Investigating the physical properties of reed fly ash modified asphalt binder

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Abstract:

Asphalt binder represents a visco-elastic material that consist of four types of chemical fractions named saturates, aromatics, resins, and asphaltene, differ in their polarity and molecular weight, and then their effect on the properties of asphalt binder. The high solar absorption of asphalt binder due to its black color, making asphalt pavements suffer from various types of distresses like: rutting, fatigue, raveling, etc. The high increment in traffic loads and volumes nowadays leads to sever increment in these distresses. Therefore, the concept of improving asphalt pavements, as well as, reducing the environmental problems and maintaining the natural resources, in addition to saving costs, have stimulated researchers to use the sustainable materials in the improvement process of asphalt binder. Nevertheless, there are limited researches deals with these modifiers. This study aims to study the effect of Reed Fly Ash (RFA) that is represents a type of by-product materials on the physical properties of asphalt binder. Neat bitumen was blend with three dosages of RFA: 6%, 12% and 18% by weight of bitumen. The effect of this modifier on the properties of bitumen was characterized in terms of penetration, softening point, ductility, penetration index, viscosity and aging. The results of these properties indicate that the use of RFA as a modifier for asphalt binder help in decrease both penetration and ductility, increase softening point, viscosity and bitumen sensitivity, as well as, help in enhance the resistance of bitumen to aging, and the influence of RFA on these properties increase as RFA increase. The results encourage the concept of enhancing the asphalt binder by fly ash products.

Keywords : Aging indices, Asphaltene, biomass Fly ash, Modified asphalt binder, Physical properties, Recycled materials.

Introduction

Neat asphalt that is obtained from distillation of crude oil, represents a complex chemical composition material, characterized with several properties like: low cost, widespread availability, besides its visco-elastic, bonding and waterproof properties; that is enable to using it in the paving applications [2-4]. The chemical composition of asphalt consists of high amounts of carbon atoms reached to 88%, hydrogen by about 11%, in addition to oxygen, nitrogen and sulfur atoms that are called heteroatoms, these latest atoms are responsible on the polarity of bitumen [5]. Lesueur [6] reported that the polarity of bitumen fractions represents a relative importance property that help in understanding the relation between chemical and physical properties of bitumen. Other designation stated that the chemical composition of asphalt binder consists of four fractions named SARA components (i.e. saturates, aromatics, resins, and asphaltene) differ in their polarity, molecular weight and solubility. Maltene consists of the non-polar light molecular weight fractions (i.e. saturates and aromatics) that represents the dispersing part in bitumen. In addition, the polar/high molecular weight fraction compared to the first two fractions is the resin, which represents the peptizing part. these three fractions are soluble in n-heptane, and have an ability to dissolution the high molecular weight, and the more polar part (i.e. asphaltene). The four fractions are forming the colloidal system of bitumen [1, 7]. Asphaltene represents the dispersed fraction that is responsible on gaining the asphalt stability and hardness properties [8, 9]. Nejres et al. [1] stated that asphaltene represents the core of bitumen structure that started from the high molecular weight molecules to the light molecular weight, also it have more influence on the physical and rheological properties of asphalt. Polacco et al.[10] reported that the decrement in aromatics and resins fractions leads to decrease the solvating ability medium then forming what means a “gel type bitumen”, due to this lower content, the lighter fractions become restricted to fill the intermicellar voids, then this causes the micelles to aggregate until form a continuous network. Contrary, when these fractions are high, “sol type bitumen” is formed, where the light weight molecules are increased, result in facilitate the asphaltene mobility. Figure (1) show a representation of bitumen structure.

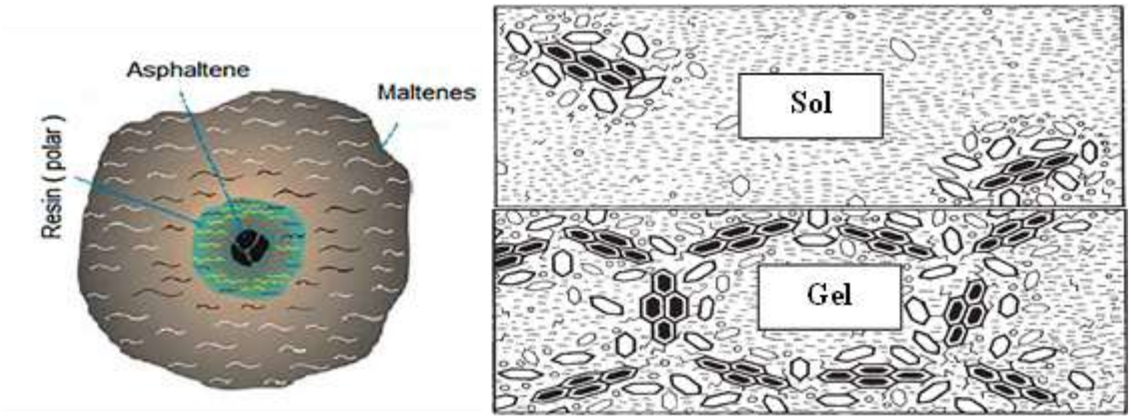


Figure 1. Bitumen structure representation, SOL, and GEL type bitumen [1].

The black color of bitumen increases its capacity to absorb the solar radiation and increase internal temperature, as well as, the increment in traffic loading and volume nowadays, make asphalt pavements suffer from various types of failures like rutting, fatigue and temperature susceptibility, in addition to problems related to aging especially under sunlight, heat, oxygen or combined [4, 11-13]. Inherent property of asphalt. May be affected by some modifiers and asphalt mix additives. Therefore, researchers tend to utilize the modifiers to enhance the properties and upgrade the performance of asphalt binder. Consequently , Asphalt mixture get better performance and increase its service life [14, 15]. Polymers are successful well-known modifiers, commonly there are two types : thermoplastic elastomers and plastomers [7, 13], these polymers may be either virgin or recycled [16, 17]. Recently, many researchers tend to investigate the effect of re-use or waste materials in asphalt binder modification, in order to reduce the costs, environmental impacts and save natural resources [18-26]. The modification process has found to causes an occurrence a series of changes in the bitumen structure in terms of physical formation (disperse a reinforcing network and/ or crosslinking inside colloidal system) and chemical interactions (increase the polarity, enhance the adhesion and cohesion). The mechanics of polymer enhancement have encouraged researchers to investigate the effect of by product fly ashes on the rheological properties of asphalt and mechanical properties of asphalt binder or mixture. Many studies have concluded that the use of such materials have a positive effect on the penetration, softening point, viscosity, dynamic shear rheometer, Marshall stability, tensile strength resistance and other properties [19, 27]. Xue et al.[28], Foroutan Mirhosseini et al. [29] and Arabani et al.[30] reported that the use of ashes like rice husk ash and sate seed ash enhance the thermal sensitivity, ductility, viscosity, complex modulus and rutting resistance of asphalt binder. Besides the improvement of asphalt mixture performance in terms of moisture damage, stiffness, stability, hardening, tensile strength, etc.

Therefore, this study is aimed to increase the understanding of the role of ashes on asphalt binder properties by investigate another type of fly ash: Reed fly ash (RFA) which is a by-product material. Reed is widely growing in Iraq, where it can propose as a source of heat recovery renewable energy plant. However, this can enforce the sustainable approach, whereas nowadays researcher worldwide tend to generate energy from biomass then invest the by-product or waste materials that produced marginally.

Materials

1. BITUMEN

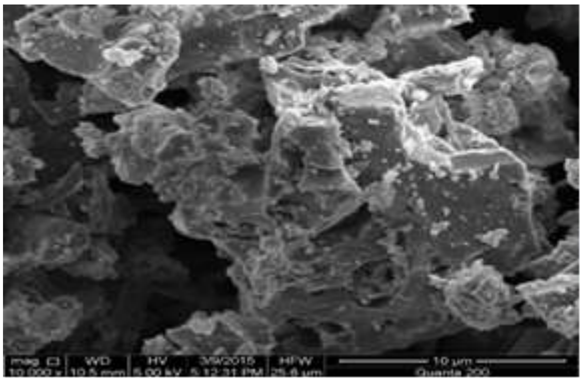
The 40-60 penetration grade bitumen was supplied from locally refinery in Iraq, the physical properties of this bitumen are summarized in Table 1. The neat asphalt binder was inspected to confirm the requirement of GSRB specification [31].

Table 1. Physical properties of neat bitumen.

Property	Measured values	ASTM specification
Penetration (25 °C, 0.1 mm)	43.5	D 5-5a [32]
Softening point (R&B°C)	49.6	D 36-95 [33]
Ductility at 25 °C (cm)	132	D 113-99 [34]
Penetration index (PI)	-1.605	[7]
Rotational Viscosity @135°C, Pa. s	0.87	ASTM D4402 [35]
Flash point, °C	355	ASTM D92 [36]
Solubility, %	99	ASTM D2042 [37]

2. REED FLY ASH (RFA)

Reed fly ash (RFA) was prepared from the burning process of reeds that is grow widely in Iraq, especially around the banks of drainages and marshes. The reeds were burned initially in site in order to reduce its size, then reburned in an oven at 950 °C for two hours as recommended by other researchers [18] in order to achieve the calcination phenomena. Thereafter, burned reeds ash were grind using mechanical grinder for one hour. The properties of RFA are illustrates in Table 2, while Figures (2 and 3) show the scanning electron microscopy and the shape of RFA through the preparation steps.



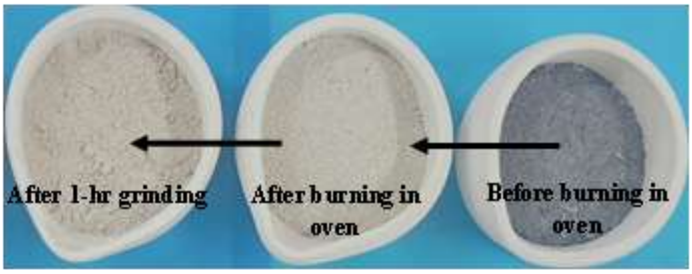


Figure 2. Scanning electron microscopy of reed fly ash . Figure 3. Steps of preparation of reed fly ash.

Table 2. Properties of reed fly ash (RFA).

Chemical properties	
Element	Concentration
SiO_2	73.41
Al_2O_3	2.78
Fe_2O_3	1.21
CaO	9.06
MgO	1.52
K_2O	10.01
Physical properties	
Specific gravity, g/cm3	2.501
Surface area (m^2/kg)	1339

EXPERIMENTAL WORK

1. Preparation of modified bitumen

Three dosages from RFA were used in this study to modify the penetration grade bitumen using mechanical shear mixer device: 6, 12 and 18% by total weight of bitumen. The dosages of RFA were selected close to that used by other researchers like Foroutan et al. [29] and Arabani et al. [30]. Initially, bitumen was heated until become fluid then placed in a preheated container mixer, after that RFA was added to the bitumen gradually where the mixing speed is 1500 rpm. Mixing process was conducted at a temperature of 150 °C as adopted by other researchers like Arabani et al. [30] and Arabani et al. [38], for 30 min duration as recommended by Ouyang et al. [39] .

2. Asphalt characterizing indices

In order to evaluate the physical properties of neat and modified bitumen, generally, three types of tests were conducted: penetration, softening point and ductility depending on the procedures recommended by ASTM D5-D5M [32], ASTM D36 [33] and ASTM D113 [40], respectively. The results of penetration and softening point then were used to calculate the temperature sensitivity index (i.e. penetration index), by using Equation 1 as reported by Read et al. [7] and other authors like Jun et al.[41] and Ameri et al. [13].

$$\mathrm{PI} = \frac{1952 - 500\ \mathrm{logpen} - 20\mathrm{SP}}{50\ \mathrm{logpen} - \mathrm{SP} - 120} \qquad (1)$$

Where: PI is penetration index, Pen. is the depth of penetration at 25 °C and SP is softening point temperature.

Moreover, rotational viscosity test was conduct to evaluate the properties of neat and modified bitumen under high temperature, as well as, the effect of variation in temperature on its behavior. Test procedure was conducted depending on Brook field procedure recommended by ASTM D4402 [35]. The rotational viscosity value represents a function of the torsion required to measure the relative rotational speed of the spindle that is lowered into bitumen sample. Each bitumen sample was tested at four temperatures, the lower one selected at 135 °C for specification requirements, the remaining temperatures 155 °C, 175 °C and 200 °C were selected to displays the effect of variation in temperature on bitumen fluidity.

In addition, the effect of aging on the bitumen behavior was investigated as a function of aging index for the results of physical properties of bitumen before and after subjected to short-term aging using thin film oven test (TFOT). Test procedure was conducted as recommended by ASTM D1754 [42], where the aged bitumen sample was subjected to 163 °C temperature for 5hr. The amount of loss in bitumen sample due to heating was calculated using Equations (2 and 3) for penetration and softening point before and after aging as recommended by Cong et al. [43], Cong et al. [12], Zhang et al.[4].

$$PAI = \frac{Pen._{after\ aging}}{Pen._{before\ aging}} \qquad (2)$$

$$SPI = SP_{after\ aging} - SP_{before\ aging} \qquad (3)$$

$$PIR = \frac{PI._{after\ aging}}{PI._{before\ aging}} \qquad (4)$$

Where: PAI is penetration aging index, SPI is softening point index and PIR is penetration index ration.

RESULTS AND DISCUSSION

1. Penetration

Penetration test gives an indication about the hardness of the bitumen, the results of penetration depth for neat bitumen (NB) and RFA modified bitumen are illustrated in Figure (4). Results show that the penetration decrease with increase the amount of RFA until reached to 27.8 dmm at 18% RFA. The reason of reduction in penetration is returned to chemical reactions with the internal components in bitumen plus physical interaction. Chemically, the polar nature of RFA tends to swollen in maltene, as recommended by [29, 44], as a result asphaltene adhesive part increase, moreover modified bitumen forming “gel type bitumen”. Physically, the high surface area and porous nature of RFA tend to absorb the light weight molecules of asphalt binder. As well as, the presence of SiO_2 in the chemical composition of RFA combined with the previous reactions tend to provide some hardness to asphalt, then resulted in decrease the penetration of modified asphalt; this also means that bitumen stiffness increase, and therefore, the resistance of bitumen to mechanical damages enhanced [30]. The trend of penetration depth appears similar to that obtained by Jeffry et al. [45] when using nanocharcoal coconut-shell ash as an asphalt modifier.

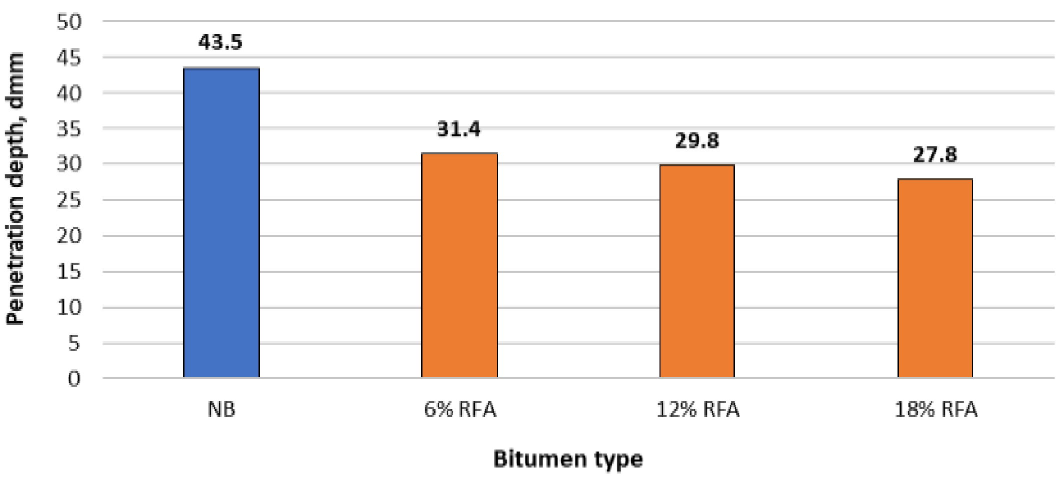


Figure 4. Penetration of neat and modified bitumen.

2. SOFTENING POINT (SP)

Softening point temperature is used to identify asphalt consistency transforming from semisolid to semiliquid. Figure (5) demonstrates the results of softening point for RFA modified bitumen. Results show that the use of modifiers help in increase softening point temperature higher than the NB, where its reached beginning of a sentence, it should be written out as "Equation (1)." Within a sentence, a figure should be cited with "Fig.," for example, "Fig. 1," and at the beginning of a sentence, it should be written out as "Figure 1."

$$Y = \frac{\partial z}{\partial y} + e^{z/x} \quad (1)$$

Italic type must be used for physical and mathematical symbols.

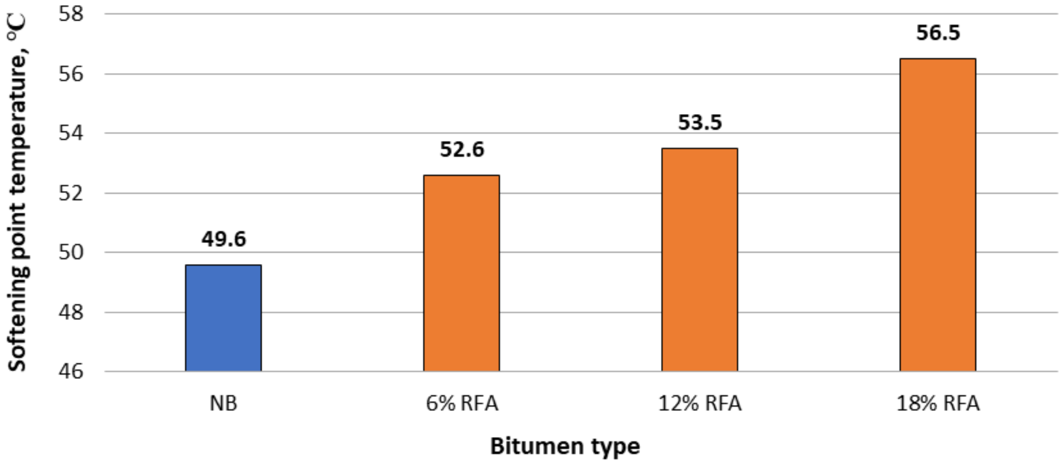


Figure 1. Softening point of neat and modified bitumen.

3. TEMPERATURE SUSCEPTIBILITY

The penetration index (PI) is very helpful in showing the amount of sensitivity of modified bitumen to temperature. The results in Figure (6) show the behavior of modified bitumen to resist temperature sensitivity. Results indicate that the use of modifiers enhance the susceptibility of bitumen to temperature as the RFA content increase, where its reached to -0.958 at 18% RFA. The main reason returns to that is the addition of RFA to asphalt binder which tend to reinforce it, through the formation of asphaltene rich phase when adding RFA to the bitumen due to its polar nature as mentioned in the above sections. Besides, the presence of silica compound in the chemical composition of RFA, the high surface area and porosity structure of RFA, combined make the amount of asphalt reduced and increased its rigidity, flexibility and stiffness. As a result, its sensitivity to temperature decrease. Foroutan et al. [29] display a trend agree with that obtained in this study when using date seed ash in the modification process of asphalt binder.

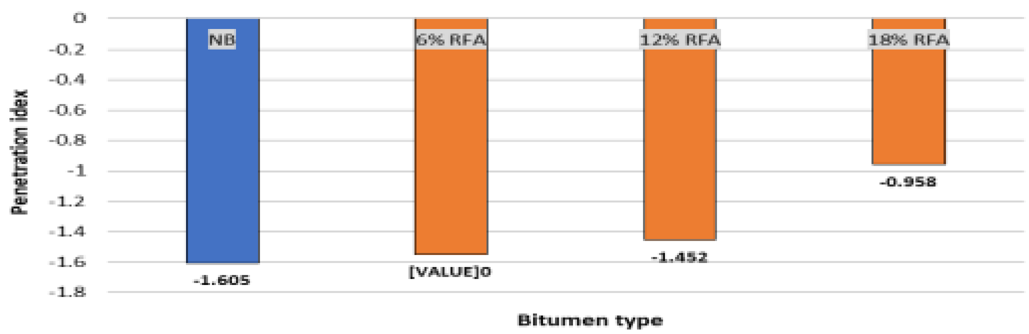


Figure 2. Penetration index of neat and modified bitumen.

4. DUCTILITY

Figure (7) shows the results of ductility for RFA modified bitumen. The test gives an indication about the ability of bituminous materials to withstand tensile stresses until breaking occur. Generally, results display that ductility of bitumen decrease after comprising RFA, where the amount of reduction reached to 20% at the higher dosage of RFA. This attributes to the high surface area and porous structure of the modifier material that tend to absorb the light wight molecules of bitumen more, then resulted in decrease the amount of it. Moreover, the addition of RFA makes the asphalt gains some rigidity due to the presence of SiO_2 in the chemical composition of RFA, as well as, the increment of asphaltene adhesive part., all these factors led to increase bitumen hardness and therefore decrease its ductility. Ductility trend appear similar to that observed in the study of Arabani et al. [38] when using them to rice husk ash to improve the properties of asphalt binder.

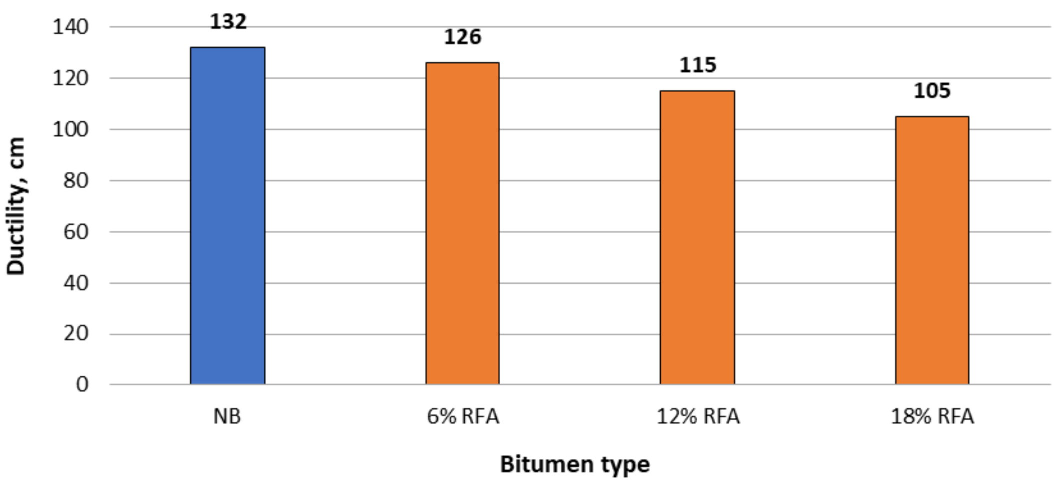


Figure 3. Ductility of neat and modified bitumen.

5. ROTATIONAL VISCOSITY

Rotational viscosity was used to evaluate the resistance of fluid against shear. Figure (8) illustrates the results of viscosity for neat and RFA modified bitumen. SHARP recommended that for practical applications in order to achieves the required workability and pumpability of asphalt, the viscosity of it should be not more than 3 Pa.s at 135 ℃ [46]. Generally, results indicate that the use of modifiers increase the viscosity of bitumen, where it led to increase viscosity to 1.11 Pa. s at 135 ℃ when using 18% RFA, and this means that it is within the acceptable limits. The reason of making bitumen viscosity increase is attributed to the increase of asphaltene adhesive part that is constitute the large fraction in bitumen reach to 25% of asphalt with high molecular weight 800-3500 g/mol compared to the remaining components [7], and it responsible on increase the viscosity of bitumen. The increment of asphaltene occur as a function of comprising RFA materials with bitumen, where these materials lead to neutralize the polar nature of bitumen as mentioned earlier. In addition to the porous nature of RFA and higher surface area that works on absorb the light weight molecules of bitumen, then resulted in reduce its amount more. These actions in turn leads to increase the rigidity and stiffness of bitumen, and therefore the viscosity of bitumen modified with RFA increased higher than the NB. Results in Figure (8) also indicate that the effect of temperature on reducing viscosity limits clear and the relation between them goes up with an exponential mode for all types of asphalt. In the case of power parameters, note that are reduced gradually after comprising RFA in bitumen, as follows: -0.042, -0.034, -0.033 and -0.031 for NB, 6% RFA, 12% RFA and 18% RFA respectively, gives clear indication about the positive effect of modification on the limits of viscosity of bitumen. Ameli et al. [47] show similar trend for viscosity when utilizing coal waste ash and rice husk ash as modifiers for asphalt binder.

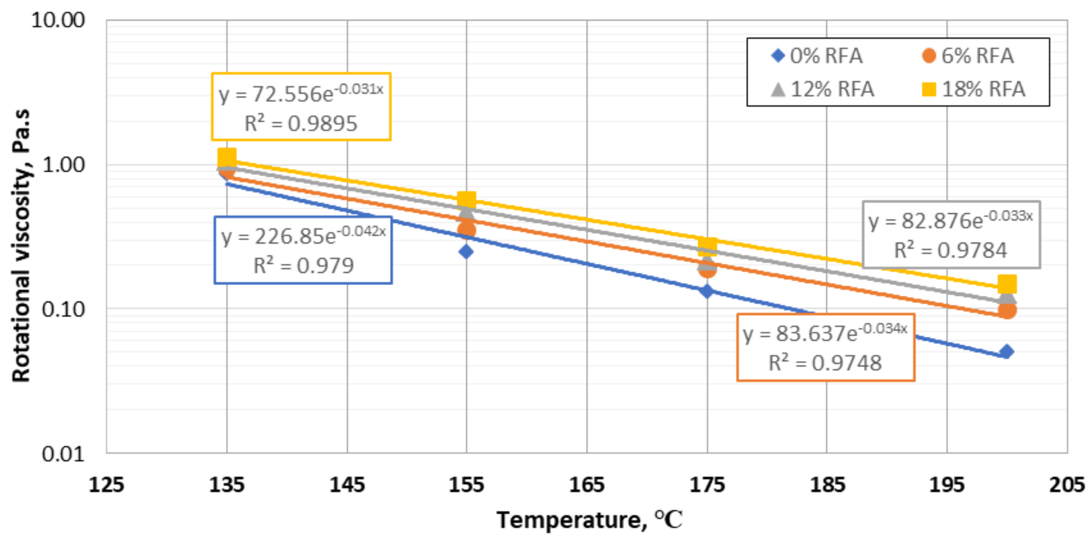


Figure 4. Rotational viscosity values of neat and modified bitumen.

6. AGING PROPERTIES

The results of aging of neat and modified bitumen as a function for penetration, softening point and PI are summarized in Figures (9, 10 and 11), respectively. TFOT aging results simulate the short-term aging for the bitumen that is occur during production, mixing and laying. Generally, results indicate that the values of penetration decreased to 23.2 dmm and softening point increased to 59 ℃ at 18% RFA, and the temperature susceptibility gives the same trend with a more decrement in the susceptibility of bitumen to temperature, by achieving an PI value equal to -0.806 at 18% RFA. The results generally attributed to that when subjecting the bitumen sample to high temperature conditions; the amounts of carbonyl functional groups (C=O) in asphalt increase after its oxidized under high temperature, as well as, the amount of asphaltene increase more than before aging [48]. Moreover, the polar nature of RFA also contribute in slight increment in asphaltene fraction furthermore. Besides the presence of SiO2 in the chemical composition of RFA that is also responsible on the hardness of the asphalt, the porosity nature and high surface area of RFA that is absorbs the light molecular weight bitumen. All these factors contribute in lowering penetration depth, increasing softening point and resulting in lower temperature susceptibility bitumen in contrast with the bitumen properties before aging. The behavior of modified asphalt after aging agreement with that obtained by Cai et al.[49] and Fini et al. [50].

However, Figures indicate that the use of modifiers enhance the susceptibility of bitumen to aging, where note that the effect of aging on penetration (i.e. PAI) reached to 0.83, while the SPI reached to 2.5 °C and the ratio of PI (PIR) reached to 0.84. This related to that after comprising of RFA with bitumen make it sensitive to react with the aromatic polar and aliphatic chains in asphalt due to the presence of hydroxyl groups in the chemical composition of it, and due to that the hydrogen atoms in this composition is less electronegative than oxygen, then this help to form hydrogen bonds with the polar fractions in asphalt that is make the asphalt less susceptible to aging. As a result, for these reactions, the carbonyl groups in asphalt reduce as RFA increase then resulted in enhance the resistance of asphalt binder to aging [29, 50]. Cai et al. [49] and Diab et al.[51] showed similar trend for PAI, and SPI when using rice husk ash as a filler modifier.

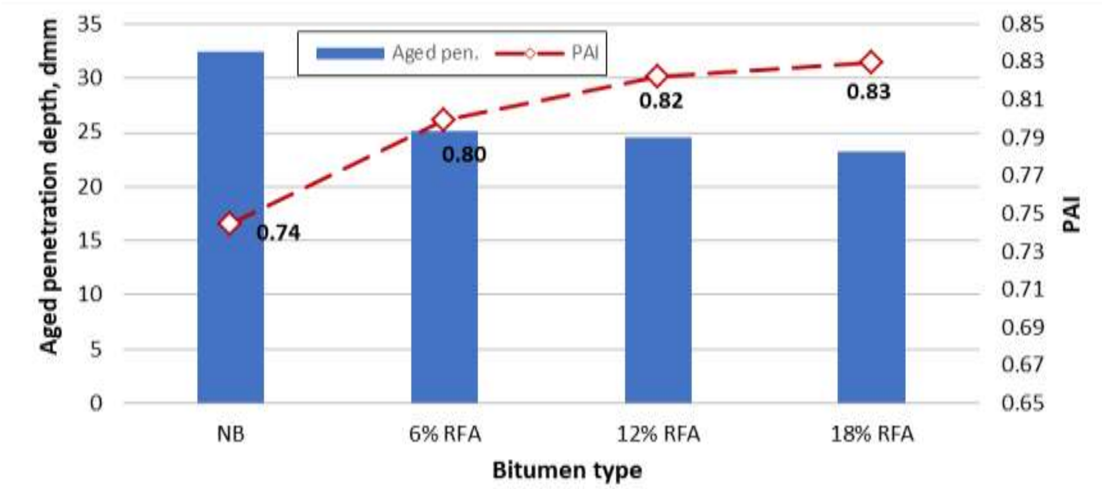


Figure 9. Aged penetration and PAI of neat and modified bitumen.

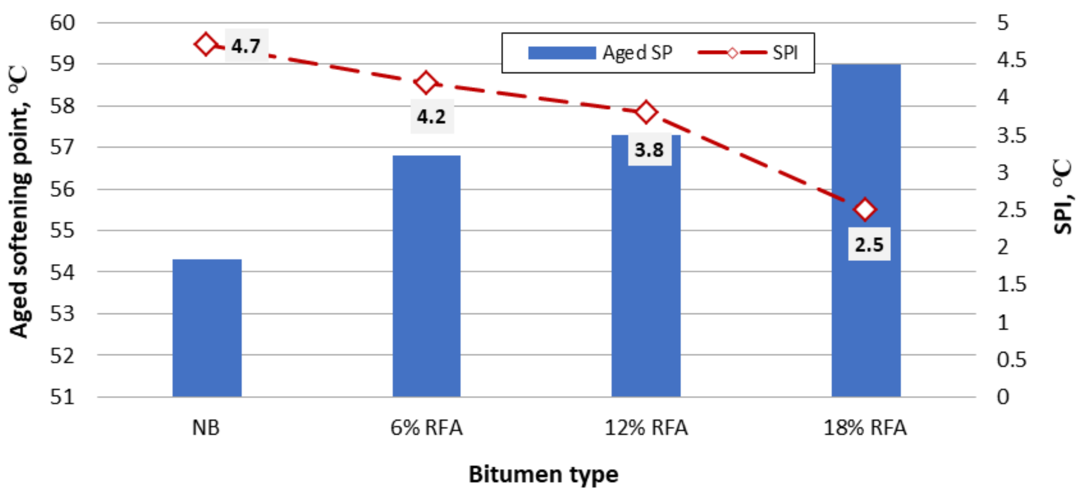


Figure 5. Aged softening point and SPI for neat and modified bitumen.

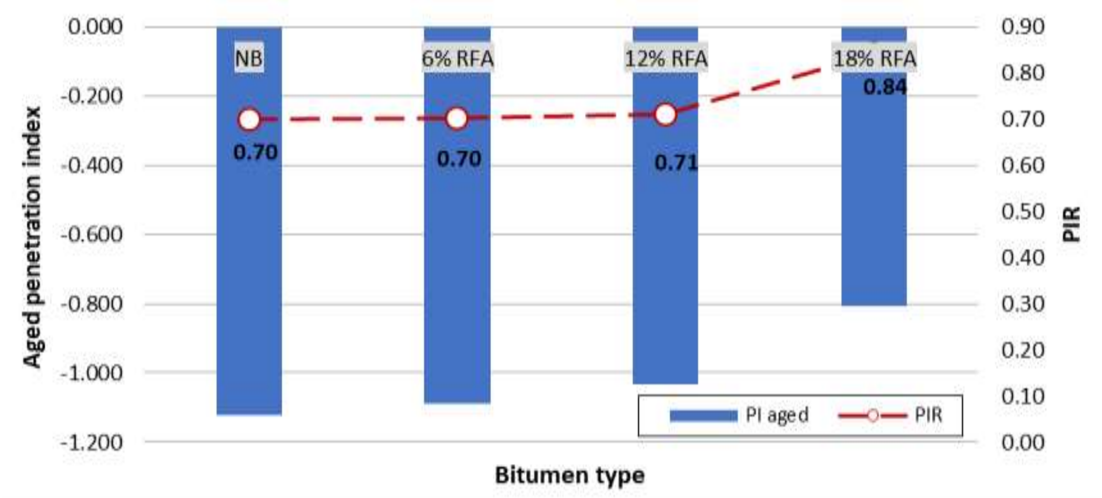


Figure 6. Penetration index after aging and PIR for neat and modified bitumen.

CONCLUSION

The consideration of selection the most appropriate modification materials to enhance the properties and performance of asphalt binder, and in the same time save the natural resources and reduce both environmental impacts and costs, making researchers trying to utilization of waste materials as a byproduct material in the modification of asphalt binder. Therefore, this research investigates the influence of comprising RFA as modifier for asphalt binder. From the observed results, the followings are concluded:

1. the use of RFA help in enhance the physical properties of bitumen.
2. using RFA as a modifier decreases penetration up to 36%.
3. RFA comprising to neat bitumen decreases ductility up to 20%.
4. softening point increases up to 14%when RFA is comprising.
5. viscosity increase up to 1.2 times in contrast with NB.
6. the use of this modifier helps in improve the sensitivity of bitumen to temperature by about 60% and improve resistance to aging by about 0.83, 2.5 ℃ and 0.84 for PAI, SPI and PIR after aging respectively if we compared it to NB.

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