

Investigation of Using Polymers to Improve Asphalt Pavement Performance

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Abstract

As the traffic volume becomes greater in recent years, the performance of asphalt pavement has decreased. Modified bituminous materials can increase performance and reduce highway maintenance. The goal of this study is to investigate the influence of polymer modification for improving pavement performance. A detailed laboratory study is carried out by preparing modified asphalt mixtures specimens using (40-50) grade asphalt from dourah refinery. A comparative study of laboratory performance of application of three polymer types: Polyvinyl chloride (PVC), Phenol resin, and Polystyrene Polymer in asphalt paving mixtures is investigated. These modified asphalt mixtures were prepared with asphalt cement previously modified by using three percent of polymer (2,4 and 6%) by weight of asphalt. To evaluate mix performance, effect of polymer modification was studied by performing indirect tensile strength and retained stability test. In order to evaluate the mixture behavior due to temperature change, two different testing temperatures are used (25, 45°C). From the results of this study, it is concluded that with the incorporation of low percentage of polystyrene polymer tensile strength increase, therefore polystyrene modified asphalt mixtures can be used in cold climate conditions. In addition, it can indicate, that using phenol resin in modified asphalt mixes will increase strength and resistance to deformation, then it can be used in hot climate conditions. The results of the present study indicated that the modified mixtures exhibited improved performance when the polymer was used.

Keywords: Polymer asphalt modification; Polyvinyl chloride; Phenol resin; Polystyrene resin; Tensile strength; Stability.

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1. Background

In Iraq, the major road deterioration occurs due to high service temperatures and excessive traffic loads. Specific requirement is needed to improve the quality of highway pavement materials in order to increase its durability.

Asphalt binder has a significant effect on hot mix asphalt performance, its viscoelastic behavior play important role in the performance of asphalt mixtures. Bituminous mixtures behavior is highly varied under traffic and environmental conditions. The performance of hot mix asphalt can be modified by adding polymers, which alter viscoelastic behavior of binder.

Adding polymer will increase the flexibility of asphalt mixture at high and intermediate temperatures, which will improve rut and fatigue resistance. Polymers generally, more viscous than asphalt binders, and show improved bonding to aggregate. This result in thicker binder coatings which will become longer to brittle from oxidation, thus improving durability of the mixtures. Polymers can be classified as: elastomers which enhance elasticity and strength; and plastomers, which enhance strength alone. Modified asphalt with polymers are widely used in high load application, and it is a cost effective way to minimize distress. In recent years, rich research had been carried out to improve the properties of asphalt cement by incorporating polymers. Some of these are represented here:

Md. Nobinur Rahman and his colleagues 2013[1] investigated of the use waste polyethylene and PVC to enhance asphalt mixture properties, and they concluded that asphalt mixtures modified with waste polyethylene up to 10% and waste PVC up to 7.5% can be used in flexible pavement construction in warm regions. I.M. Nassar and his colleagues 2011[2] investigated of the use wastes (WPS) to enhance the performance of hot mix asphalt. Five percentage of WPS was mixed with bitumen, and physical properties of modified and unmodified bitumen was tested. Durability was evaluated using marshall tests. The results indicated that polymer modified asphalt (PMAs) containing (5% WPS) will improve workability and enhances the resistance to deformation. Xiaohu Lu and his colleagues 2013[3] study the durability of polymer modified binders in terms of resistance to aging, rutting and cracking. Asphalt samples were taken from test roads where polymer modified binders were tested in different layers. Various tests were carried out, including chemical and mechanical tests. It was found that the polymer modified binders show better rheological properties even after several years in asphalt pavements. The improved binder properties should be beneficial in terms of resistance to asphalt rutting and cracking. Jiqing Zhu and his colleagues 2014[4] reviewed Some technical developments for removing drawbacks of bitumen polymer modification, including saturation, sulfur vulcanization, adding antioxidants, using hydrophobic clay minerals, functionalization and application of reactive polymers. Jaffar Emad Al-Mulla, and Makky, S. M. 2017[5] studied the effects of recycling polyethylene terephthalate (PET) plastic waste as an asphalt modifier, a PET waste was blended with asphalt cement in three percentages, and traditional physical tests were carried out. Results show that adding PETW has a significant effect on the rheological behavior and binder stiffness at high temperatures. Nikhil Saboo, & Praveen Kumar (2016)[6] evaluated Fatigue sensitivity of four different asphalt binders and three different asphalt mixes. Binders were subjected to Linear Amplitude Sweep, Four-point beam bending test was subjected to asphalt mixtures. Tests like retained Marshall Stability and indirect tensile strength (ITS) were also carried out to judge the mix performance. Experimental studies

demonstrated that elastomeric modified binder and mixes gave the best performance in fatigue. Plastomeric modification was found to be highly strain susceptible and resulted in poor fatigue performance. Mousa Bani Baker and his colleagues 2016[7], studied the addition of polystyrene waste to the bitumen, conventional empirical tests were carried out, results show that increasing the polystyrene ratio in the asphalt will have a direct impact on the bitumen properties. N. M. Asmael 2008[8] investigated three different types of polymer resins Epoxy, Phenol and Polyester resin which were used to modify asphalt binder. Physical properties of asphalt cement were tested before and after polymer modification for penetration and softening point. Indirect tensile strength and creep tests were used to evaluate asphalt mixes. The results of the study show that using phenol resin in modified asphalt mixes will increase the resistance to deformation under various traffic loadings.

2. Objective of the Study

The objective of this work is to determine modified binders of different polymers have comparable performance and to identify the influence of polymers on the performance of HMA.

3. Materials used in the investigation

3.1 Materials

The Materials used are locally available. The selected material is currently materials used in road construction in Iraq.

3.1.1 Asphalt Cement

One type of asphalt cement (40-50) penetration graded was used in this study, is obtained from Dourah refinery. The physical properties of this type of asphalt cement are shown in Table (1).

Table 1: Physical Properties of Asphalt Cement.

Test	Unit	ASTM	Results
Penetration 25°C, 100 gm, 5 sec.	1/10 mm	D5	45
Absolute Viscosity at 60°C (*)	Poise	D2171	2090
Kinematics' Viscosity at 135°C (*)	C St.	D2170	380
Ductility (25°C, 5 cm/min.)	Cm.	D 113	>100
Softening Point	C°	D 36	52
Specific Gravity at 25°C (*)	D 70	1.04
Flash Point	C°	D 92	335

(*) The test was conducted in Dourah refinery

3.1.2 Aggregate

One type of crushed aggregate was used in this study, which was brought from Amanat Baghdad. The source of this type of aggregate is Al-Taji quarry.

The physical properties of the aggregate are shown in Table (2), The coarse and fine aggregates were sieved and recombined in the proper proportions to meet the gradation as required by SCRB specification[9].

Mixes were designed for heavy traffic level using the traditional Marshall methodology.

The gradation curve for the aggregate is shown Figure (1) and presented in Table (3).

Table 2: Physical Properties of Al-Taji Quarry Aggregate.

Property	Aggregate	
	Coarse	Fine
Bulk specific gravity ASTM C 128	2.518	2.615
Apparent specific gravity	2.553	2.662
ASTM C127 and C128		
Percent water absorption	0.556	0.68
ASTM C 127 and C 128		

Table 3: Gradation as required by SCRB specification [9].

Sieve size	Max.- Min.	% Passing
		(Mid- Range)
19	100	100
12.5	90 – 100	95
9.5	76 – 90	83
4.75	44 - 74	59
2.36	28 - 58	43
No. 50	5 - 21	13
No. 200	4-10	7
Asphalt Cement	4 - 6	

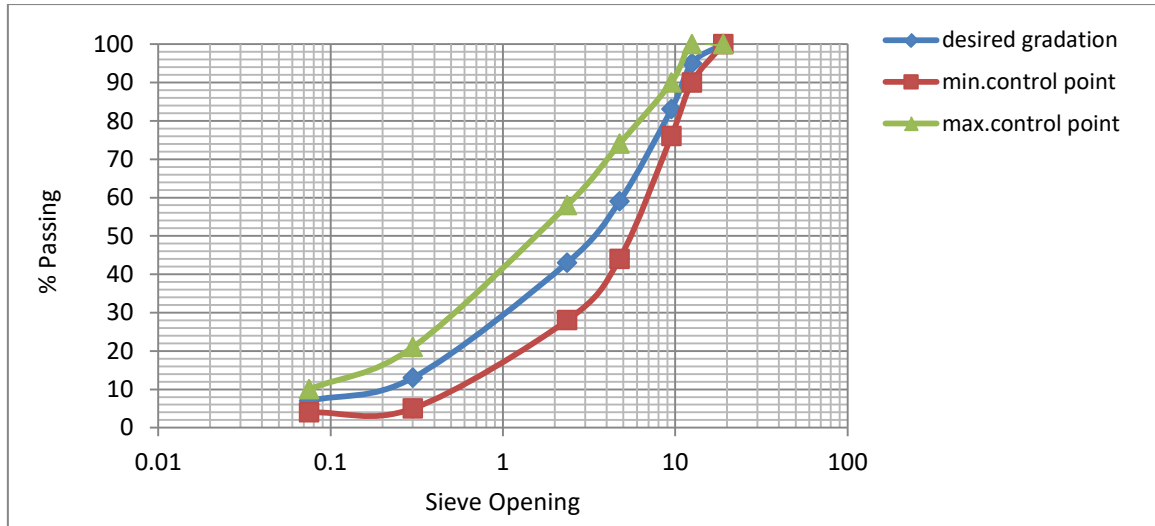


Figure 1: Selected Gradation

3.1.3 Mineral Filler

The passing sieve No.200 (0.075mm) is mineral filler which is a non-plastic material. In this study, the asphalt mixes were prepared using cement as mineral filler, which is obtained from Badoush factory. The physical properties are shown in Table (4).

Table 4: Physical Properties of Filler (Cement).

Property	Results
Specific Gravity	3.12
% Passing sieve No.200 ASTM C117	95

3.1.4 Polymer additives

The selection of polymer type must have low cost, durable, good adhesion, and available. Different types of polymers are locally available, but three types of polymer were selected in this study: Polyvinyl chloride (PVC), Polystyrene Polymer and Phenol resin are presented to evaluate in asphalt paving mixtures.

Phenol resins have used in the woodworking industry, Novolac phenol resin in powder form is used.

Polystyrene polymer is an attractive material because of low cost, it is widely used in plastics. Polyvinyl chloride (PVC) is a thermoplastic material, widely used in construction works, it is cheap, durable and easy workability. Figure 2 shows different polymers used in this study.

These polymers will use to modify asphalt cement by using three percent of polymer (2, 4 and 6) percent by weight of asphalt. To evaluate the mixture characteristics of the modified mixes, a laboratory test of, indirect tensile strength, retained stability was conducted on a compacted Marshall specimens.



(a)



(b)



(c)

Figure 2: Types of Polymers a) Polyvinyl chloride b) Phenol Resin c) Polystyrene polymer

4. Asphalt Mixture Design

Asphalt mixture was prepared using the Marshall mix design method according to (ASTM Designation: D 1559-89)[10]. The asphalt cement with known weight was heated in an oven until reaching a temperature of 150C°, then asphalt was added to heated aggregates and filler in the mixing bowl. All components were mixed thoroughly, until all aggregates were completely coated with asphalt. The mixture was put in the preheated mold, 75 blows were applied on the top and bottom of the specimen, then specimen was removed from the mold. Three Marshall specimens were prepared at each asphalt content.

The Marshall test was performed at a deformation rate of 51 mm/min (2 inch/min) and at temperature of 60C°. Marshall stability and flow values were obtained from this test. Stability defined as a maximum load that the asphalt mixture can be carried. The flow is the deformation when the load begins to decrease. Stability is measured in (KN) and flow in (mm). Marshall Specimens prepared with various Asphalt cement content were tested to determine Marshall Properties. The optimum asphalt content of the various mixes is determined, and it is found equal to (4.83). Marshall properties are shown in Figure(3).

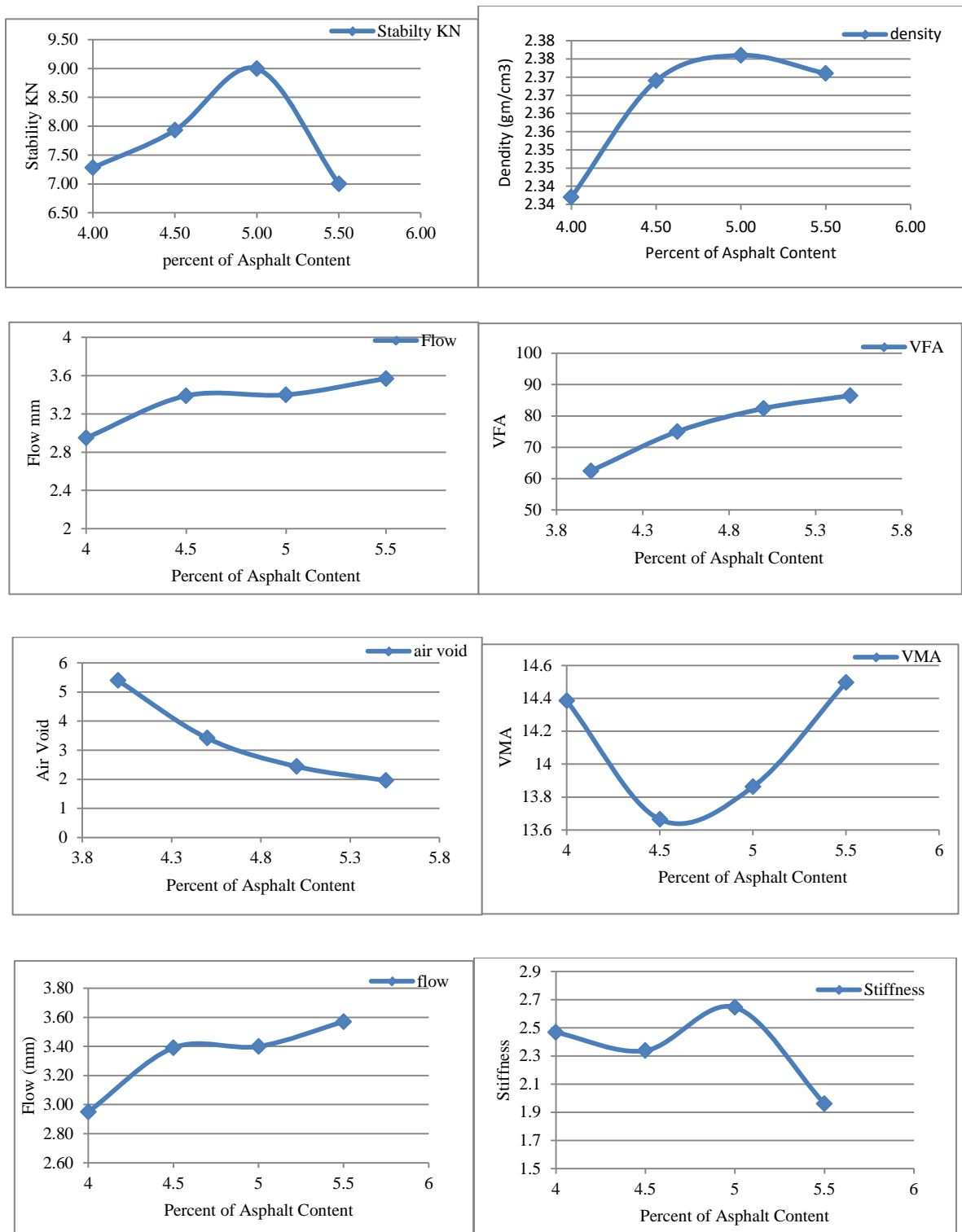


Figure 3: Marshall Properties

5. Preparation of Modified Asphalt Mixtures

Three types of modified binder were prepared with three percentages of polymer. Polymer content used to be 2%, 4%, 6% by weight of asphalt for the three types of polymer. To prepare modified asphalt, a proper mixing of polymer into the asphalt for 2 minutes was done at 150°C, then added the modified asphalt to the aggregate. It

must care to make polymer thoroughly compatible in the mixture in order to prevent polymer separation during mixing, which will cause a problem of inconsistent binder quality.

6. Modified Asphalt Concrete Performance Tests

To evaluate polymer modified asphalt mixtures, it is important to determine performance properties. Indirect tensile test for prediction of tensile strength was carried out. Two testing temperatures (25,45C°) were used to predict changes of the modified asphalt concrete with temperature. A Retained Marshall Stability test for evaluating the durability of asphalt polymer modified was also carried out.

6.1 Indirect Tensile Strength

To evaluate the engineering properties of asphalt mixtures, the indirect tensile test has been used. The test is conducted by loading specimen with a parallel load to the vertical diameter, this causes specimen failure along the vertical diameter [11]. The test gives information on tensile strength and fatigue characteristics.

The indirect tensile strength (I.T.S) is calculated, as follows:

$$I.T.S = \frac{2P_{ult}}{\pi D} \dots\dots\dots(1)$$

Where:

P_{ult} = Ultimate load up to failure (N).

T = Thickness of specimen (mm), and

D = Diameter of specimen (mm).

The test was conducted on modified asphalt mixtures at 25,45 C° testing temperature.

6.2 Retained Marshall stability

In this test, two groups of Marshall cylindrical specimens were prepared, each group consists of four specimens, the first group is tested immediately without treated using the Marshall test.

The Second group is treated under vacuum and then soaked in a water bath at 60 for 48 h and then will be tested by Marshall test. For all groups Marshall stability was determined.

Retained Marshall stability defined as a ratio of stability of treated specimens to the stability of untreated specimens. A retained Marshall stability value of 75 % is acceptable, Hunter R. N. and his colleagues (2015).

7. Effect of Asphalt Modification on the Performance of HMA

The tensile test is an important test for observing changes in binder strength over a wide range of pavement service temperature. Figure (4) shows the evaluation of tensile strength for modified asphalt mixtures with two different testing temperature

. From the results of tensile strength test, it can be concluded that all types of the mixes would satisfy the tensile strength and modified specimen with polystyrene polymer and phenol resin have the highest tensile strength.

The most effect on tensile properties occurs for binder modified with polystyrene polymer at a low percentage(2%), and phenol resin at high percentage (6%). The change in tensile strength with temperature does provide an indication of the temperature susceptibility of the polymer–asphalt system.

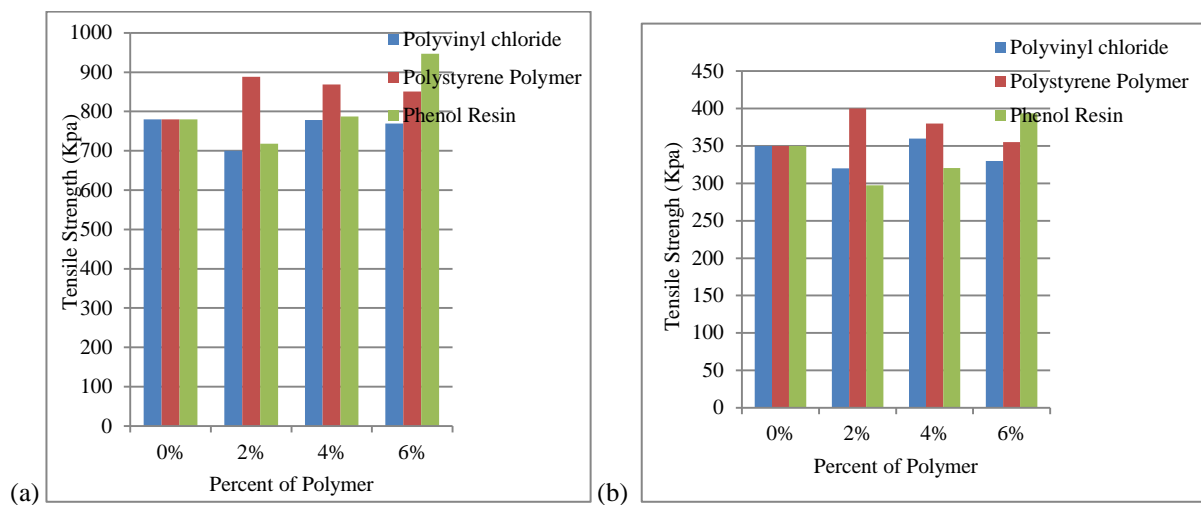


Figure4: Tensile Strength of Different Polymer Modified Mixture: a) at Temperature 25 C° b) at Temperature 45 C°

Results of stability and tensile test showed that, the phenolic resin and polystyrene polymer which used to modify asphalt cement provide better performance than control mix after adding the proper amount of polymer, advantage like high strength, high temperature resistance, fatigue resistance will be achieved.

Figure (5) shows stability results of untreated and treated specimens. From the results of percent retained stability

as shown in Figure (6), mechanical properties of asphalt can be improved using polymers which will increase durability and provide better performance. From Figure (7),

it can be shown that permanent deformation can be reduced when using PVC or phenol resin.

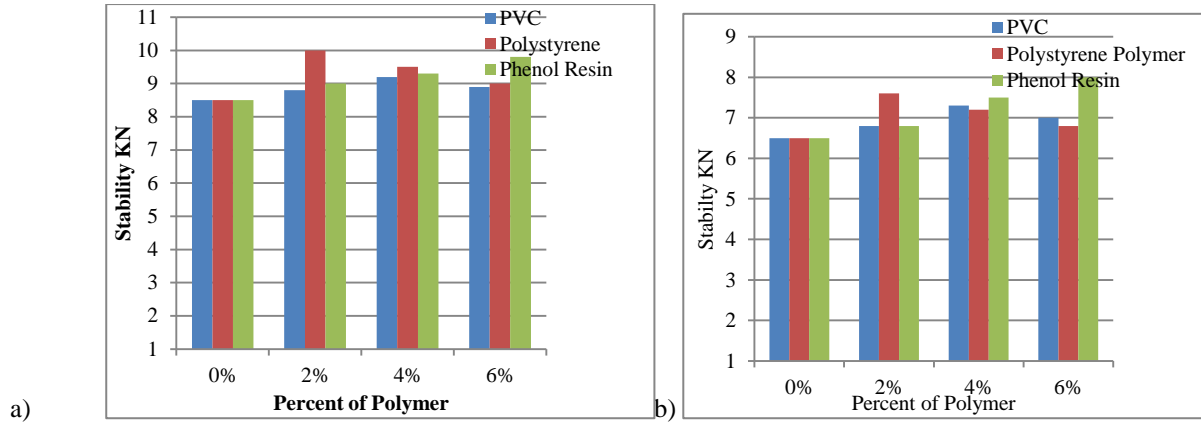


Figure 5: Stability Results a) untreated specimens b) treated specimens

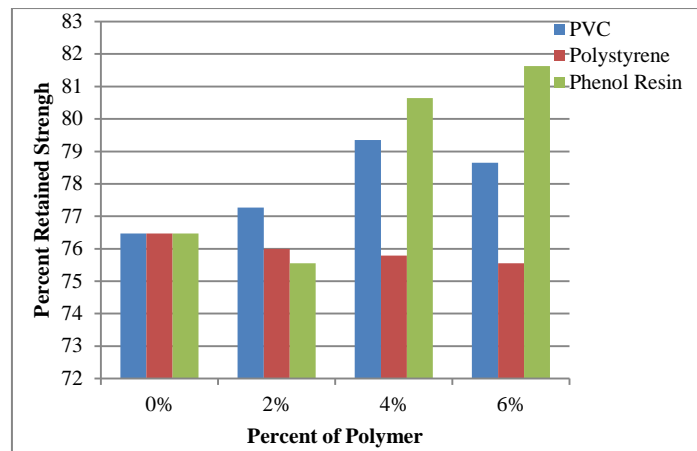


Figure 6: Percent Retained Strength.

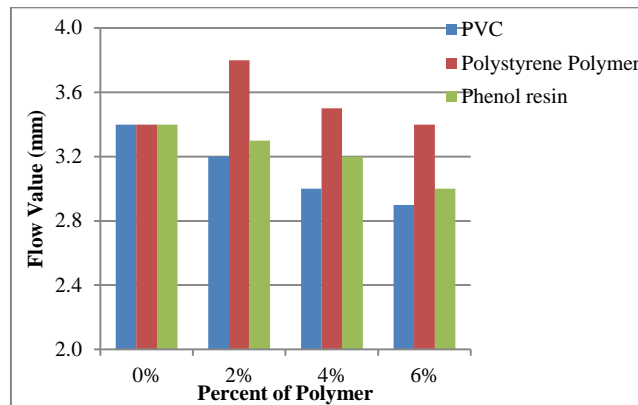


Figure 7: Flow Value of untreated asphalt modified mixture.

8. Conclusions

Based on the results of this study, it can be concluded that modified asphalt mixture with polystyrene will improve strength material properties and decrease the resistance to deformation when being used in the

construction in hot climate conditions. Further research is needed for use polystyrene polymer in asphalt mixtures. Asphalt mixtures modified with phenol will increase the resistance to deformation when being used in the construction in hot climate conditions. To achieve sufficient performance, PVC and phenol resin can be used to resist deformation under heavy loads which will increase strength and durability.

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