

## PERFORMANCE PROPERTIES OF ASA POLYMER MODIFIED ASPHALT BINDERS AND MIXTURES

SHABAN ISMAEL ALBRKA<sup>1</sup>, AMIRUDDIN ISMAIL<sup>1,2,\*</sup>, NUR IZZI MD.  
YUSOFF<sup>1,2</sup>, DHAWO IBRAHIM ALHAMALI<sup>1</sup>, ALLAM MUSBAH<sup>3</sup>

<sup>1</sup>Sustainable Urban Transport Research Centre (SUTRA)

<sup>2</sup>Department of Civil and Structural Engineering, Faculty of Engineering and Built Environment, Universiti Kebangsaan Malaysia, 43600 UKM Bangi, Selangor DE, Malaysia

<sup>3</sup>Department of Civil and Structural Engineering, University Tun Hussein Onn, Johor Bahru, Malaysia 86400 Parit Raja, Johor, Malaysia

\*Corresponding Author: aismail@ukm.edu.my

### Abstract

Asphalt is commonly used as a binder in the construction of highways and runways, due to its good viscoelastic properties, natural asphalt cement does not have sufficient strength to resist sudden stresses of excessive loading or stress from low and high temperatures. Therefore, modification of asphalt is necessary in order to improve its material temperature sensitivity, adhesion, durability, oxidation and aging resistance. The property of base asphalt and polymer modified asphalt binders and mixtures has been characterized using the conventional tests and dynamic creep tests. It has been found that, the addition of Acrylate Styrene Acrylonitrile (ASA) polymer content has magnificent influence on the properties of the asphalt binders and mixtures. The temperature susceptibility of modified asphalt binders was reduced compared with base asphalt binder as the penetration increase and softening point decrease. The reduction in penetration was up to 69%, while the improvement in softening point was up to 19%. Moreover, it was approved from the storage stability test that, the ASA polymer has a great compatibility with asphalt binder up to 5% ASA. In addition, it was observed reduction in permanent deformation of modified asphalt mixtures with increase of modifier up to 5% ASA, which lead to better resistance to rutting at high temperatures, and the reduction was up to 36%. As a result, the modification of asphalt binder and mixture with ASA polymer can be considered a proper alternative technique to improve the properties of asphalt binder and mixture and 5% ASA was the optimum content of the modifier.

Keywords: ASA polymer, Polymer modified binders, Storage stability, Permanent deformation and dynamic creep.

## 1. Introduction

The Asphalt binder additives such as polymers and nanomaterials should be able to improve the binder properties at both low and high in-service temperatures [1]. Consequently, it should be strong enough to withstand traffic loads at high temperature, which any cause permanent deformation, and flexible enough to avoid excessive thermal stresses at low asphalt temperatures [2]. Increased of traffic, heavier trucks and excessive tire pressures have induced severe stresses on asphalt road surface. Although surface treatment courses are not load bearing layers, however, sever traffic stresses and field temperature variations require that these provide increased properties in terms of cohesion within mixes [3]. This aim can be achieve upon improving their binder properties using polymer modified bitumen (PMB) [4-6]. The use of modified binders offers a promising way to improve asphalt binder and mixture. It has been observed for a long time that the use of PMB achieved better asphalt binder and mixture performance, the polymer content and characteristics have a significant role to improve the properties of PMB [7, 8].

Moreover, the polymers should be compatible with asphalt binder in blended process with conventional mixing equipment and can kept up their main properties, and the most ordinarily used polymers worldwide includes elastomer and plastomers [9]. Asphalt mixes design techniques attempt to balance the composition of aggregate and asphalt cement to achieve long lasting performance in a roadway structure. It is identified that asphalt mixes consists primarily of asphalt cement, mineral aggregates and air voids. The main purpose of a mix design is to produce mixtures with high resistance to deformation and cracking. The properties of the produced mixes are depending on the physical and chemical properties of the used materials. Each of the component materials needs to be carefully selected and controlled to ensure that they are of a suitable quality for the asphalt mixes and the expected performance.

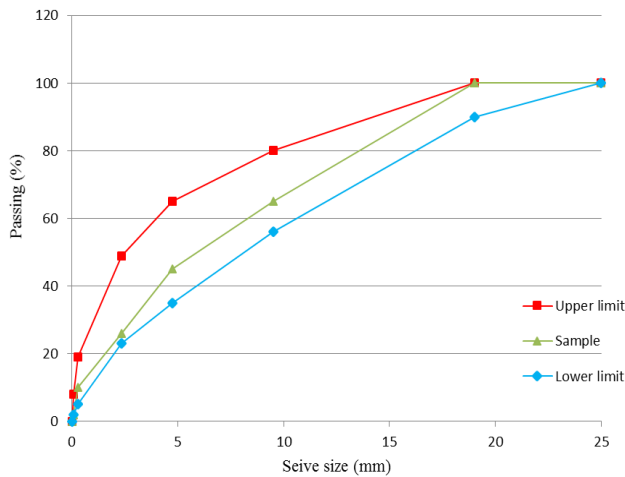
## 2. Experimental Design

### 2.1. Materials

Two materials were used to produce a numeral of laboratory mixed; base asphalt binder and polymer. Base asphalt cement was 60/70 penetration grade, supplied from a factory in Port Klang, Malaysia and polymer was Acrylate Styrene Acrylonhrtilrei (ASA), white powder with bulk density of  $0.30 \text{ g/cm}^3$  was produced from the factory of the Shijiazhuang Chanchiang Corporation company in China. The physical properties of the base bitumen and the ASA used are shown in Table 1. Six stockpiles of aggregate (19.00, 9.50, 4.75, 2.36, 0.30 and 0.075 mm) were used to produce the base and modified asphalt mixes, stockpiles were coarse aggregate and others were fine aggregate. The Superpave uses the nominal maximum aggregate size (NMAS) of the aggregate to categorize mixes and define graduation requirements; the nominal maximum particle size was 19 mm in this study. aggregate properties defined as the aggregate which has proper particles size and grading, strong and tough, and consists of angular, the surface of the aggregate is clean and rough [10]. However, selecting an aggregate material for use in asphalt mixes also depend on the availability and cost of the material as well as the type of construction. Figure 1 shows the sample of aggregate design for asphalt mixes (dense-graded) according to ASTM D 3551 mix grading size.

**Table 1. Physical properties of the base asphalt and the ASA material.**

	Properties	TEST METHOD	Value
<b>Bitumen 60/70</b>	Specific Gravity	ASTM D70	1.03
	Penetration @ 25°C	ASTM D5	70
	Softening point (°C)	ASTM D36	46.0
	Viscosity @ 135°C (Pa.s)	ASTM D4402	0.5
	Ductility (cm) @ 25°C,	ASTM D113	129
	Size mm	-	2
	Specific Gravity	-	0.30



**Fig. 1. Sample of aggregate design of asphalt mixes.**

**2.2. Sample preparation**

Samples of asphalt binder were prepared using melt blending technique, and ASA modified asphalt were formed by adding 0, 3, 5 and 7%.wt content by weight of asphalt cement (wt) with base asphalt cement. The asphalt binder were heated till becomes fluid and Silverson high shear mixer was used for the mixing process at 170°C (±1°C) under speed of 5000 rpm for 90 min to produce homogenous modified binders. To produce a homogenous asphalt blend during the mixing process, the asphalt cement must be allowed to coat the aggregate and then to adhere them together. According to the Asphalt Institute [10], the mixing and compaction temperatures should correspond, respectively, to viscosity ranges 0.17+0.2 and 0.28+0.3 Pa.s for base asphalt binder. Yildirim et al. [11] suggested that appropriate mixing and compaction temperatures for PMB is equivalent viscosities to 0.28 Pa.s and 0.55 Pa.s at a shear rate of 500 s<sup>-1</sup>. Using of this method as the foundation, Table 2 shows the mixing and compaction temperatures of base asphalt mixes and modified asphalt mixes with ASA polymer.

**Table 2 Mixing and compaction temperatures of asphalt mixes modified with ASA polymer.**

Asphalt Modifier	ASA Polymer			
	0	3	5	7
Concentration (%)				
Mixing Temperature (°C)	158	163	168	182
Compaction Temperature (°C)	145	150	154	167

### 2.3. Physical properties

The conventional tests, such as; penetration and softening point measurements were done according to ASTM specifications to evaluate the property changes of modified asphalt binder compared to the base Asphalt binder.

### 2.4. Storage stability test

The modified asphalt binder storage stability was measured as follows; the samples were poured into an aluminium foil tube; the height of the tube is 16 cm in with 3 cm in diameter. The foil tubes were closed and stored vertically at a temperature of  $163 \pm 5^\circ\text{C}$  in an oven for 48 hours, therefore cooled at room temperature and divided horizontally into three equal parts. The samples taken from the upper and lower sections were used to assess the storage stability of the ASA modified asphalt cement by determining the sections softening points, if the difference between the top and the bottom parts was less than  $2.5^\circ\text{C}$ , then the samples were considered to have a great high temperature storage stability. If the softening points differed by more than  $2.5^\circ\text{C}$ , the ASA modified asphalt binder was considered to be unstable [12].

### 2.5. Dynamic creep test

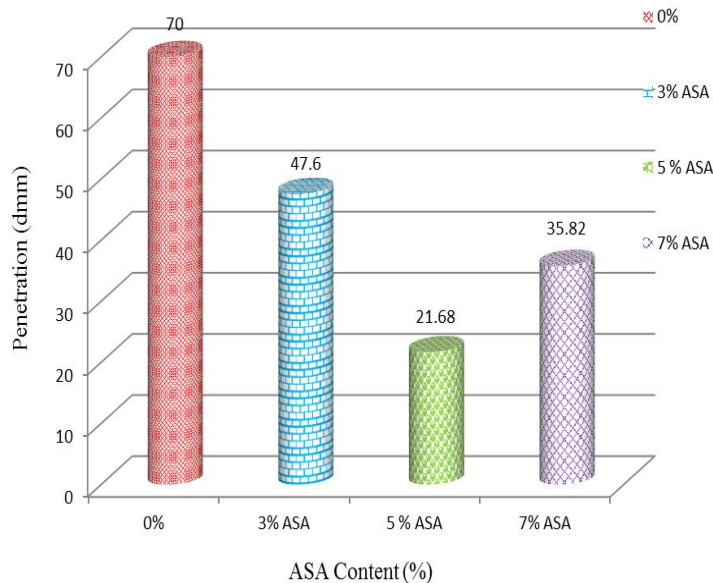
The dynamic creep test in this study, was under haversine load pulse was conducted for the base asphalt and modified asphalt mixes with both modifiers according to protocols developed by NCHRP 9-19 Superpave Models for intermediate traffic level design. Three replicate samples compacted by gyratory compacter at 4% air voids with a diameter of 100 mm and 63 ( $\pm 2$ ) mm height were conditioned on providing chamber at a temperature of  $40^\circ\text{C}$  for four hours minimum before testing is started. During the initial stage of testing, the sample was pre-loaded with conditioning, stress at 10 kPa for 120 seconds to ensure the platen is loaded flat in the sample. Then, the sample is applied with a haversine wave load cycle, which consists of 100 kPa stress pulse with 100 ms pulse width followed by 900 ms rest period. The test was terminated when the accumulative strains reached 10000 micro-strains or until 3600 cycles.

## 3. Results and Discussion

### 3.1. Effects of ASA polymer on physical properties

The influence of various concentrations of ASA polymer on the properties of asphalt binder, in particular the variation in the results of penetration can be seen in Fig. 2. The ASA polymer modified asphalt binder samples show a pronounced decrease in penetration for up to 5% of ASA polymer, however, the value increased in the case of 7% specimen. The decreases in penetration denote an increase in stiffness of the modified binders. Therefore, increasing the stiffness lead to the increase of the PI, and thereby, also leads to improved temperature susceptibility of the modified asphalt binders. The different behaviour of 7% of the ASA modified asphalt binder is might due the incompatibility in phases between the base asphalt binder and ASA polymer. The results obtained were similar with Sengoz and Isikyakar [13] investigation, when EVA was used as a modifier of asphalt binder by

concentrations of 2 to 6%.wt. The penetration also declined up to 5% the then it does not show any improvement in 6%. Moreover, Haddadi et al. [14] also noted that the penetration decreases with increase the addition of EVA.



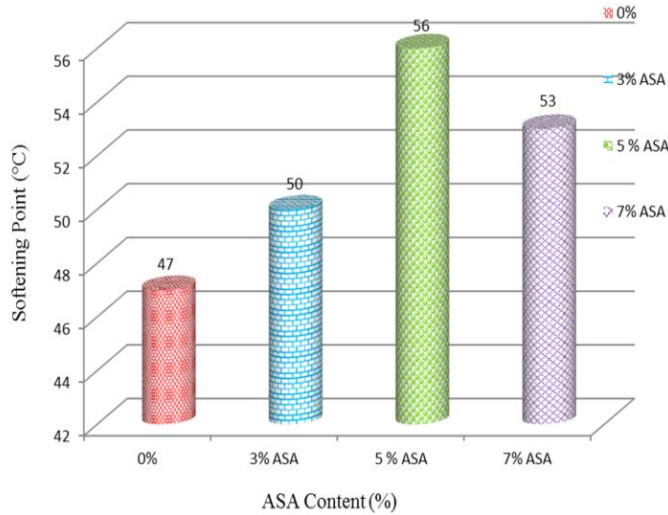
**Fig. 2. Penetration of base asphalt and modified asphalt binders.**

The modifying effects on ring and ball softening point test of base asphalt binder using ASA polymer modified asphalt binders are shown in Fig.3. The consequences show that the modified asphalt binders have the highest values compared with base asphalt binder. This indicates that the addition of ASA polymer capable to increase the stiffness of the base asphalt binder. Moreover, the highest improvement was noted with the addition of 5% ASA followed by 7% ASA and 3% ASA. Therefore, it is noted that 7% for both modifiers slightly decreased, but still, it's better than the base asphalt binder. This is as the result of the increases in penetration of 7% ASA due to the less interaction between asphalt binder and polymer. However, similar results of reduction in softening point were observed in previous studies using different polymers such as ENR and EVA. In addition, El-Shafie et al. [15] modified asphalt cement with nanoclay with concentrations of 2, 4, 6 and 8%.wt shows the same increase in the softening temperature up to 12°C compared to the base asphalt cement. The best asphalt cement performance was when the addition of nanoclay was 6%.

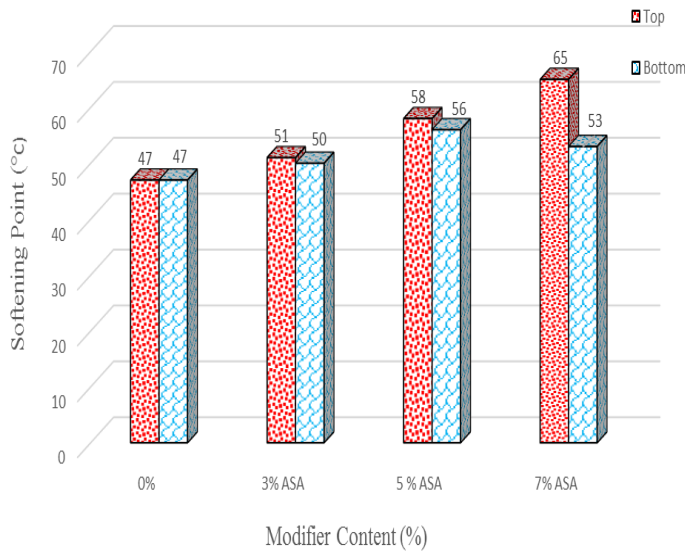
### 3.2. Storage stability

Referable to the dissimilarity in the solubility bound and density between ASA polymer and asphalt binder, stage separation might take place in the ASA polymer modified asphalt binders during storing at high temperatures. The ASA droplets dissolve and dispersed in asphalt binder are commonly accumulated and float in the upper of the asphalt binder at high temperatures and stationary state [16, 17]. The storage stabilities of the ASA polymer modified asphalt binders

were tested and the results are shown in Fig. 4. Apparently, for the ASA polymer modified asphalt binders, the differences in softening points were up to 12°C. Moreover, the modified asphalt binders' distinct effects as it is increased the softening point up to 51°C for 3%, 58°C for 5% and 55°C for 7%. Thus, the improvement of softening point means the modified binder becomes stiffer than the base binder. Therefore, the differences between the top and bottom of ASA polymer modified asphalt binders are less than 2.5°C up to 5%, which means the ASA was stable during stored at high temperatures. But for 7% the differences are exceeding the permitted values.



**Fig. 3. Softening point of base asphalt and ASA polymer modified asphalt binders.**



**Fig. 4. Storage stabilities of base asphalt and modified asphalt binders.**

### 3.3. Dynamic creep test

Figure 5 shows the results of the dynamic creep test of the base asphalt mixture and modified asphalt mixtures with ASA polymer at a temperature of 40°C and loads of 100 kPa. The accumulated strain is recorded at each load cycle and termination occurred when the number of cycles reaches 3600 cycles. The results show in Fig. 5 that with the increase the modifier the resistance to deformation increased up to 5% ASA. The 5% ASA shows the high amount of resistance to the rutting, meanwhile the base asphalt mixes as expected has the lowest resistance to the deformation. 7% ASA shows an increase in the value of deformation, this is due to segregation phase accrue between binder and ASA polymer which lead to make the weakness in asphalt mixes. The decrease in deformation of modified asphalt mixes with ASA polymer means an increase in the stiffness of modified mixes, and the permanent deformation dependence on load and temperature.

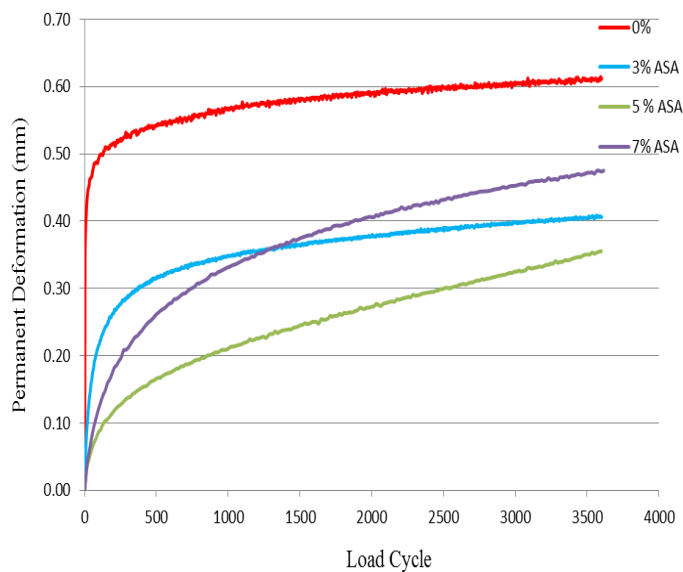
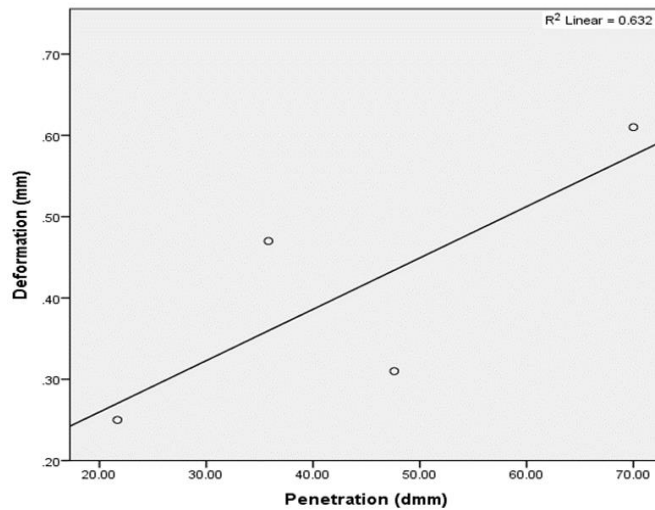


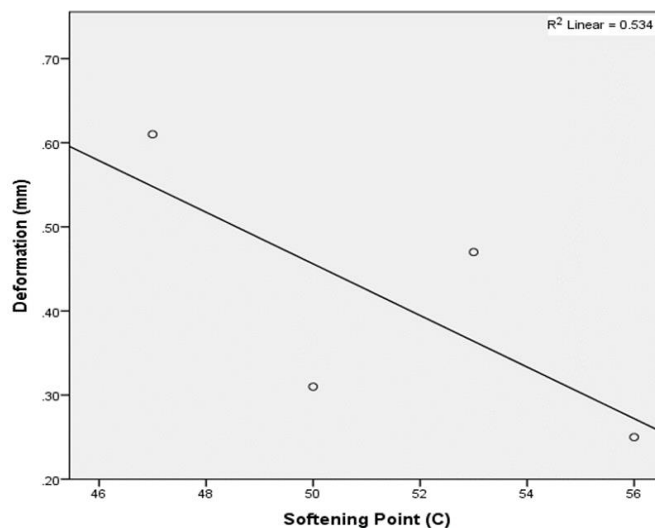
Fig. 5. Dynamic creep of base asphalt mixture and modified asphalt mixtures.

### 3.4. Correlation between penetration, softening point and dynamic creep

In order to estimate the correlations between various test parameters, it is supposed that the results outlined from rheological asphalt binder tests are the independent variables, while the engineering properties of mixtures are dependent variables. Therefore, penetration and softening point are independent variables, while the dynamic creep is the dependent variable. Figures 6 and 7 show the correlations between penetration and dynamic creep and softening point and dynamic creep, strong relations between penetration and dynamic creep with  $R^2=0.632$ . Also, a good negative relation between softening point and dynamic creep with  $R^2=0.534$ . In other words, due to the increment of stiffness of asphalt binder the penetration and dynamic creep were decreased, while the softening point increased.



**Fig. 6. Correlation between penetration and dynamic creep.**



**Fig. 7. Correlation softening point and dynamic creep.**

#### 4. Conclusions

The properties of asphalt binder and mixture modified with ASA polymer were investigated using conventional tests; penetration and softening point, storage stability and dynamic creep test. It was found that, the properties of modified asphalt binders and mixtures improved with the addition increment of modifier content. The penetration decrease and softening point increase with increase of ASA polymer up to 5%. The higher enhancement observes when the concentration of ASA polymer was 5% ASA while the base asphalt binder has the lowest improvement. The percentages of improvement of penetration were 32% for 3%



ASA, 69% for 5% ASA and 48% for 7% ASA, while the enhancements of softening points were 6% for 3% ASA, 19% for 5% ASA and 12% for 7% ASA. Storage stability results exposed that the modified asphalt binders have good storage stability as the values between tops and bottoms were less than 2.5°C for 3% ASA and 5% ASA. 7% ASA shows different behaviour with the differences exceed the permitted value as the phase segregation occurs between asphalt binder and the modifier. The results of dynamic creep tests show that with the addition of modifier the permanent deformation decrease due to an increase in the stiffness of modified asphalt mixtures.

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