and dehydrating may have different performance as the result of weathering effects (R. A. Al-Mansob et al., 2017).

Table 1.1:different polymers modifiers used mostly for modified bitumen.

categories	Main used
Thermoplastics Polymers	polyethylene (PE), Polypropylene (PP) Ethylene-Vinyl-Acetate (EVA), PVC and EBA
Thermosets	Epoxy resin, Polyurethane resin Acrylic Tresin and Phenolic resin
Thermoplastic Elastomer	Styrene-Butadiene-Styrene-Block copolymers (SBS) Styrene-Isoprene-Styrene-Block copolymers (SIS)
Natural and Synthetic Rubbers	styrene-ButaTdiene Rubber (SBR) Natural rubber, TPolydiolefins, and Reclaimed Tire rubber
bitumen Chemical Modifier	Sulphur (S), Polyphosphoric acid (PPA), Reactive Polymers Maleic Anhydride (MAH) and Nanocomposite Modifiers

There are different types of Laboratory tests and experimentation must be conducted to the asphalt binders in order to find out the properties of it. Using those tests providing the details properties and characters of binder will lead to which type of modifiers as plastic, polymers, and Nano-materials were added to the base asphalt to improve the performance of the asphalt mixture (Cuadri et al., 2011b). However, due to the weathering effect on rubber binder uses this practice test and experimental mathematical and computational models not providing accurate performance and composition of asphalt pavement. After the experimental raw data collected as input/output and formulated in normalized ways to use in soft computing ideas for training and testing data. To implement this soft computing, several researchers apply ANFIS because of the accuracy prediction considering weathering effects and it is application makes hydride of ANN with fuzzy inference. The estimation of the performance of pavement in order to save the energy within time efficiency and cost is taken out as important in ANFIS modeling. (A. El-Shafie et al., 2011). ANFIS is developed to reduce the error during the prediction, as it is capable and interpolated in the way of output from ANN and rearranging the functions of membership in the system of fuzzy inference linguistic algorithm (Wang et al., 2006). In this context, the ANFIS architecture involves a five-layer feed-forward neural network considering this Many researchers have been used ANFIS in the pavement field due to its adaptability and computational efficiency to deal with Complex behavior of pavement materials.

1.2 Problem Statement

In asphalt pavement construction, to provide an accurate estimation of the performance of the mixture and modifiers for the quality of asphalt mixture with varies modifiers used. Due to the high cost of some materials and leakage in laboratory equipment, that leads to a limited number of studies that have been acknowledging the performance of modified bitumen with nanomaterial (Firouzinia & Shafabakhsh, 2018; Ziari et al., 2018). Most of the studies which have been done to asphalt binders modified with polymer Nanocomposite materials like natural rubber are limited to be addressed by experimental investigations and the tangibility of artificial intelligence modeling in this matter requires further study. Therefore, Adaptive Neuro-Fuzzy Inference System (ANFIS) models were implemented in this study using physical properties of, bitumen modified with polymer-like natural rubber at various weathering (temperature and rainfall) effect condition as predictor and the performance characteristics indicator, complex modulus (G*) and phase angle as the predicted variable to find out the behavior of Bitumen modified with polymer and polymer Nanocomposite materials.

1.3 The objective of the study

The objectives of the study are to:

- ✓ To undertake a literature review that discusses and analyses the application of the Adaptive Neuro-Fuzzy Inference System (ANFIS) in the field of pavement design.
- ✓ To develop the ANFIS model to predict the weathering (temperature and rainfall) effect of natural rubber modified asphalt binders.
- ✓ To establish a comparison study between the Adaptive Neuro-Fuzzy Inference System (ANFIS) modeling and the experimental results.

1.4 Significant of the study

In further studies, Due to the leakage of the studies that have been discussed the performance of modified bitumen with nanomaterial and the studies which have been conducted to asphalt binders modified with polymer nanocomposite materials are limited to be addressed only by experimental test therefore, the results of the study will be of great benefit to the pavement field by finding the viscoelastic properties of modified asphalt mixed at elevated temperatures and frequencies using Adaptive Neuro-Fuzzy Inference System (ANFIS) model within performance evaluation in the prediction process and showing the capability and efficiency of this applications to deal with Complex properties of pavement materials.

1.5 Thesis Organization

Chapter one is explaining the introduction about the topic, problem statement, and objective of the study while chapter two is addressing the previous studies carried on or related to the study area. In addition, Chapter three is providing in detail the methods and procedures that carried on achieving the objectives of the study and chapter for discusses the results of the research while chapter five is about the conclusion.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter presents a review of different issues related to natural rubber modifiers in asphalt mixtures. In the beginning section, the pavement performance characteristics of the modified asphalt binder will be discussed. In this discussion, the performance asphalt binder characteristics are performed regarding the deformation in different cracking types as the effect of weathering. On the next unit that will review, the pavement problems result over distress within weather condition that that is most commonly used to evaluate the performance of natural rubber in the modified asphalt binder. As a continues section, asphalt binder modifiers will describe and discuss for better performance in the asphalt mixture characterization. Finally, soft computing will be considered and the formulating ANFIS model presented.

2.2 The Performance Properties of the Binder

In general, the binder properties of pavement structure will govern the rheological performance of modified asphalt binders by making influences on the viscous-elasticity characteristics of bitumen materials (Lee, 2006). Thus, the flow of viscous properties of bitumen change according to stress and temperature conditions. The failure, or loss of the desirable properties of bitumen, can be noticed as it takes the form of hardening. Resultantly, a decrease in flow and adhesive properties and an increase in the coefficient of thermal expansion and the softening point temperature (Mochinaga et al., 2006). All bituminous materials have colors ranging from dark brown to black. Also, asphalts are thermoplastic materials, meaning that they liquefy when heated and solidify when cooled (Ali et al., 2017).

Van der Poel (1954) investigated the behavior of bitumen for suitable binder characters in the form of graphic characters, which functional behaviors depend on temperature and frequency. Regarding this finding even if, the not applicable for complex stress-strain behavior of bitumen researcher were tried to simulated the graphic properties to provide linear behavior of bitumen in viscous-elasticity relation by applying rheological parameters (Jongepier et al., 1969; Hall, 1972 and Ossa, 2005; Cheung, 1995; Cheung and Cebon, 1997a,b,c). In the complex behaviors of viscous-elasticity, the temperature has a critical impact considering the time of traffic loading to determine the value of stiffness and elastic, which is at low temperature solid stiff and at high-temperature liquid elastic. This makes viscous-elasticity as changeover unit is named viscosity (Brown and Sparks, 1958; Gaskins et al. 1960); Moavenzadeh and Stander Jr 1967).

2.3 The Performance Properties of the Asphalt mixture.

In bituminous materials contain mainly of bitumen and have strong adhesive properties. Those Bituminous materials are a hydrocarbon obtained as a product of the distillation of crude petroleum or found in natural deposits (Read & Whiteoak, 2003). It has the capacity to adhere to a solid surface in a fluid stat depending on the surface's nature, while the adhesion could be prevented by adding water to the surface; therefore the Bitumen is water-resistant. In addition, bitumen applied in asphalt mixed pavement due to its performance, economical, increase Adhesive Nature, melts at a low point, its Rheological and Physical Properties produce Flexibility, recycled, and diversity colors. In this manner to use the specific bitumen the criteria to differentiate is on the safety, inconsistency with the durability, physical properties, and solubility.

The performance of asphalt may not be satisfactory in all situations of weathering effect as checked-in accelerated weathering system feature. To check the effective performance of asphalt in the practical area understanding the fundamental binders designing physical properties under weathering affects. To consider this determining the properties of Asphalt the following testing methods are carried out: Direct Tension (DTT), Bending Beam Rheometer (BBR), Rolling Thin Film Oven (RTFO), Pressure Aging Vessel (PAV), Absolute Viscosity, Absolute Viscosity, Kinematic Viscosity, Apparent Viscosity of Non-Newtonian Bitumen (ASTM D4957), Rotational Viscosity, Penetration, Specific Gravity, Softening Point, Flash

Point, Solubility (ASTM D2042), Ductility, Elastic Recovery, Force Ductility, Screen Test, Thin Film Oven, Separation, and Dynamic Shear Rheometer (DSR).

2.3.1 Asphalt distresses

In general different types of distresses of asphalt in flexible pavements happen according to the natural and physical properties of the asphalt binder, while the other possible occurrences are the weather conditions and the loads which applied by the tracks. Stable deformation is considered as one of the main distresses of asphalt that occurs in flexible pavements when subjected to natural and physical properties of the asphalt binder, traffic load, and weathering effects. In most of the time the asphalt distress occurs due to rutting in to two main factors of pavement as weakness of sub-layer putted under the pavement structure, which is structural rutting and as the fails of asphalt mixture properties of design due to the lack of controlling the vertical load exerted makes fails shear strength, which is non-structural rutting as shown in Figure 2.1

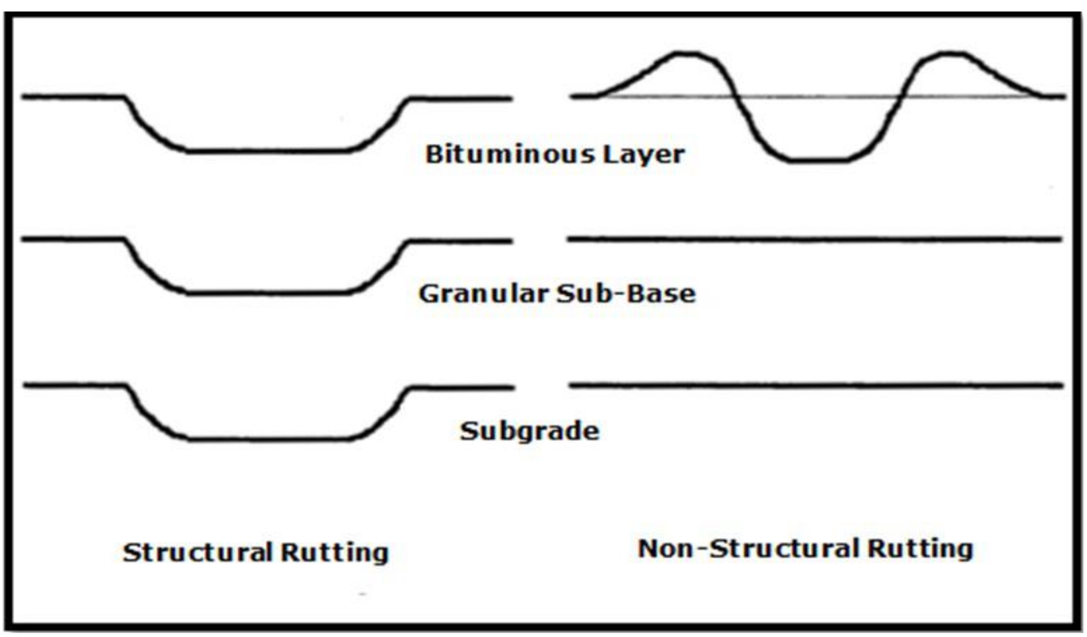


Figure 2.1: rutting impact as structural rutting and Non-structural (Gibb, 1996)

Specifically, the distress of the asphalt will discuss as the following:

A. Fatigue

Fatigue is the principal structural distress, the layer materials and thicknesses of pavement, applied loads the consistency of the asphalt cement, the Bitumen content and the air voids and aggregate characteristics of the asphalt concrete mix are the factors which affect the development of fatigue(El-Basyouny & Witczak, 2005).

B. *Bleeding*

Is the potential for the pavement to make care hazard as drop addition of asphalt materials in the surface structure of the pavement. However, when the mixture drops to make shiny the surface of the pavement is not enough and/or exceeds the limit the mixed space will have a void and fill with air during high temperature the bleeding will happen (Xu & Huang, 2012).

C. Frost heave

It happens in freezing climates, in frost-susceptible soils when enough water is available. When the temperature in the soil reaches the freezing point, this water freezes and becomes ice lenses, which will be thicker. The progressive growth process of these ice lenses is still continuing as additional water is drawn to the freezing front that produces the dramatic raising of the road surface known as frost heave (Johanneck & Khazanovich, 2010).

D. Pothole

It is a bowl-shaped hole through one or more layers of the asphalt pavement structure, between 15 cm to 90 cm in diameter. Potholes start to form when crumbs of asphalt concrete are displaced by traffic wheels, in fatigue-cracked areas. Potholes increase in depth and size as water present in the hole and penetrate into the base and subgrade, which increases weakness in the vicinity of the pothole (Koch, Jog, & Brilakis, 2012).

E. Raveling

Raveling is occurred by the continued infiltration of water and the break downing of an asphalt top layer. When the water is presented on the top layer of asphalt bitumen and sunlight will start to damage the asphalt surface by breaking the bond between the aggregate and asphalt bitumen. it will affect the asphalt surface losing its impermeable properties and will let water enter the surface. When water begins to enter into an asphalt surface it will lead to further cracks then the pavement failure occurs (Adlinge & Gupta, 2013).

F. Rutting

Rutting is channeled depressions in asphalt surface. When the deformation takes a place only in the asphalt concrete it may occur by plastic flow or consolidation. Asphalt cement stiffness is a big influence for rutting resistance of asphalt mixes while the Stiffer asphalt cement can increase rutting resistance (Xiao, Amirkhanian, & Juang, 2007).

2.4 Modification of Pavement

The pavements issues have an undesirable effect on the safe side for beings and to the economic side for the society particularly the countries where financial resource for pavement maintenance is often insufficient and due to the restrictions of bitumen about the temperatures, modification of bitumen is one of the best techniques to develop the properties of bitumen different types of modifiers such as polymers, plastic, still slag and glass, additional to the base asphalt to advance the performance of the asphalt mixture (Cuadri, Partal, Navarro, García-Morales, & Gallegos, 2011). Thus, The convention of modified asphalt gives the capacity to regulator the limits of mechanical stability of road surfacing by enhancing the properties of some types of surfacing during hard extremely conditions of services (Sarsam & Lafta, 2014). By using modifiers with asphalt showed increasing in performance by raising the cohesion of the bitumen, and increase the viscosity and decrease the thermal capability of the binder (Al-Khateeb & Al-Akhras, 2011). Some studies conducted that by using a minimum of 10% of modified bitumen leads to longer enduring streets with better execution (Sabadra, 2017).

In the research, Several studies conducted to modified asphalt and it concluded that by adding modifiers to asphalt its heat and strength resistance to reach the double and that leads to improving the shearing resistance it also showed that the density of modified asphalt is more than density of the base asphalt and it gains by increasing the content of modifiers so the water saturation, respectively, reduces (Kishchynskyi, Nagaychuk, & Bezuglyi, 2016). In addition, Sarsam and Lafta studied different type of modified asphalts to find out the physical properties of it and, obtained result showed that by adding the modifiers to the base asphalt, the penetration value of asphalt cement decreased, while the Softening point of asphalt cement gained and Ductility of asphalt cement decreased (Sarsam & Lafta, 2014).

2.4.1 Polymer materials modified asphalt

The polymer is a chemical compound with molecules and bond together to create a long repeating chain. It can be used in a different field due to its unique properties (Sabadra, 2017). Polymers widely used as a modifiers for binder it can be classified as the following: plastomers, thermoplastic elastomers, and reactive polymer, it has the ability to enhance the thermal capability of asphalt binders, each one of them has its particular impact according to their properties: Thermoplastic elastomers increase the resistance of the binder to fatigue by improving the elastic properties, reactive polymers and plastomers increase the resistance to deformation and also increase the stiffness, (Brasileiro, Moreno-Navarro, Tauste-Martínez, Matos, & Rubio-Gámez, 2019).

The usage of polymer modified bitumen showed the ability to increase the resistance of the mixture against rutting and thermal cracking. Furthermore, the incompatibility between the bitumen and polymers leads to phase segregation among the blends which deuced the strength of pavement (Ali et al., 2017). By modifying the bitumen with polymer, the polymers differ the viscoelastic properties and the strength of the Asphalt, by providing the ductility, improve the Fracture strength, increase the elastic response and improve the cohesive property (Yildirim, 2007). And a study conducted by (Becker et al., 2001) the results indicated that the polymer used as modifiers in paving field due to its capability to enhance the physical properties of the binders, the introduction of polymer improves the rutting resistance, high temperature sensitivity, fatigue, stripping and thermal cracking. Mostly it's used when durability and high performance are necessary (Becker & Méndez, 2001).

In the rheological properties of polymers elastomeric, the main role in the modified asphalt binder is to govern elasticity of pavement in order to control and repel the constant deformation as rutting effect, develop asphalt strength in collaborate the structure together and to minimizing the extreme cold weathering cracking due to low temperature (Robinson, 2005). In this manner, the polymers will reunite the structure of unmodified asphalt binders together in order to decrease the phase angle to provide more flexible elastic modified asphalt binders for long service life within good performance quality under the weathering effects (Airey, 2003).

In a study for Burger et al. (2001) a frequency sweeps test was used in their study. The results obtained showed that when the polymer is added to the binder it increases its performance at low frequencies and under a high temperature means a decrease in resistance to deformation compared to unmodified bitumen, the polymer modified binders had a more elastic response under these conditions. While it can be noticed that the addition of polymer doesn't affect the binder response to loading in terms of the relative distribution between elastic and viscous response (Burger, Van de Ven, Jenkins, & Muller, 2001). And Studies conducted to polymer modified bitumen showed that when the polymer is added to bitumen it increases the softening point and imparts a high elasticity to bitumen. On the other hand, it showed that the mixture has a lower temperature sensitivity. It has higher strength at high temperatures and lower strength at low temperatures (Kishchynskyi et al., 2016).

One of the main limits of polymer modifiers is that the polymers are thermodynamically unsuited with asphalt due to the large differences of density, molecular weight, solubility and polarity between the polymer and the asphalt. This may lead to delamination of the composite during thermal storage, which cannot be noticed easily and badly affects the material (Fang, Yu, Liu, & Li, 2013).

In general, the high cost of the polymer modifiers is the reason that affects a wide use of it and to improve the bonding of polymer elements, between themselves and with bitumen, plasticizer was added in a polymer composition in some situations (Kishchynskyi et al., 2016).

2.4.2 Epoxidized Natural Rubber

Epoxidized natural rubber is polymer type of modifier for asphalt binder produced from elastic material natural rubber achieved from fluid of trees and make chemical reaction with proxy formic acid. This material improved the performance characterizations of rheological properties providing high strength giving capability to allow stress-strain illustration. It is able to improve the resistance of oil, increase adhesion, loading resistance and reduced permeability of gas. More over its increased viscous-elasticity related to stiffness and elastic properties of asphalt binder by decreasing the exposure temperature of binders (Al-Mansob RA et. al, 2017a).

2.4.3 Nanomaterials modified asphalt

As (Ezzat, El-Badawy, Gabr, Zaki, & Breakah, 2016) Nanomaterials are of morphological features on the nanoscale, and especially have special properties stemming from their nanoscale dimensions (Fang, Yu, Liu, & Li, 2013). Many studies in airport engineering and highway field have been done to explore the utilize of nanomaterials as a modifier for asphalt, and they found that when nanoparticles are added to the binder, the viscosity and the cohesion of asphalt can be increased, which mean the mixture may have a good performance under high-temperature conditions. In the conduct of Abdelrahman et al. (2014) made an experimental on the NC-asphalt nanocomposite. The indicated results showed that Nano clay modification of asphalt enhances the physical properties of asphalt. Raising Nano Clay concentration in the binders increase the temperature susceptibility of asphalt, as well as rising the complex modulus while decreasing phase angle (Abdelrahman, Katti, Ghavibazoo, Upadhyay, & Katti, 2014).

A study was done by comparative test Jahromi & Khodaii. (2009) their study bassed on a comparative rheological test on the base bitumen and nanoclay modified bitumen. The essential rheological test by dynamic shear rheometer (DSR) is done on base bitumen and modified. The results showed that the presence of nanoclay can change the rheological properties of bitumen by decreasing the phase angle and increasing the stiffness, it showed the capability to improve ageing resistances(Jahromi & Khodaii, 2009). Also, Amirkhanian et al. (2010) investigated and estimated the rheological properties of the binders containing various percentages of carbon nanoparticles under high temperatures. Their test resulted that the viscosity of binders increased as the rate of nanoparticles increased, also an increase in failure temperature was noted, but the percent increase depends on the binder grade, phase angles were consistently reduced, addition of the particles resulted in more resistance to deformation and higher elasticity, while elastic and viscous modulus values showed an increase with the addition of nanoparticles. (Amirkhanian, Xiao, & Amirkhanian, 2010).

A study conducted by you et al. (2011) on the effects of nano -clays on the rheological properties of asphalt by blending surfactant- modified Nano-clay at Two percent and four percent by weight of asphalt. It was found that the addition of nano-clay increases the viscosity of the base binder across varying temperatures. Also, the nanoclay-modified asphalt showed that the phase angle was decreased while the complex modulus was increased which mean the binder has a good performance under high temperature (You et al., 2011).it is the studies conducted to asphalt modified with nanomaterial, it found that the aging resistance, thermal storage and rheological properties of asphalt modified with nanomaterials are improved, which increase the service life of the asphalt pavement (Fang, Yu, Liu, & Li, 2013).

The previous studies have reported that the performance of bitumen modified with nanomaterials shows that the complex shear modulus of modified bitumen improved while the phase angle decreased, indicating that the permanent deformation (rutting) of modified bitumen could be minimized (Ali et al., 2017). And in the study conducted of Ezzat et al. (2016) to evaluate the Asphalt Binders Modified with Nanoclay and Nanosilica, it concludes that the mixture resistance to permanent deformation could be improved using the proper amount of nanomodifier and, the nanomodified asphalt binder can be stored to be used after few days it can be up to 10 days without big effect on its properties obtained by modification process in the bingeing.

The nanomaterials have been introduced as another way to improve the properties of bitumen and enhance the compatibility among the bitumen and polymers. Nanomaterials have been developing and incorporated rapidly in the field of asphalt mixture as it has unique properties. These properties include high surface work, a large fraction of surface atoms, structural features, quantum effects, and spatial confinement (Saltan, Terzi, & Karahancer, 2018). In the predicting study of Ali et al., (2017) that modification of bitumen with nanomaterials would improve the properties of bitumen including an increase of stiffness of bitumen which leads to be less susceptible to the temperature and improve the strength of bitumen against moisture damage. Some nanomaterials have been used to modify polymer modified bitumen such as; nanoclay, nanofibers, carbon nanotubes and nanosilica (Ali et al., 2017).

It can be noticed, although Nano-materials are promising, some type of Nano-materials are expensive and demands further research to exploring and optimizing the enhancement in the binder properties before field testing and applications (Ezzat et al., 2016). In addition to this, due to the limitation of time and the high cost of the materials and experiments, also the leakage in equipment therefor some studies were conducted to predict the behavior of modified Bitumen using Adaptive Neuro-Fuzzy Inference System (ANFIS). Using the Artificial intelligence models to solve the different type of real-life procedures in engineering and environmental field shows its products and capabilities by dealing with a non-linear characteristic. AI applications can be used in the modeling of different real-life procedures in the field of engineering due to their predictive capacities and nonlinear characteristics (Asadi, Hassan, Nadiri, & Dylla, 2014).

It is incredible truth, those complex real-world problems may require intelligent systems that possess human-like expertise within a specific domain, adapt themselves to changing environments, and be able to explain how they make decisions or take actions (Bradshaw, 1997).

2.5 Adaptive Neuro-Fuzzy Inference System (ANFIS)

Most researchers agree that ANFIS can be considered as a universal estimator that is used to preform highly nonlinear functions. ANFIS has many advantages than the other artificial intelligence (AI) techniques because it represents the amalgamation of fuzzy logic and neural network techniques so it takes advantage of the merits and eliminates their drawbacks (Cüneyt Aydin, Tortum, & Yavuz, 2006). In this manner, previous studies apply the application of ANFIS in the pavement field used by many researchers.

In the recent 10 years, in order to predict, control and model the characteristics performance of asphalt many researchers have applied ANFIS soft computing. From those (Mustafa Alas1 and Shaban Ismael Albrka Ali, 2019; F. Khademi et al., 2016; M.S.Pourtahmsb et al., 2015; Moghaddam et al., 2015; Shafabakhsh and Tanakizadeh, 2015; Kandil, 2013; Ozgan et al., 2012; Bianchini and Bandini, 2010) are literal viewed as the following:

A study by Mustafa Alas and Shaban Ismael Albrka Ali (2019), investigate to the performance of asphalt by analyzing the modulus of complex shear, loss, and storage, and phase angle within formulating as input the experimental result using ANN modeling. In the system analysis, they used temperatures and frequency as define factors within a different concentration of polymers and from their evaluation using the criteria of R^2 and RMSE. They Found the model for testing value was not predict inaccuracy due to not capable of epoch the complication data and they develop the model with training predict value.

A study by F. Khademi et al (2016) used three artificial intelligence techniques: Artificial Neural Network (ANN), Adaptive Neuro-Fuzzy Inference System (ANFIS) and Multiple Linear Regression (MLR) to predict the 28 days compressive strength of concrete using 14 different input variables. The obtained result that ANN and ANFIS models efficient in predicting the 28 days compressive strength of concrete and are recommended due to its high efficiency especially when high accuracy is needed. (Khademi, Jamal, Deshpande, & Londhe, 2016).

M. S. Pourtahmsb et al. (2015) investigated to replicate the performance of hot asphalt mix with in different polymer by analysis the resilient modulus using ANFIS modeling. The system input was concrete aggregate recycling, stone mastic asphalt within different concentrations and temperature as a defining factor. Their evaluation was based on the statics indicator of R^2, RMSE, and R and found HMA within SMA predict were accurate regarding the experimental result and failed of HMA within RCA achieved.

As the study of Moghaddam et al. (2015) to investigate the prediction of the deformation: rutting characteristic performance of modified asphalt binder mixture by analysis polyethylene terephthalate PET using ANFIS modeling. The analysis to formulate input defined factor is tested temperature, stress level, PET concentration. From their assessment based on RMSE and they conclude as predict were increasingly good for the input analysis of asphalt mixture.

As the investigation of Shafabakhsh and Tanakizadeh (2015) to search the resilient modulus under the effect of loading features in the time interval by formulating the indirect tensile test result using ANFIS. The system analyses were temperature and loading period as defined factors. Their evaluation based on the fraction of the rest period to the loading period and found that MR was improved within decreasing of temperature, which shows the prediction is capable in order to reduce the cost expensive and time loss for the experimental test.

CHAPTER 3

MATERIALS AND METHODOLOGY

3.1 Experimental Procedures

3.1.1 Materials and properties

In this study, the base bitumen utilized was of 80% penetration grade, from Malaysia bitumen factor at port Klang and ENR was applied ENR 50 as the polymer modifier at 0% and 6% concentration to the weight of base bitumen. Samples were prepared using a silverson high shear mixer at a constant temperature of 160 ^{o}C ±1 ^{o}C and at a speed of 4000 rpm for one hour in order to provide homogeneous mixtures. Evaluation of the physical properties of the unmodified, polymer modified and polymer Epoxidize natural rubber binders were conducted by specific gravity (ASTM D70), penetration (ASTM D5), softening point (ASTM D36) and others tests within different temperature values. The findings are presented in Table 3.1.

Table 3.1: Physical properties for bitumen and ENR

Materials	Properties	Value	Specification
Bitumen	Specific gravity	1.028	ASTM D70
80/100	Penetration @ 25 °C	82	ASTM D5
	Softening point (°C)	45.7	ASTM D36
	Viscosity @ 80°C (Pa.s)	12.6	ASTM D4402
	Ductility (cm) @ 10°C and 5 cm/min	20	ASTM D113
	Size (mm)	2.36	-
ENR	Specific gravity	0.94	-

3.1.2 Dynamic Shear Rheometer

In this study, a Dynamic Shear Rheometer (DSR) was used rheometer HAAKE the stress to observe the rheological properties of modified binder samples mentioned in the Materials and Properties section above. Tests were performed at temperatures ranging from 10 ^{o}C to 80 ^{o}C with increments of 6 ^{o}C as specified in Superpave PG guidelines. Temperature control of the samples was achieved by a fluid bath system and temperature control unit in order to keep temperatures constant and uniform over the range of temperatures in which the experiments were conducted. The DSR equipment shown in Figure 3.1 consists of top and bottom plates. Samples of asphalt binder in a recording of DSR tests were leading on base bitumen and polymer modified asphalt binders (ENR) at 0% and 6% concentrations in order to understand the effect of test parameters and the influence of modification on the performance of the modified binders. Where RTFO of 39 ± 1 gram placed in the oven on 163 ^{o}C ± 1 in place of 85 minutes for short term during the constructed period of 4-5hrs and PAV of 50 ± 1 gram placed in oven on 100 ^{o}C ± 1 in place of 20hrs for long term period of 3-5years and 5-10 years was prepared. And the performance of the modified binders was observed in a range of temperatures (10 ^{o}C-80 ^{o}C) and frequencies (1.5Hz-146Hz), while isochronal plots, master curves, and rutting parameter plots were used in the evaluation of performance characteristics. The tests were software controlled, while measured stresses and resulting strains were obtained in terms of complex modulus (G*) and phase angle (δ), which are considered as the most significant parameters to define the rutting (G*/sin δ) and fatigue (G*.sin δ) performance of asphalt binders. The effect of temperature on the performance of asphalt binders was illustrated using isochronal plots, black diagram curves, and rutting performance graphs. G* results were used in the construction of black diagram curves. In order to represent the results in a single curve known as a black diagram curve, a specified selected temperature of 20 ^{o}C, 60 ^{o}C, and 80 ^{o}C was defined with regarding frequencies relative to the temperature.

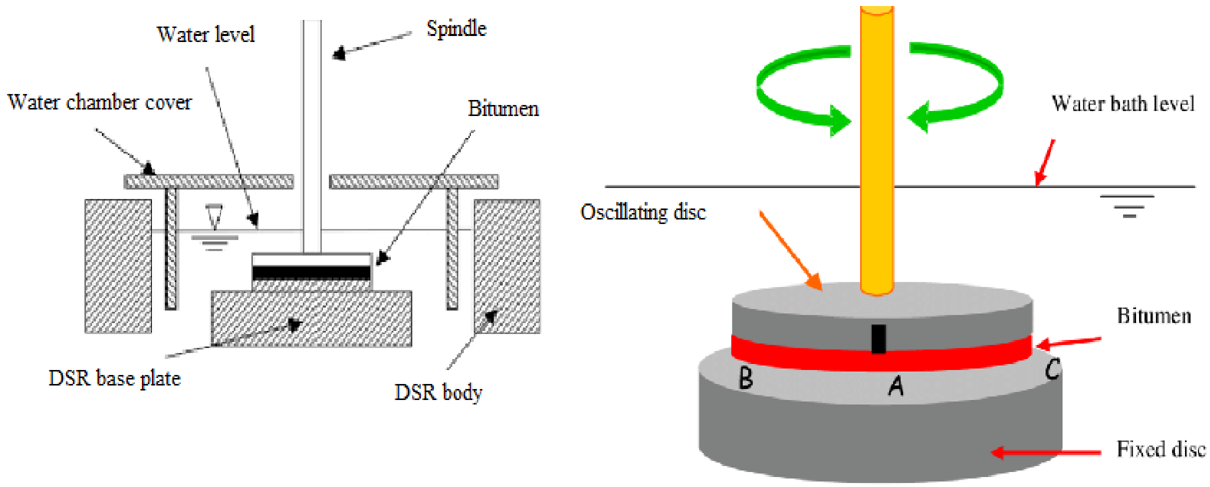


Figure 3.1: Schematic presentation of DSR

3.2 Modeling Procedures

In this study, ANFIS approaches are applied to calculate the complex modulus for base asphalt and ENR modified asphalt. The inputs of those models are Temperature and frequency. The data were observed from a dynamic shear rheometer (DSR) test. The resulted G* from the artificial intelligent techniques compared with the experimental result then the resulted complex modulus from the Adaptive Neuro-fuzzy inference system model are compared with together. Conclusions can be made upon the comparison. The general procedure of how this study was conducted is illustrated in Figure 3.2.

A set of 432 data points from six different mixtures of asphalt at different concentrations were used in the modelling of ANFIS, the data is provided in Appendix 1. Furthermore, 324 (75%) for training and 108 (25%) of the data points were used for testing of the models. The idea behind using a testing data set for the model has significance since it shows the prediction capacity of the network for the untrained data set. And check the potential for the model every the data.

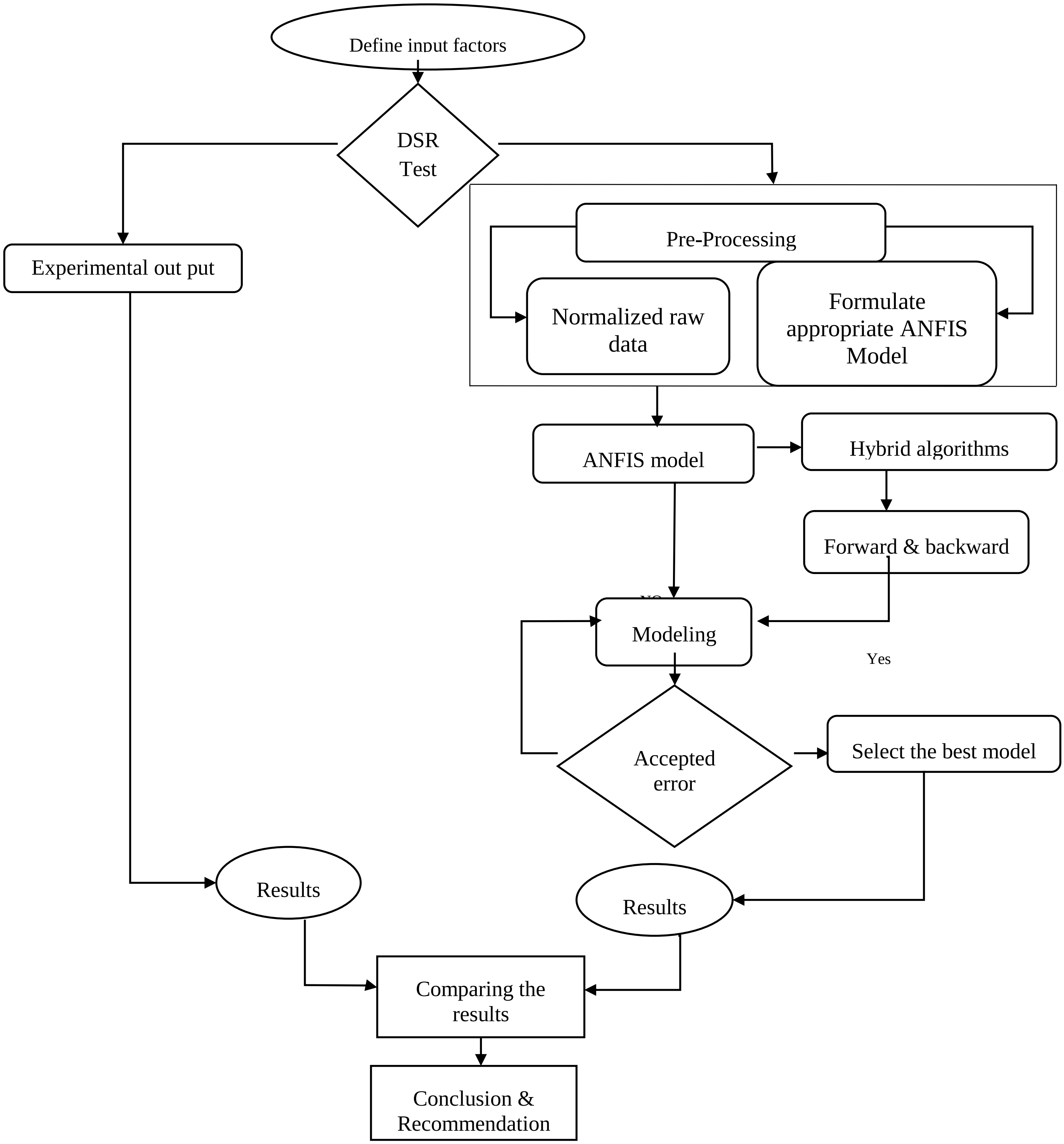
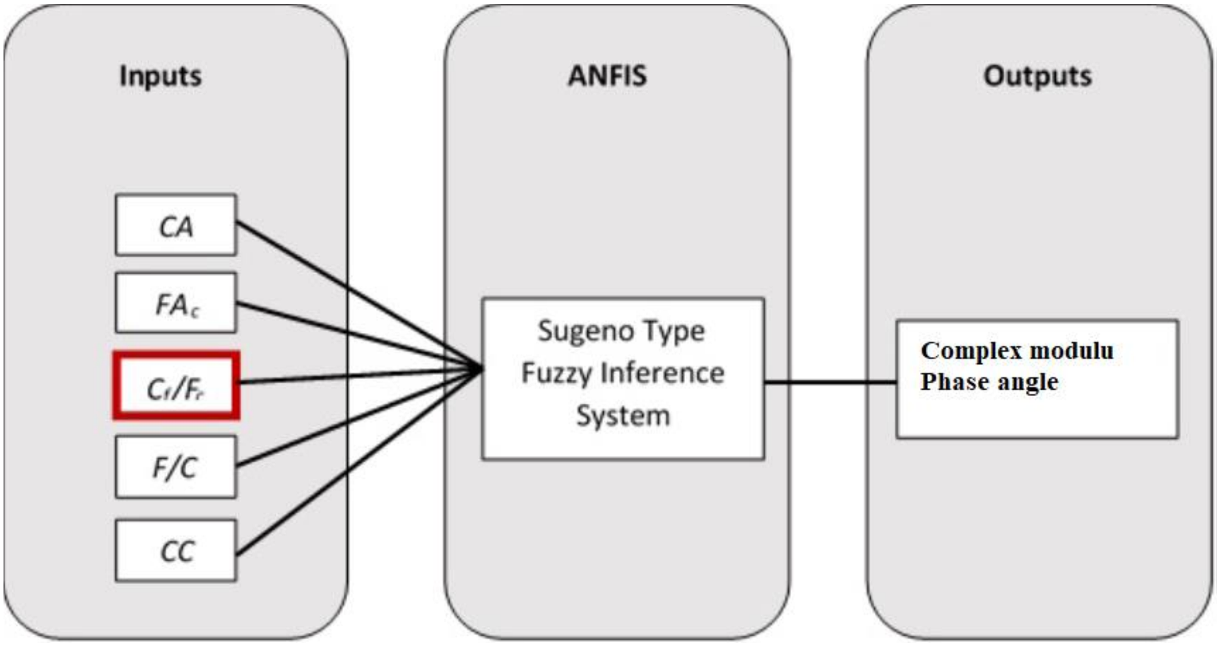


Figure 3.2: Flowchart of the study

3.3 Adaptive Neuro-Fuzzy Inference System

In the analyzing of ANFIS model construction, there are three main structures to implement the model for predicting and controlling involved as five input parameters, inference fuzzy system and output as a result of the prediction model shown in Figure 3.3. In the modeling process, the training value and testing value is not considered randomly also, has no equal datasets. And in analysis, each input parameter will have defined membership functions, which are leveled as low, medium and high for considering all normalized experimental data in an equal manner. During the constructing modeling process the resulting output depends on the combination of lowest to highest and their ratio through the define membership functions, this makes the training and testing modeling process to train and test their self as analysis input parameters. In this context, the inference fuzzy system will interpret the best prediction as ANFIS modeling. The membership functions for C_f/F_c are shown in Figure 3.4 From two methods in ANFIS modeling to be used first one Mamdani fuzzy inference and second one Sugeno fuzzy inference, those methods are similar to each other in the first two parts of the fuzzy inference process, fuzzifying the inputs and applying the fuzzy operator, while the main difference between Sugeno and Mamdani is that the Sugeno output membership functions are either linear or constant. For this study Sugeno system considered since the Sugeno, system is suited for modeling nonlinear systems by interpolating between multiple linear models and it uses adaptive techniques for constructing fuzzy models which can be used to customize the membership functions so that the fuzzy system best models the data

From the memberships functions, the output result will be linear. A typical Sugeno type fuzzy inference system rule is: *If Input 1 = x and Input 2 = y*, then output $z = ax + by + c$, for



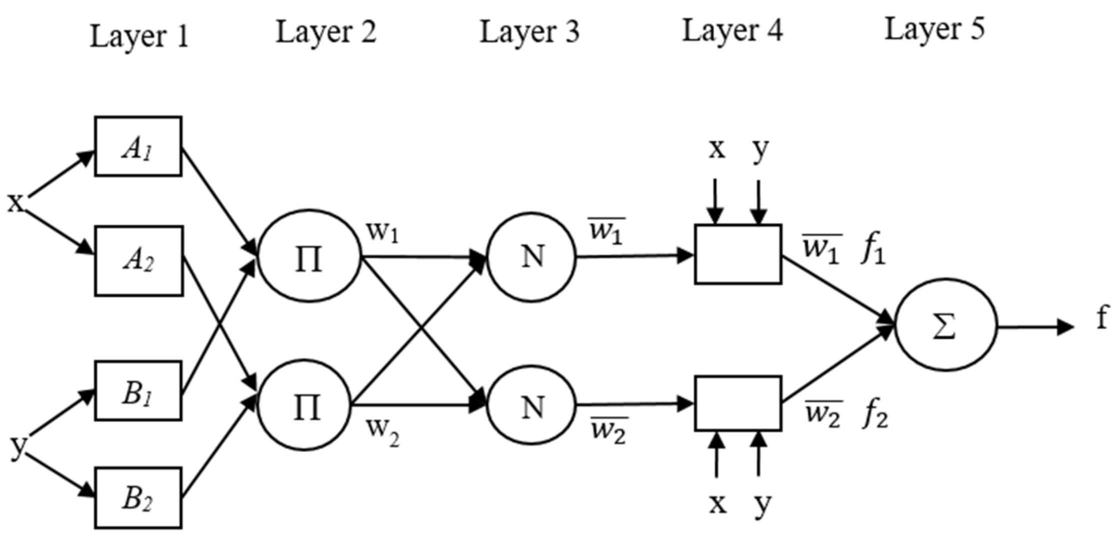


Figure 3.3: ANFIS architecture for two-input Sugeno fuzzy model with two rules (Talpur, Salleh, & Hussain, 2017)

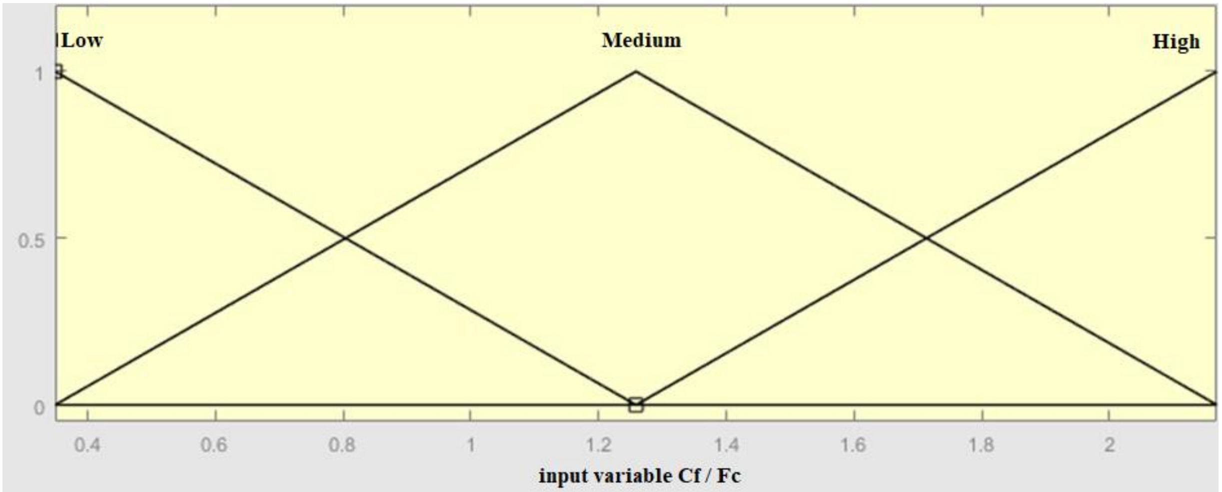


Figure 3.4: Membership function of Cf/Fc

Fuzzy modelling is a branch of system identification which deals with the construction of a fuzzy inference system or fuzzy model that can predict and explain the behaviour of an unknown system described by a set of sample data (Jang, Sun, Mizutani, & Ho, 1998). The adaptive neuro-fuzzy inference system (ANFIS) is efficient approximates model that combines neuro-fuzzy systems and the other machine learning techniques. The ANFIS's map is significantly different from that of the ANN. It goes from input characteristics to input membership functions, from rules to a set of output characteristics, then to output membership functions, to a single-valued output, or to a decision associated with the output.

ANFIS is a class of adaptive, multi-layer feedforward networks, which is comprised of input and output variables and fuzzy rule base of Tabkagi-Sugeno fuzzy if-then rules for a first-order Sugeno fuzzy model, (Tavakkolizadeh, M. and H. Saadatmanesh, 2003). A two rule-based ANFIS model with x and y inputs and f output are expressed in Eqns.3.1 and 3.2.

Rule (1): If x is A_1 and y is $B_{1,}$ then $f_1 = p_1x + q_1y + r_1$ (3.1)

Rule (2): If x is A_2 then y is B_2 then $f_2 = p_2x + q_2y + r_2$ (3.2)

Where A_1 and A_2 are the input membership function (MFs) for the input layer, B_1 and B_2 are the inputs (MFs) of y, respectively. The output function parameters are p_1, q_1, r_1 and p_2, q_2,r_2. The framework of ANFIS consists of five layers, which are described below:

Layer 1: This layer is responsible for the production of the input variable membership grades in each node. The values of membership functions for each i th nodes are defined in this layer:

$$Qi^1 = \mu Ai\ (x) = \frac{1}{1+\left[\left(\frac{x-Ci}{ai}\right)^2\right]^{bi}} \qquad (3.3)$$

Where x is the input to node i and Ai if the linguistic label associated with this node function, ai,bi,ci is the parameter set that changes the shapes of the membership function.

Layer 2: In this layer, each node multiplies by the incoming signals, as shown by Eqn. 3.4:

$$Qi^2 = wi = \mu Ai\ (x)\ \mu Ai\ (x) \times \mu Bi\ (y),\ I = 1, 2\ \ldots. \qquad (3.4)$$

Layer 3: This layer is responsible for the normalized firing strength for the membership values in node i th by the equation:

$$Qi^3 = wi = \frac{w1}{(w1+w2)}\ \ i = 1, 2\ldots. \qquad (3.5)$$

Layer 4: In this layer, the relationship between the input and output value can be established by the equation:

$$Qi^4 = wi\ (pi\ x + qi\ y + ri) \qquad (3.6)$$

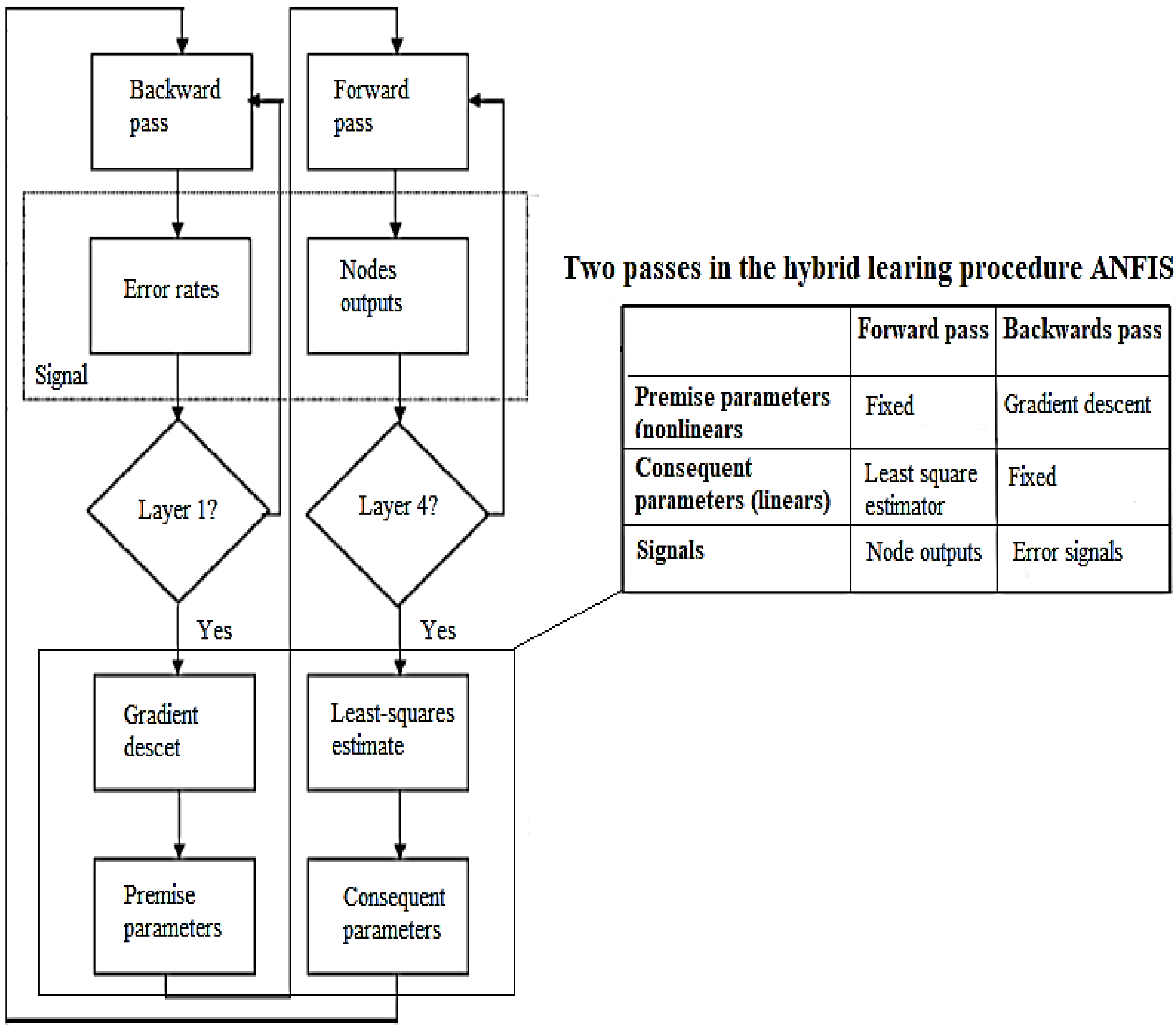
Where wi is the output from layer 3, andpi, qi, ri are the parameters. Parameters in this layer will be referred to as ‘consequent parameters.

Layer 5: This layer includes only one node and it makes a summation of all the output results which comes from the previous node and gives the output in a single node by the equation:

$$Qi^5 = \frac{\sum iwi\, fi}{\sum iwi} \tag{3.7}$$

The learning rule of ANFIS is exactly the same as the back-propagation learning rule used in the common feed-forward neural networks (Rumelhart, Hinton, & Williams, 1985). The optimization parameters are, ci which are the premise parameters, while $,qi$ $,ri$ are the consequent parameters. A hybrid-learning rule was employed in this research, which involves gathering the gradient descent and the least-squares method in order to find the appropriate set of preceding and consequent parameters (Aqil, Kita, Yano, & Nishiyama, 2007). The advantage of using a hybrid-learning rule was that it also seemed to be significantly faster than the classical back-propagation method (Jang et al., 1998).

The hybrid-learning procedure includes two passes, namely the forward pass and the backward pass. In the forward pass, the functional signals will go forward till layer 4 and the least-squares technique will identify the consequent parameters. In the backward pass, the error rates transmit backward and the gradient descent (finding the minimum) will update the premise parameters (justify parameter). While the values of the premise parameters are fixed, it's possible to express the overall output as a linear combination of the consequent parameters (Cüneyt Aydin et al., 2006). Figure 3.5; show the Hybrid-learning procedure of ANFIS.



	Forward pass	Backwards pass
Premise parameters (nonlinears	Fixed	Gradient descent
Consequent parameters (linears)	Least square estimator	Fixed
Signals	Node outputs	Error signals

Figure 3.5: Hybrid-learning procedure of ANFIS (Cüneyt Aydin et al., 2006).

3.4 Data normalization and Performance Evaluation

To ensure equal attention is given to all inputs and output, and to eliminate their dimensions, the data used in this study were scaled between 0 and 1. The main advantage of data normalization before the application of AI models is to reduce data redundancy, to avoid numerical difficulties in the calculation, and to avoid the using of attributes in bigger numeric ranges that overshadow those in smaller numeric ranges (Sola & Sevilla, 1997). Therefore, the data used in this study were normalized using Eqn. 3.8 prior to ANFIS modelling.

$$\frac{x - x_{min}}{x_{max} - x_{min}} \tag{3.8}$$

ANFIS models developed with training and testing data sets were evaluated for their prediction capacity using the performance indicator metrics. Coefficient of determination (R^2), covariance (COV), mean squared error (MSE), root mean squared error (RMSE) and correlation factors (R) were the common statistical performance indicators adopted in various studies (El-Badawy, Abd El-Hakim, & Awed, 2018; Kok et al., 2010; Liu, Yan, Liu, & Zhao, 2018).). R^2, RMSE, and R as expressed in Eqn. 3.9, 3.10 and 3.11 were adopted in this study.

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(\hat{\gamma}_i - \gamma_i)^2} \tag{3.9}$$

$$R^2 = 1 - \left[\frac{(\gamma - \hat{\gamma})^2}{(\gamma - \gamma_{mean})^2}\right] \tag{3.10}$$

$$R = \sqrt{R^2} \tag{3.11}$$

Where γ_i is the data observed in the experiments, $\hat{\gamma}_i$ is the ANFIS model predicted data and n is the number of target values.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

In general, this chapter presents the discussion on both of the results from soft computing and experimental issues related to natural rubber modifiers in asphalt mixtures. In the first section for experimental, to understands the performance polymers mixed asphalt throughout aging in the conduct of un-aging (normal), RTFO and PAV. The dynamic viscoelastic property is evaluated by the indicators plots of dynamic mechanical analysis isochronal plots, Black diagrams, and rutting parameters. The following section will be discussed on ANFIS outputs, which is evaluated within different performance criteria. On the final section, ANFIS output assessed by performance criteria will be considered compare with experimental results evaluated by rheological properties will be presented.

4.2 Rheological Viscoelastic Properties

4.2.1 Isochronal plots

In general, Figs. 4.1, 4.2, 4.3 and 4.4 are isochronal plots of complex modulus G* and phase angle at 1.5 Hz and 146 Hz respectively of natural rubber composite of asphalt modified versus temperature. These plots are shown for the un-aged (normal), short term aging, long term and together short term with long term for weathering effects of binders. were these plots used to provide the effects of weathering within constant frequency on the basic association of complex modulus on given temperature as well phase angle on the given temperature to inferred rheological properties of mixed asphalt after aging.

In order to analyze the influence of weathering effects on chemical, physical and rheological properties of natural rubber asphalt binder after aging assessing RTFO together with PAV will offer better representation. It is seen that the combination of asphalt modified binders complexes modulus increase within increasing the concentration percentage of Expoxidised Natural Rubber binders. As for plot shows, RTFO + PAV within 6ENR is higher than all other types of binders in which the increasing of G* observed within reeducation of temperature vulnerability, this makes the different characteristics of asphalt binder as well as increased. In this manner, un-aged normal asphalt binder confirms that the increasing G* is until only reaction aging of unmodified asphalt binder.

However, because the reaction of modifiers ENR takes place in delay period throughout the aging process within the rising temperature ranging from 60°C to 80°C the un-aged stiffness becomes lower than modified asphalt binder clearly shown on 146Hz plots. And it is understandable the ENR polymers sensitive to transition at low frequency with high temperature, which makes modified asphalt binder developed to resist the deformation cracking.

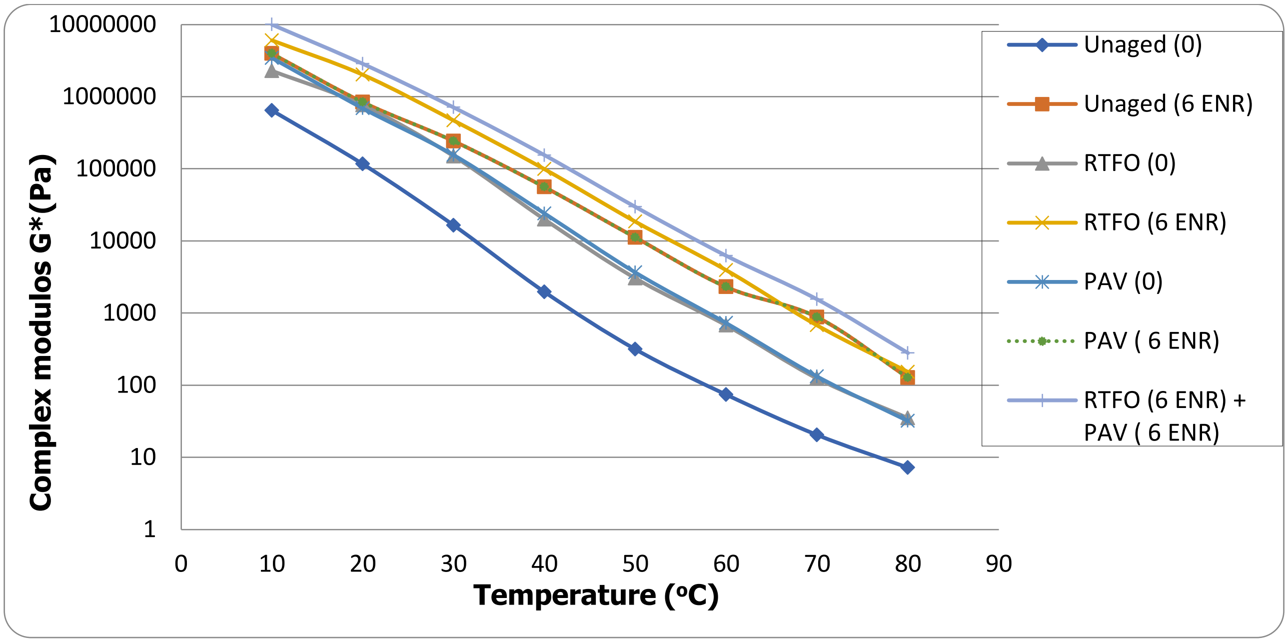


Figure 4.1: Isochronal plot of G* at 1.5 Hz

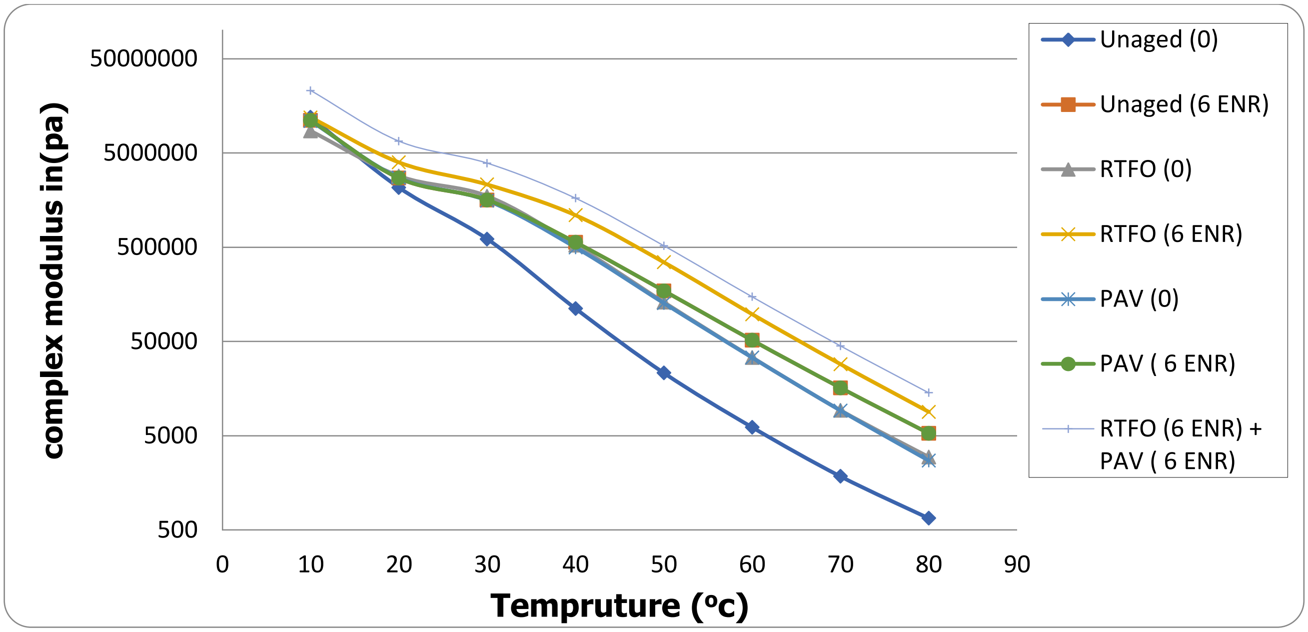


Figure 4.2: Isochronal plot of G* at 146 Hz

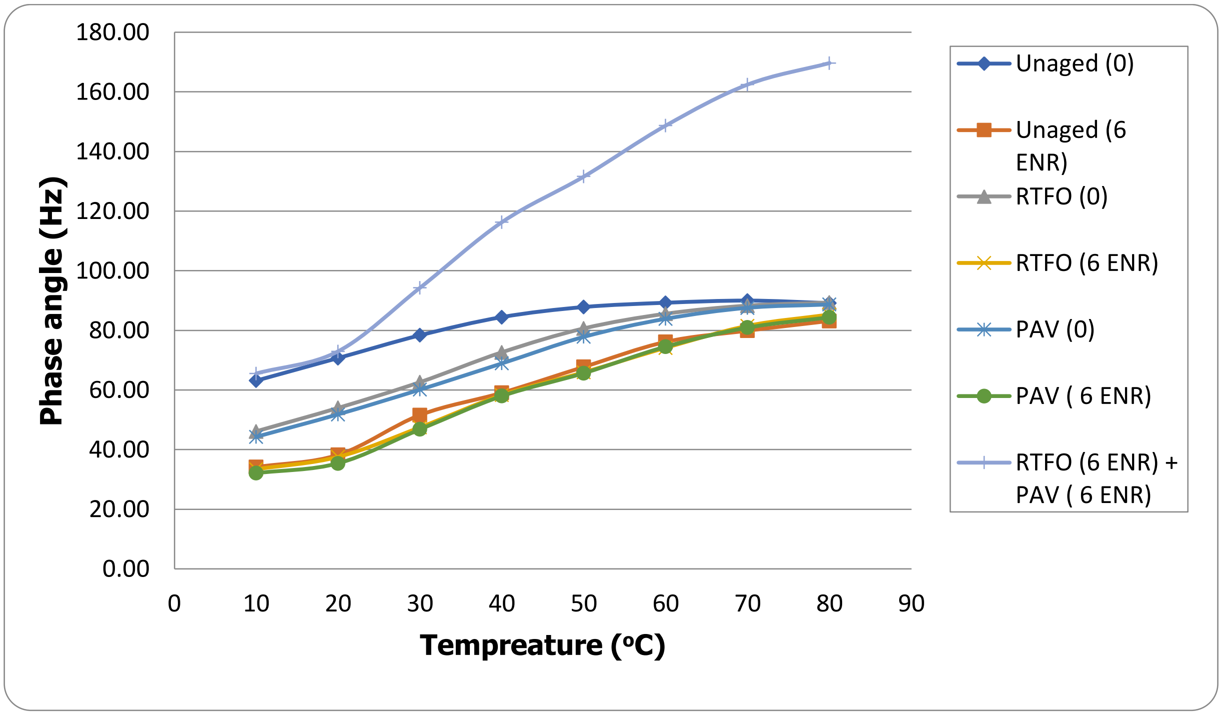


Figure 4.3: Isochronal plot of phase angle at 1.5 Hz

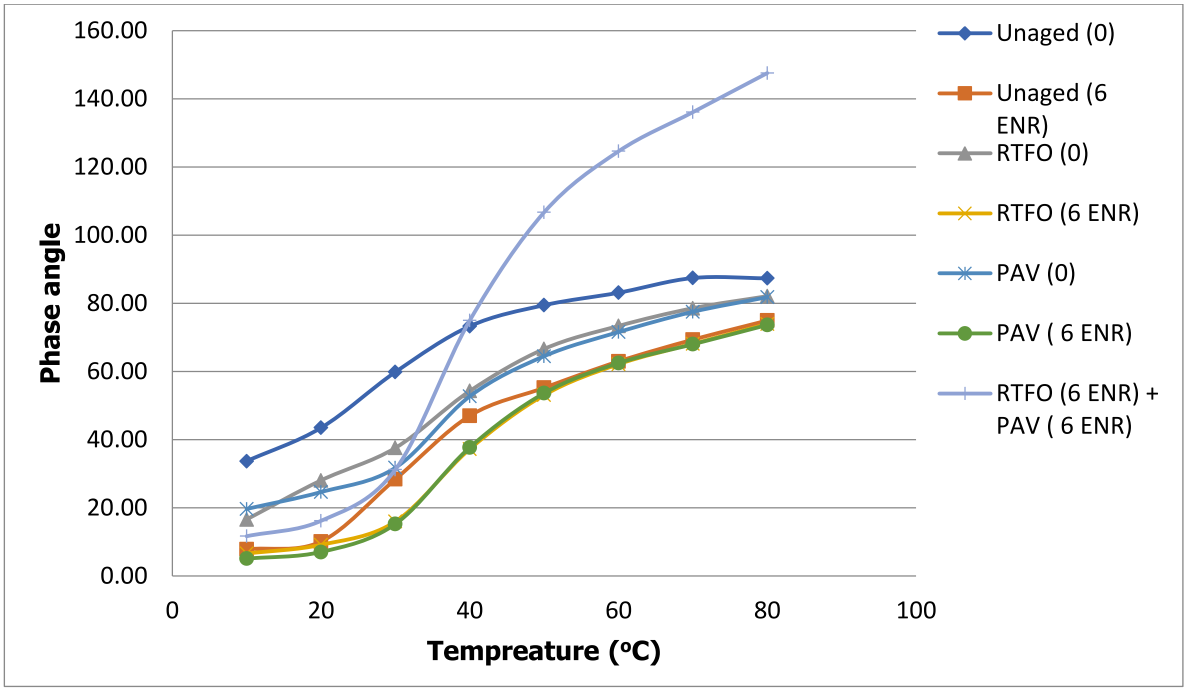


Figure 4.4: Isochronal plot of phase angle at 146Hz

In phase angle, throughout the change of temperature special from intermediate to high indicated that the phase angle ENR values being decreased due to increasing the concentration percentage of Epoxidised Natural Rubber binders. In this context, throughout the aging process the transition of phase angle to increasing in the same way for un-aged, RTFO and PAV of modifier concentration content with rising temperature shown starting 50^{o}C on the plots, however until intermediate temperature unmodified asphalt binder control for the characters of the binder. Since in viscoelasticity relation increasing temperature and frequency loading within increasing concentration content of binders leads to decrease phase angle which suitable for modifier binders more elastic. This implies that if increasing phase angle for jointing base asphalt and binders will improve the binder elasticity, however, starting from 20 ^{o}C and 30 ^{o}C for 1.5 Hz and 146 Hz respectively.

4.2.2 Black diagram Curves

This type of representation of test data eliminates the frequency and temperature and allows us to compare the viscoelastic response of bituminous materials without manipulating the raw data through the time-temperature superposition principle. Generally, a black diagram is a useful tool in identifying possible discrepancies in test data, in verifying time-temperature equivalence and the thermo-rheological simplicity of test samples, and in identifying different types of asphalt binders. From this viscoelasticity response observed on the diagram the elasticity of the modified binder increases with increasing the concentration percentage of modifiers binders and decreasing phase angle; also, from curve shows decreasing G* lead to decreasing stiffness and decreasing phase angle lead to increase elasticity.

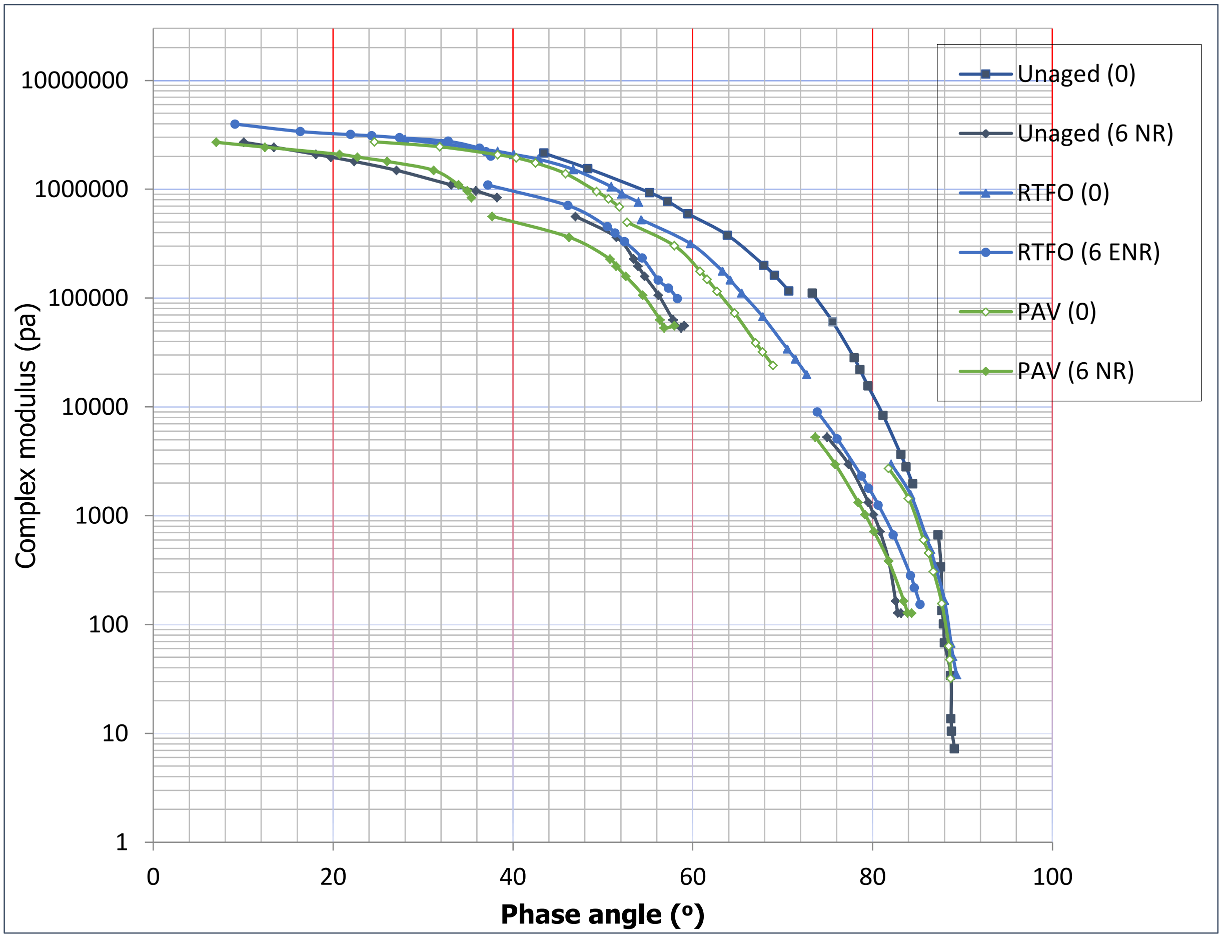


Figure 4.5: Black diagram plots of complex modulus against phase angle

As on the black diagram curve; as the Visco-elasticity, the elasticity of ENR asphalt binder modifier will increase as increasing the content of modifier, also increase G* and decrease phase angle within high temperature and low frequency throughout the aging process. And In short term aging, as temperature increased both 0% and 6% composite of ENR asphalt binder of un-aged, RTFO, and PAV become more near each other. However, after long term aging 6% content of binder becomes stiffer at low temperature; high frequency and more elastic at high temperature; low frequency. This makes modified natural rubber asphalt binder more resist rutting and cracking.

4.2.3 Rutting resistance

The rutting parameter calculated as the division of the complex modulus G* and phase angle in the existing modified asphalt binders not only to provide a rutting performance evaluator, but also determinate the high temperature performance grade of binders, which are required as minimum of resisting rutting the $G^*/\sin\delta > 1.0$kPa for original un-aged binder and $G^*/\sin\delta > 2.2$kPa for RTFO and PAV binder at a maximum pavement design temperature. So, the rutting These plots described the role of a modified binder in order to constant rutting (deformation), which implies the repelling of asphalt binder of cracking rutting within factors of frequent traffic load G* and non-recoverable loading period of energy. The scatter plots show that the increasing ENR concentration content leads to develop the performance of modified asphalt binder RTFO and PAV within increasing G* and decreasing phase angle used to repel the deformation. The performance grade of RTFOs and PAV improved with the addition of ENR, this indicating that ENR improves the rutting resistance. Throughout the aging process un-modified of un-aged (0) was higher than unmodified RTFO (0) and PAV (0). However, the $G^*/\sin\delta$ for un-aged (6 ENR) after 6 ENR of RTFO and PAV were decreased, except at 10 ^oC.

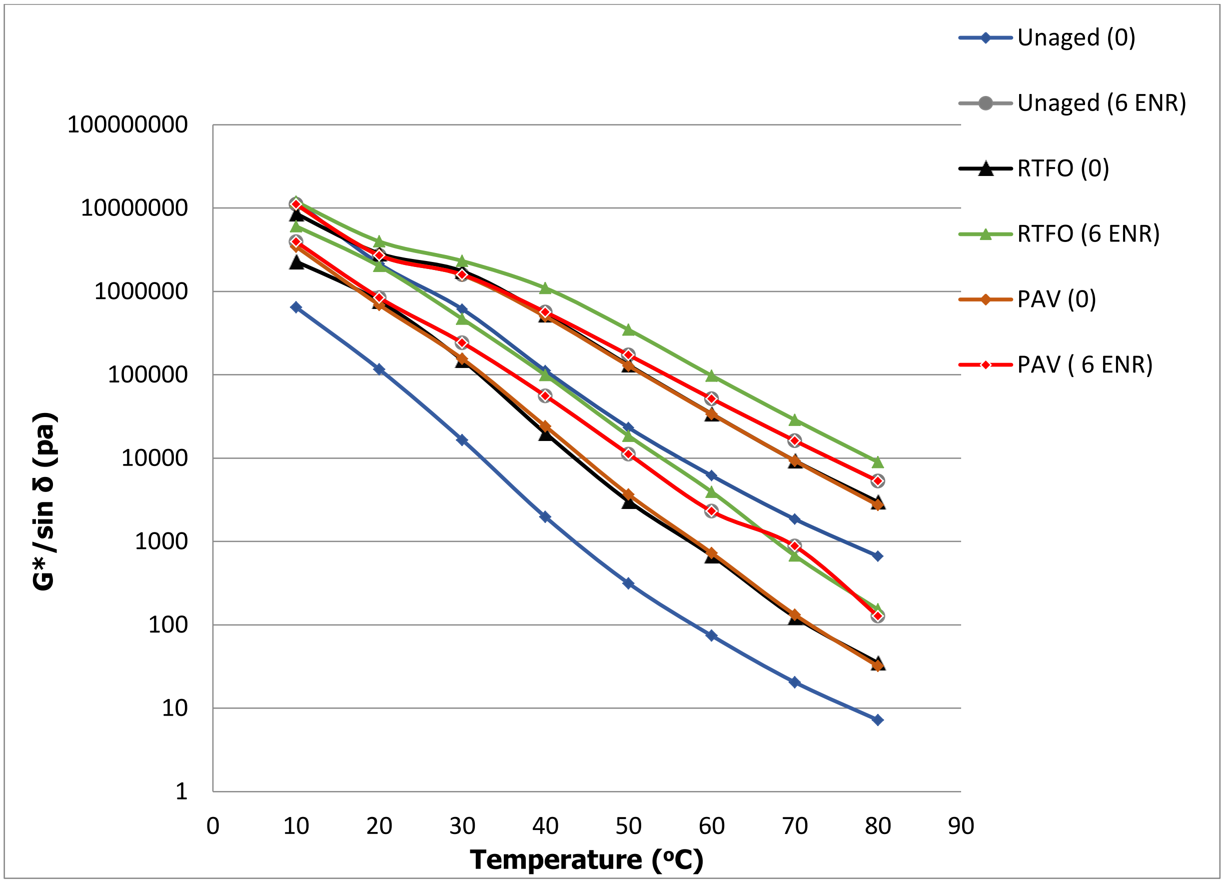


Figure 4.6: Effect of temperature on the rutting resisting.

4.3 Adaptive Neuro-Fuzzy Inference System Model

In general, the ANFIS Model was accomplished within the trail and test process that can be considered the input formulated with and without the output of experimental normalized data using a Sugeno type fuzzy inference algorithm. In order to predict in good manner trial and error were 50 times the procedure was adopted for the formulation of the structure of the ANFIS model. in this context, As stated in the earlier chapter the classified dataset used for training, and, testing the network in this way, the data severance was reduced. Additionally, in ANFIS the performance of the ANFIS model with the training and testing dataset for complex modulus and phase angle in a different perspective of the ANFIS model is represented in Fig. 4.7 and 4.8.

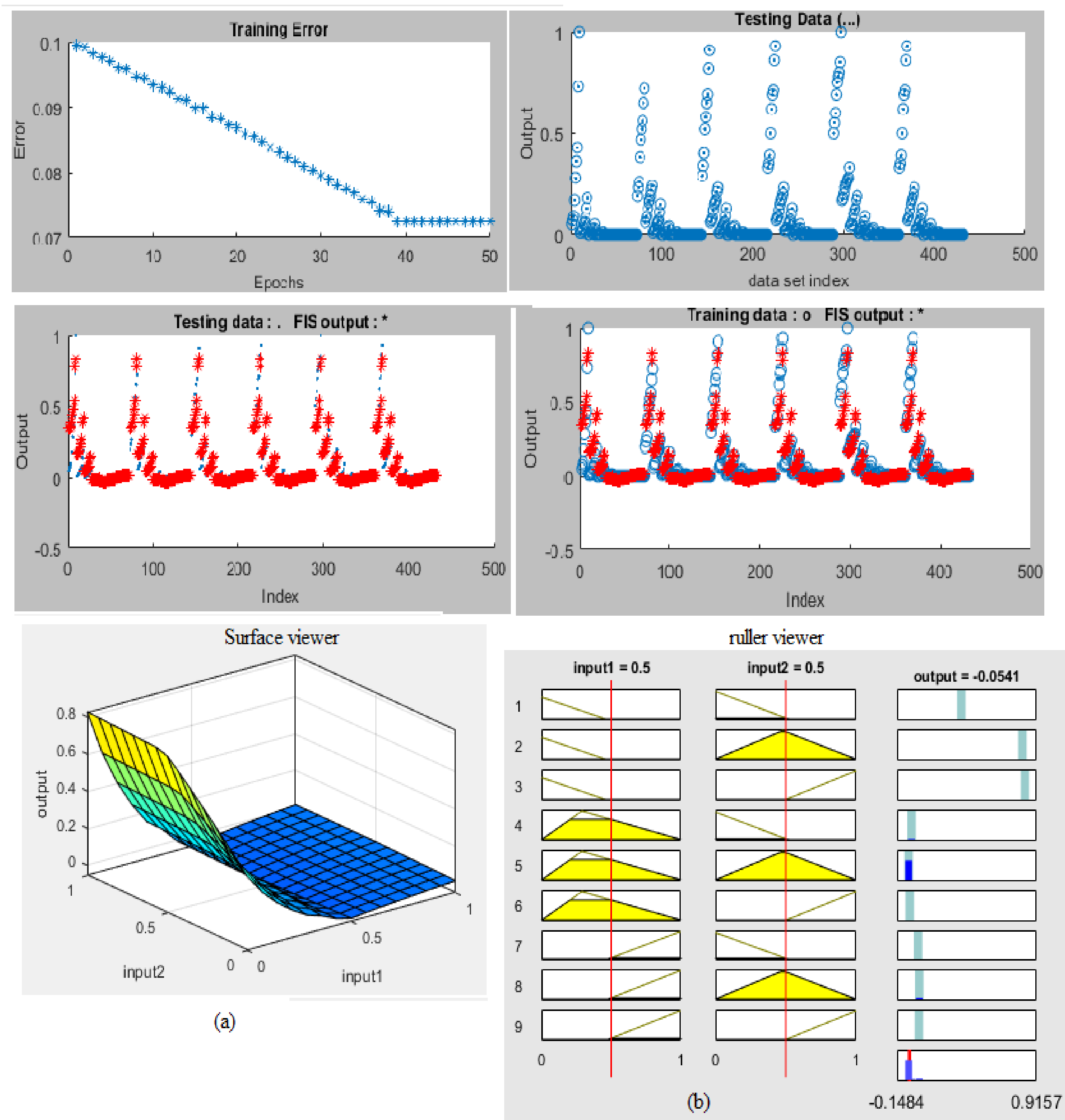
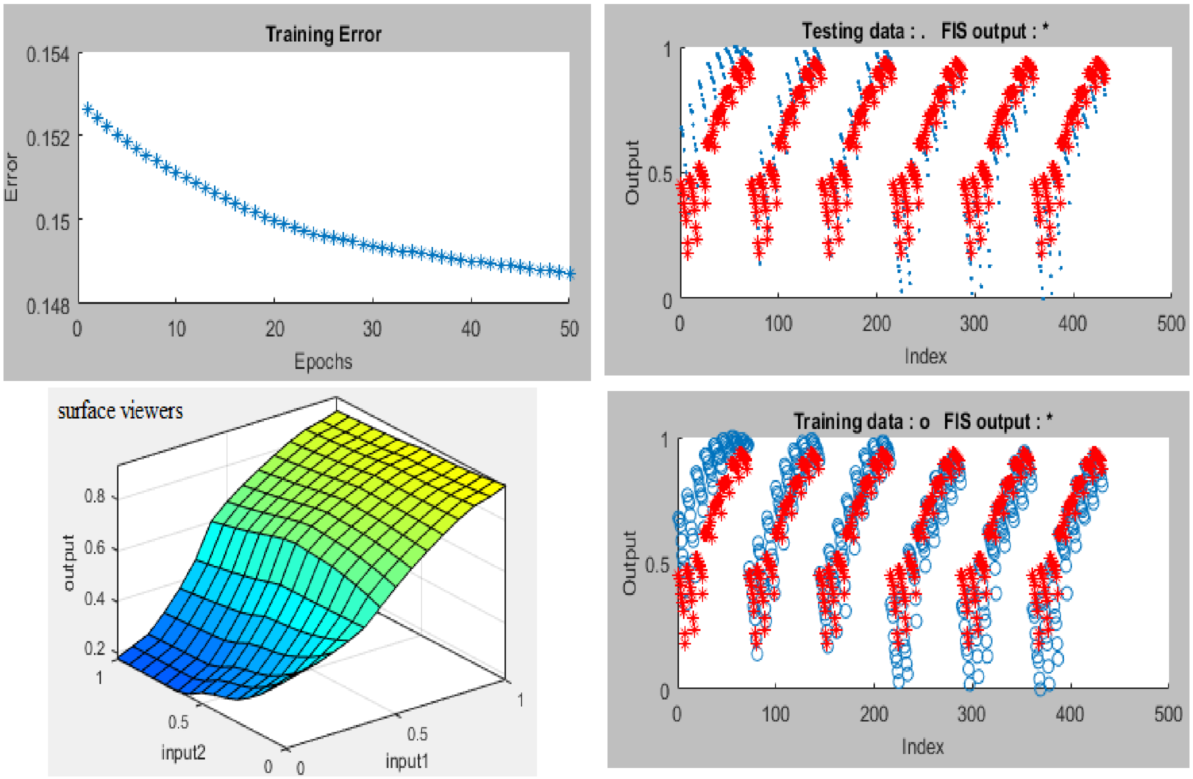


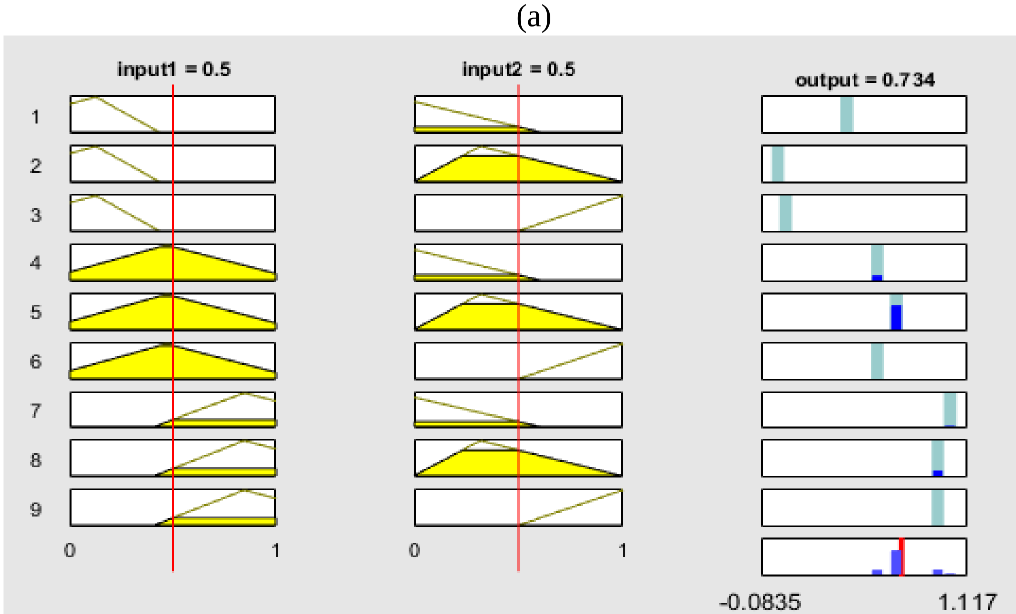
Figure 4.7: ANFIS network modelling performance of G*: (a) Testing data, Training data input output and surface, (b) ruler viewer for random input.

In the commencing,   the ANFIS network was trained with data measured in the presented experimental procedure. 75% of data was used for training and 25% of data was used for testing. Three bell-shaped membership functions were used to fuzzily the ANFIS inputs. After the training process to determine the error approach throughout defining the learning technique, the ANFIS network was tested to determine the predicted complex modulus and phase angle and displays ANFIS decision surfaces as shown in Fig. 4.7 and 4.8 (a). to show the accuracy of the predicted results, the rule viewer of complex modulus and phase angle which was selected randomly was plotted. To predicts for complex modulus as shown in Fig. 4.8 (b) within 2 inputs and 9 rules were applied related to the rules and consist of membership functions corresponding to each of the inputs and the final output is observed. The last column of this figure which is identified as the consequent membership depicts the exact value of complex modulus for this special case that is equal to 0.734 which is in good agreement with the experimental result.

The values predicted by the ANFIS model are shown in the form of scatter plots in Fig. 4.9, 4.10, 4.11, 4.12 for the complex modulus and phase of different types of binders. These results represent 75% of the total as training results and 25%of total data for testing results plots. According to training data of G* plotted in Fig. 4.9, shows, the R^2 value for the fitted line is 0.8565, which is adequate value.



(a)



(b)

Figure 4.8: ANFIS network modelling performance of phase angle: (a) Testing data, Training data input output and surface, (b) ruler viewer for random input.

The R^2 value for the fitted line is the value used to designate the prediction output of ANFIS modeling by making a line within the simple linear free equation of co-related predicted and measured to check whether the line is the cross output of predict. In addition, this value can compare with the linear equality line and 95% predict bounders in order to check and designate the predicted models for further controlling to implement for several prediction outputs. In general, as shown on those Figs of comparing predicted with measured complex modulus and phase angle using training and testing results, this modeling of the prediction outputs is adequate and has a good capacity to model and provide predict of accurate performance of each binders type. Since the predicted model outputs had an adequate R^2 value and covered in 95% of the predicted area.

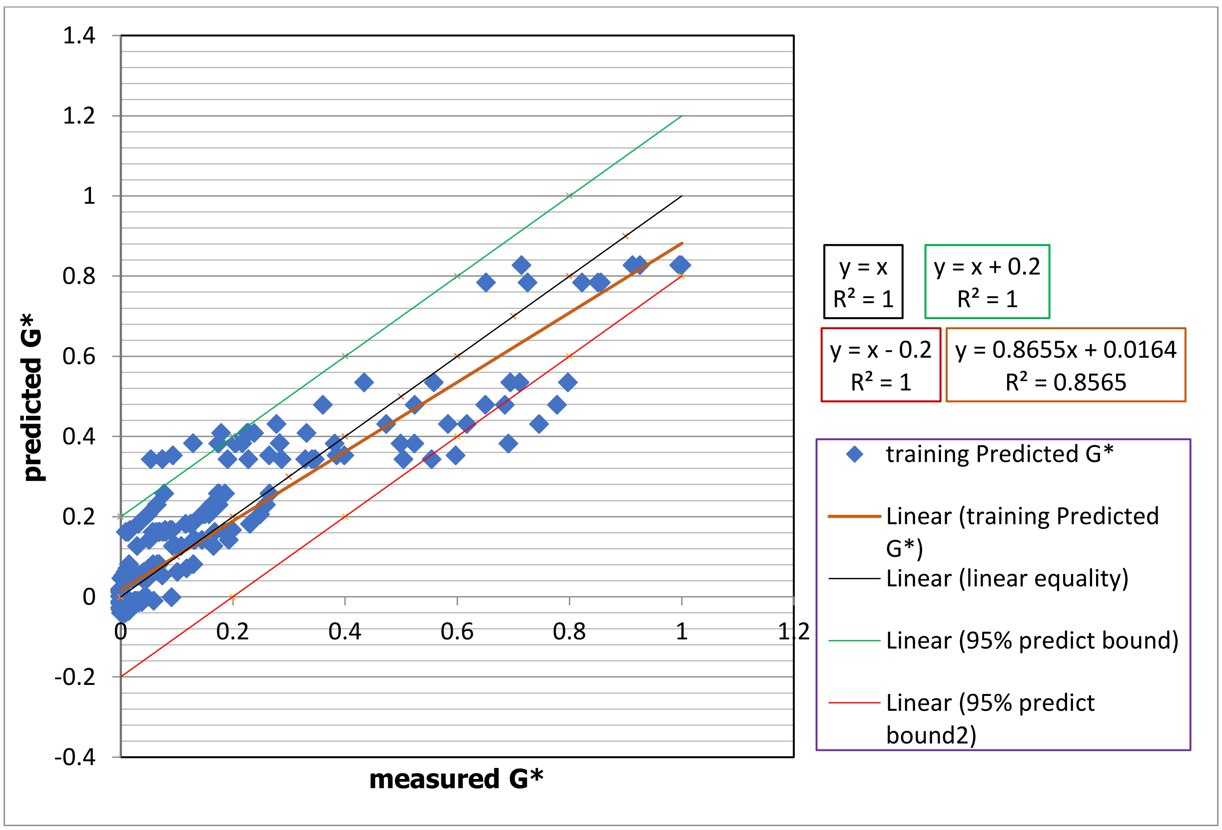


Figure 4.9: Comparing of predicted and measured G* results using training data.

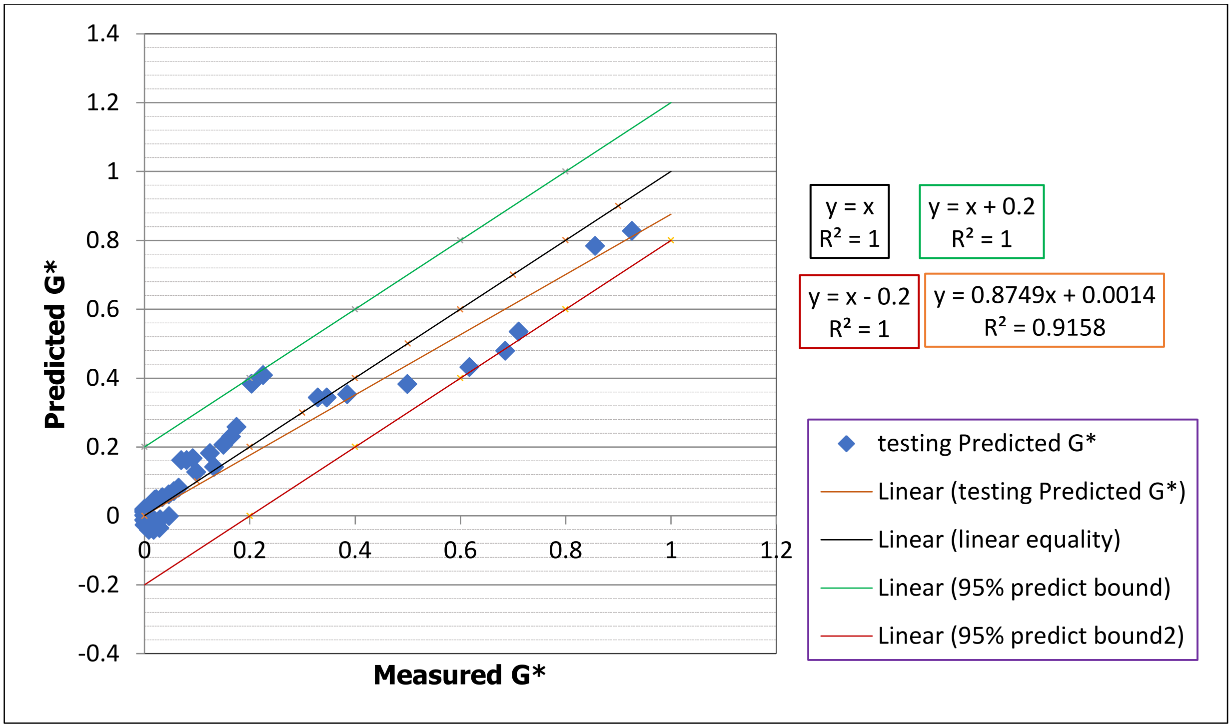


Figure 4.10: Comparing of predicted and measured G* results using testing data.

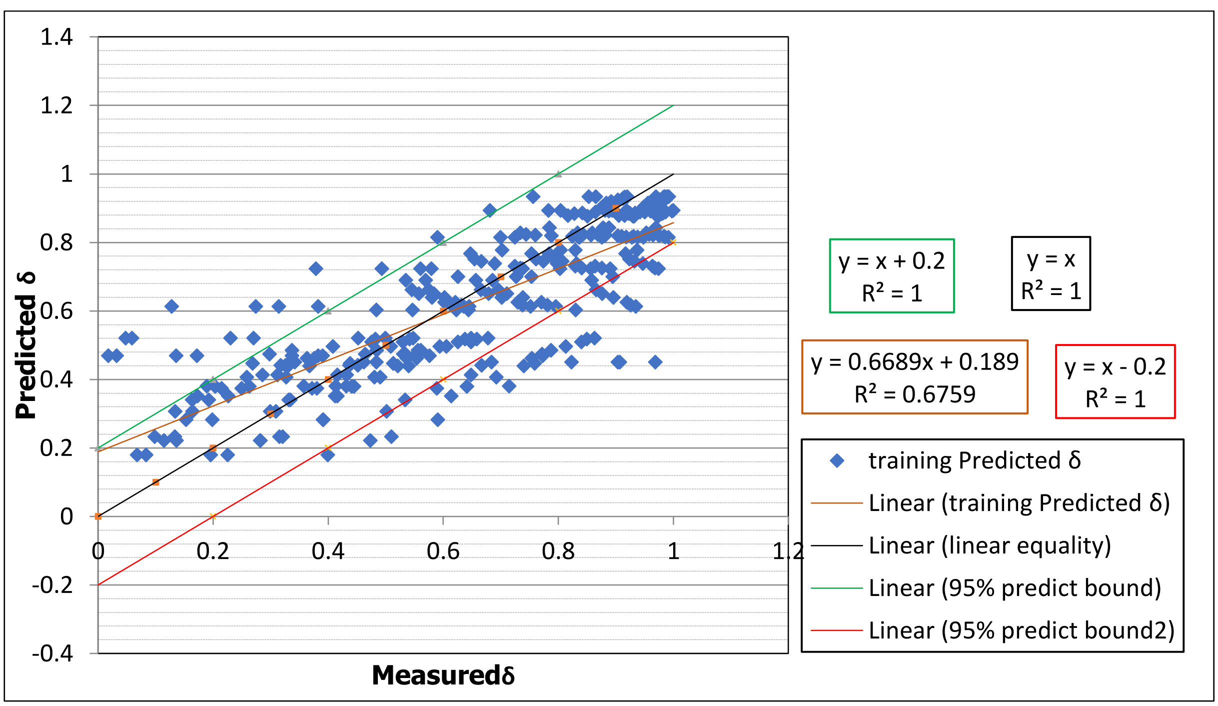


Figure 4.11: Comparing predicted δ and measured δ results using training data.

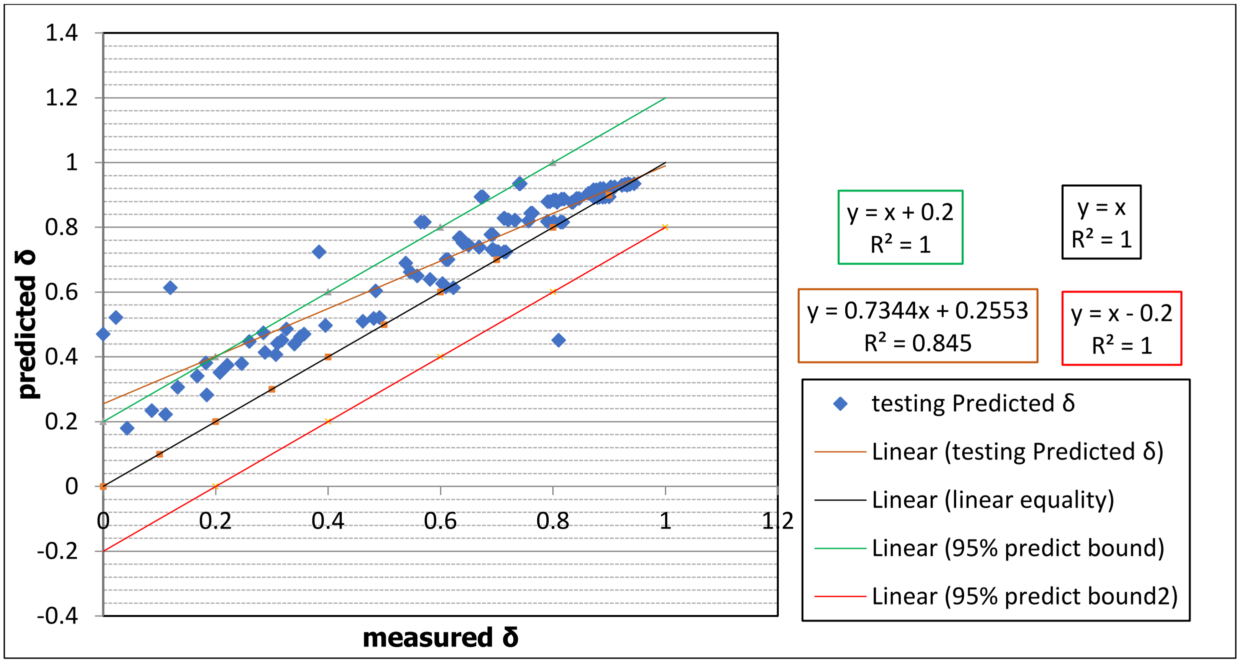


Figure 4.12: Comparing predicted δ and measured δ results using testing data.

In this study, to evaluate the ANFIS model performance and measurement values, the following statistical indicators were selected: Coefficient of determination (R^2), Root-mean-square error (RMSE), and correlation factors (R). An R^2 and R values, which is a measure of the correlation between predicted and measured values, close to 1 reflect a good agreement between the predicted values from the ANFIS model and measured values. The lower the RMSE value the lower the error in the prediction; therefore good prediction is achieved with higher R^2 and lower RMSE. And R was used to evaluate the regression performance of the ANFIS model. R^2 and RMSE were used to evaluate the degree of correlation stiffness and elasticity between each input. The R^2, RMSE and R values for the model are shown in Table 4.1. Considering this, the better to be predicted with high accuracy performance of prediction for the future confirms that the R^2, RMSE and R statistics evaluated in Table 4.1 and Fig.4.13. It can be concluded that ANFIS model 1 can be used to highly reliably forecast complex modulus.

Table 4.1: Performance of ANFIS Model

Target	Training data			Testing data		
	R^2	RMSE	R	R^2	RMSE	R
G*	0.856	0.078	0.925	0.912	0.052	0.955
δ	0.663	0.153	0.814	0.704	0.136	0.839

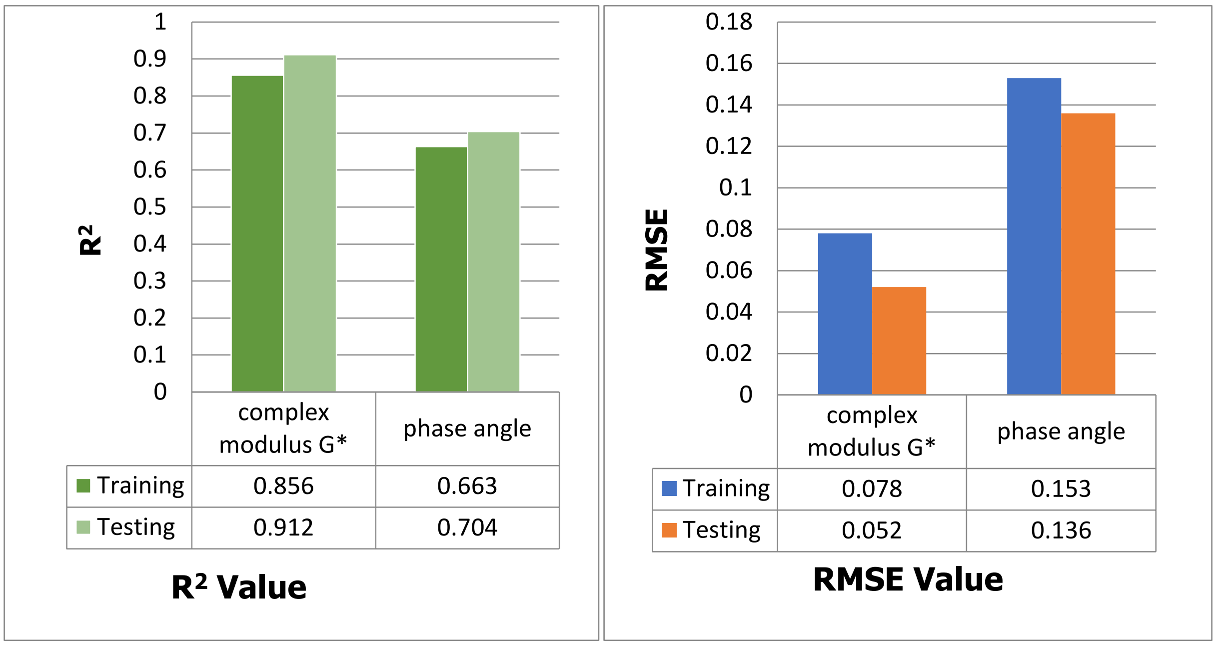


Figure 4.13: Comparing graphical R^2 and RMSE for training and testing data.

4.4 Comparison between Experimental results and ANFIS

In this study, the experimental result is to inspect the performance characteristics of physical and rheological properties of asphalt binder as un-aged, RTFO and PAV in different binder types within the current output of laboratory tests for the practical case in constructed condition. Based on the experimental investigation the input and output factor will determine the evaluation of the potential of different asphalt binders using different plots of scatters within phase angel, complex modulus, temperatures, and frequency as indicators of performance. In general, when the stiffness complex modulus increased as the phase angle reduced and adding modifiers considering the weathering effects of asphalt binders will improve the performance characters of rheological properties of different modifiers asphalt binders types. However, for non-linear and complex output data, which are not determine within scatters plots to evaluate the performance of rheological properties of natural rubber asphalt binders modifier required more experimental complex calculation and needs further experimental tests by changing the contents of modifiers within different binders types to get the accurate characteristics of applied natural rubber asphalt binder modifiers. In this case, experimental methods will be cost money for materials and laboratory expenses and expend much time with energy loss.

Soft computing is the critical pattern in order to simplify the complexity and loss of energy by reducing cost-effective in the practice of construct pavement situations as well as, in the future for repairing experimental results natural rubber asphalt binder modifiers. In this manner, ANFIS can predicted, model and control the performance of natural rubber asphalt binder modifiers during construction (RTFO) and in the future (PAV) under consideration of weathering effects (RTFO + PAV). According to the analysis of ANFIS modeling, the developed models will evaluate the experimental data goodness in the prediction condition using the statics performance indicators criteria of R^2, RMSE, and R for exploring the weathering effects features on natural rubber asphalt binder modifiers shown on fig. 4.14.

Table 4.2: summary Comparison between experimental results with ANFIS modeling

As comparing of	Descriptions
Experimental results	Inspect the performance characteristics of physical and rheological properties of asphalt binder as un-aged, RTFO and PAV: • Using scatters within δ, G*, temp., and frequency as indicators of performance from output of laboratory tests for the constructed condition. • Found that, as the stiffness G* increased as the δ reduced within adding modifiers considering the weathering effects of asphalt binders will improve the performance.

	• However, for non-linear & complex output data as shown on Fig. 4.14 more experimental complex calculation & further experimental tests is required, as well changing the contents of modifiers, this make it loss of cost, time and energy happened.
ANFIS modeling	Predict, control & model the performance characteristics of physical and rheological properties of asphalt binder as un-aged, RTFO and PAV including non-linear & complex output of experimental data: • Using R^2, RMSE & R as indicators of performance from modeling of ANFIS in the future condition. • Found that, as the analysis of ANFIS modeling, the developed models for the experimental data of asphalt binders is in good performance.

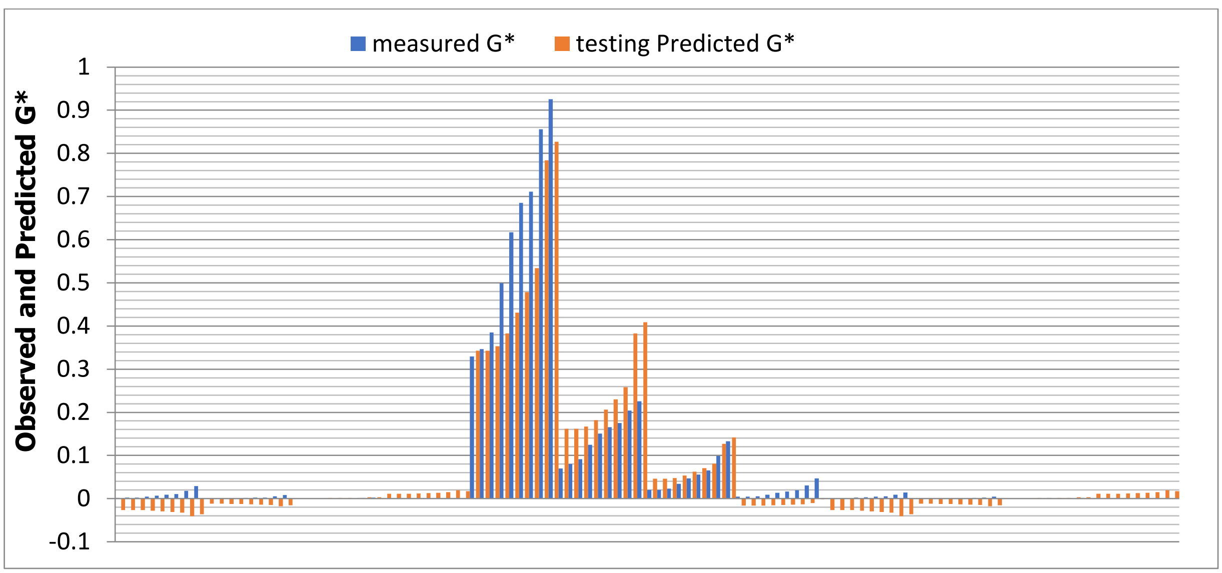


Figure 4.14: Comparing graphical predicted vs measured G* results using testing data

CHAPTER 5

CONCLUSIONS AND RECOMMENDATION

5.1 Conclusions

The foremost conclusions of these studies can be concluded into two analyses of results regarding experimental results and soft computing models to evaluate the performance, the following statements can be concluded:

5.1.1 Experimental results

- The performance characters of rheological of asphalt binders as un-aged, RTFO and PAV by adding 0, and 6% of ENR using DSR and microstructure testing methods.
- Based on the isochronal rheological parameter of complex modulus; increasing concentration of ENR from 0% to 6 % binder types will increase G*, this improved increase stiffness within increasing a frequency and decreasing temperature. It is notable that asphalt binder at un-aged normal had larger G* than asphalt binder with 0% ENR at a low temperature until modifiers initiate reaction. However, due to the rearrangement of ENR, as the temperatures get higher from 60^{o}C to 80^{o}C all types of modified asphalt binder un-aged, RTFO and PAV of G* decreased.
- As demonstrated by isochronal rheological properties of phase angle; increasing the percentage of ENR 0 to 6% will decrease the phase angle that makes binder flexible as temperatures higher, especially on intermediate from 40-80^{o}C.
- Based on the black diagram curve; as the Viscous-elasticity, the elasticity of ENR asphalt binder modifier will increase as increasing the content of modifier, also increase G* and decrease phase angle within high temperature and low frequency throughout the aging process. And In short term aging, as temperature increased both 0% and 6% composite of ENR asphalt binder of un-aged, RTFO, and PAV become more near each other. However, after long term aging 6% content of binder becomes stiffer at low temperature; high frequency and more elastic at high temperature; low

frequency. This makes modified natural rubber asphalt binder more resist rutting and cracking.

- According to rheological parameter indicators in the aging process of modifiers the RTFO + PAV, together with the show that a better performance than all types of binders, which is more satisfactory in order to resist the extreme weathering effects like earthquakes, and storm disaster.

5.1.2 ANFIS model prediction

- As ANFIS modeling analysis the measured experimental data after normalized will formulated in order to run in an analysis of the Sugeno fuzzy inference algorithm as training and testing epoch.
- In developing a model of predict for the experimental input/output measurement the G* will govern due to it is sensitivity for stiffness and elastic performance properties of viscous-elasticity within defined factors of temperature and frequency.
- Based on performance statics indicators of the prediction will be by R^2, RMSE and R 0.912, 0.052 and 0.955 value, which is the closest accuracy prediction, performance model.
- However, the value of training R^2 0.856 is an acceptable model of predict but, not satisfactory predict value, which may fail of unable to training or failed in recording experimental data. So, R criteria of indicator applied to check the goodness of model whether close to 1 value, the model is good since R is 0.925.

5.2 Recommendation

The performance of asphalt binders will be improved within the mixture of modifiers like polymers as epoxidized natural rubber under consideration of weathering effects. For this study, the modified asphalt within 80/100 penetration prepared sample of RTFO for short term aging and PAV for long term aging, after properly setup under DSR recording machine as adjusted factors with temperature and frequency to measure the complex modulus and phase angle for different types of binder with concentration of ENR 0 to 6% of un-aged, RTFO, PAV and RTFO + PAV. For this, the prediction in the future for the performance of modified asphalt binder from experimental raw data will be normalized in order to formulate as input for ANFIS modeling. The formulate data run in the construction system as input parameters using the Sugeno inference fuzzy system and observe outputs throughout the training and testing analysis. In the final, the observed result from ANFIS modeling evaluated as checking point whether the prediction is well accurate for the performance of physical and rheological properties of modified asphalt binders using criteria of statics indicators R^2, RMSE, and R. in this respect, as presented by this thesis, strongly recommended that for now and the coming times in the future investigating of researches would be motivated on this analysis, model and control within related to the experimental datasets and ANFIS modeling prediction.

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ETHICS LETTER

TO GRADUATE SCHOOL OF APPLİED SCİENCES

REFERENCE: ENG. YIGREM GETACHEW (20183908))

I would like to inform you that the above candidate is one of our postgraduate students in Civil Engineering department, he was taking a thesis under my supervision, the thesis entailed: **PREDICT THE WEATHERING EFFECT OF NATURAL RUBBER MODIFIED ASPHALT BINDERS USING ADAPTIVE NEURO-FUZZY INFERENCE SYSTEM (ANFIS).** The data used in this study did not belong to anyone, it was our own data.

Please do not hesitate to contact me if you have any further queries or questions.

Thank you very much indeed.

Best Regards,

Dr. Shaban Ismael Albrka

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