INVESTIGATE PERFORMANCE OF POLYMER MODIFIED ASPHALT MIXTURES

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Abstract: In recent years, traffic loads have increased, and the sizes and loads of vehicles have become greater, thereby affecting the performance of asphalt pavements. Modified bituminous materials assist to add benefits to performance, maintenance and construction, in terms of better and longer lasting road, and saving in total road life cost. This study attempts to identify the influence of polymer modification in improving asphalt mixture performance. Three types of polymer resins were used, namely, Epoxy resin, Phenol resin, and Polyester resin. The physical properties of asphalt cement were tested by penetration and softening point. Apart from mix performance, the effect of modification on Marshall properties was studied. To estimate the tensile strength and evaluate the mixture's susceptibility to temperature variations, three test temperatures were used (15, 30, and 45°C). Furthermore, modified mixtures were tested by measurement of static creep. Based on the study results, it was found that increasing the phenol or epoxy resin quantities in asphalt cement lead to an increase softening point and reduce penetration. Material properties can be improved by the incorporation of phenol and polyester resins, since recovery property can be improved. Moreover, using phenol resin in asphalt mixes can increase the resistance to deformation when exposed to traffic loading.

Keywords: polymer modified asphalt mixtures; epoxy resin; phenol resin; polyester resin; creep test; tensile strength

ISPITIVANJE PONAŠANJA POLIMEROM MODIFICIRANIH ASFALTNIH MJEŠAVINA

Sažetak: Posljednjih godina prometno opterećenje je u porastu, kao i veličina i opterećenje vozila, što utječe na ponašanje asfaltnog kolnika. Materijali od modificiranog bitumena unaprjeđuju ponašanje, održavanje i izgradnju asfaltnih mješavina u smislu bolje kvalitete i trajnosti ceste te uštede ukupnih troškova tijekom projektnog razdoblja. Ovim istraživanjem pokušava se identificirati utjecaj polimernih modifikacija na poboljšanje ponašanja asfaltnih mješavina. Korištene su tri vrste polimernih smola: epoksidna smola, fenolna smola i poliesterska smola. Fizikalna svojstva asfaltnog veziva ispitivana su testom penetracije i točke razmekšanja. Ispitivan je utjecaj modifikacije polimerom i na Marshallova svojstva. Za procjenu vlačne čvrstoće i procjenu osjetljivosti mješavine na promjene temperature, korištene su tri različite temperature ispitivanja (15, 30, 45 C˚). Također, modificirane mješavine su ispitane i statičkim testom puzanja. Na temelju rezultata ispitivanja, zaključeno je kako povećanje fenolne ili epoksidne smole u asfaltnom vezivu rezultira povećanjem točke razmekšanja i smanjenjem penetracije. Svojstva materijala mogu se poboljšati primjenom fenolne i poliesterske smole s obzirom na poboljšanje svojstava izdvajanja veziva. Osim toga, uporaba fenolne smole u asfaltnim mješavinama povećava otpornost na deformacije pod prometnim opterećenjem.

Ključne riječi: polimerom modificirane asfaltne mješavine; epoksidna smola; fenolna smola; poliesterska smola; test puzanja; vlačna čvrstoća

1 BACKGROUND

In the first layer of a pavement structure, hot mix asphalt is used which distributes stresses and protects the pavement from environmental effects throughout the pavement's designed life. The action of the bituminous mixture is highly complicated and varies under different traffic and environmental conditions. Although only a small amount of binder is used in the mixtures, it has a significant effect on performance. In the asphalt industry, polymers represent one of the types of bitumen modifiers that are currently available, and play an important role in improving asphalt properties. Polymers are added to improve the performance of asphalt mixtures. Polymer modifiers are widely used to modify the viscoelastic behavior of the asphalt cement, thus increasing the performance of asphalt mixture. The asphalt properties that effect on mixture performance are adhesion and cohesion [1]. When a polymer is added to base asphalt, the polymer viscosity (stiffness) increases, and flexibility of the mix at high and intermediate temperatures improves, both of which improve the rut resistance and fatigue characteristics [2]. Polymer modified binders improve the adhesive bonding to aggregate, resulting in a thicker binder coating than with unmodified binders. This makes polymer modified binders brittle due to oxidation, thereby increasing durability. Good adhesion also minimizes drain down during construction [3]. Ahmedzade and Yilmaz [4] studied the effects of adding polyester resin on asphalt mixture properties. Their investigation demonstrated that modified bitumen with polyester resin improves the properties of bituminous mixtures. Hashem and Rashwan [5] conducted an experimental investigation to demonstrate the effect of adding Polyester and epoxy resin on the performance of asphalt mixtures. They concluded that adding resin modifier improves asphalt mix stability and performance, resulting in significant benefits. Al-Adham and Wahhab [6] studied nonrecoverable creep compliance (Jnr) values versus temperature on different types of polymer modified asphalt binders. They concluded that the amount and type of polymer, and testing temperature, are the factors that have the most significant effect on the recovery behavior of asphalt binders. Albrka et al. [7] stated that adding Acrylate Styrene Acrylonhrtilrei (ASA) polymer to modify asphalt binders can be considered an appropriate technique to enhance the properties of asphalt binders and mixtures. Saboo and Kumar [8] studied the characteristic fatigue performance of polymer modified asphalt by using elastomeric Styrene, Butadiene Styrene, and plastomeric EthyleneVinyl Acetate (EVA), and point that the modification by the plastomeric polymer was highly strain susceptible, leading to poor fatigue performance.

2 OBJECTIVE OF THE STUDY

The focus of the current study is to

1- Determine if the base and modified binders of the same grade provide comparable performance.
2- Identify the influence of modifiers on the performance of HMA.
3- Study the behavior of the polymer-modified binder.

3 MATERIALS CHARACTERIZATION

Selected materials include locally available asphalt, aggregate, and polymers. These materials are used in the asphalt paving industry, and in most road projects in Iraq.

3.1 Asphalt Cement

Asphalt cement with penetration grade 40/50 was used in this work, which was sourced from the Al-Durrah refinery. Conventional tests were implemented according to ASTM to determine the physical properties of the asphalt cement. The results are presented in Table 1.

Table 1 Asphalt Cement Properties (*).

Test	Test Result	Unit	ASTM Standard
Penetration	47	1/10 mm	D5
Ductility	>100	cm	D 113
Specific Gravity at 25 °C	1.04	Kg/m^3	D 70
Softening Point (Ring and Ball)	50	°C	D 36
Absolute Viscosity at 60 °C	2070	Poise	D2171
Flash Point	332	°C	D 92
Kinematic Viscosity at 135 °C	370	cSt	D2170

(*) These tests were implemented at the Al-Durrah refinery

3.2 Aggregate

Crushed quartz aggregate obtained from the Al-Taji quarry was used in this study. Gradation was selected in the requirement of the specification of the Iraq State Commission for Roads and Bridges (SCRB/R9-2003) [9] for the wearing course. Two aggregate gradations (G1 and G2) were adopted to compare the effects of gradation on the mix performance. Mixes were designed and compacted by 75 blows using the traditional Marshall method. These gradations are depicted in Figure 1, and presented in Table 2. The properties of the aggregates are listed in Table 3.

Table 2 Selected Gradation of Wearing Course.

Sieve opening (mm)	Percent Passing		SCRB Specification
	Selected Gradation		
	G1	G2	
19	100	100	100
12.5	92	90	90–100
9.5	84	78	76–90
4.75	67	55	44–74
2.36	41	30	28–58
0.3	15	16	5–21
0.075	9.5	9.5	4–10

Table 3 Al-Taji Quarry Aggregate Properties

Property	Standard	Coarse Aggregate		Fine Aggregate	
		G1	G2	G1	G2
Apparent specific gravity (g/cm^3)	ASTM C127 and C128	2.553	2.554	2.662	2.689
Bulk specific gravity (g/cm^3)	ASTM C 128	2.518	2.518	2.615	2.622
Percent water absorption	ASTM C 127 and C 128	0.556	0.56	0.68	0.94

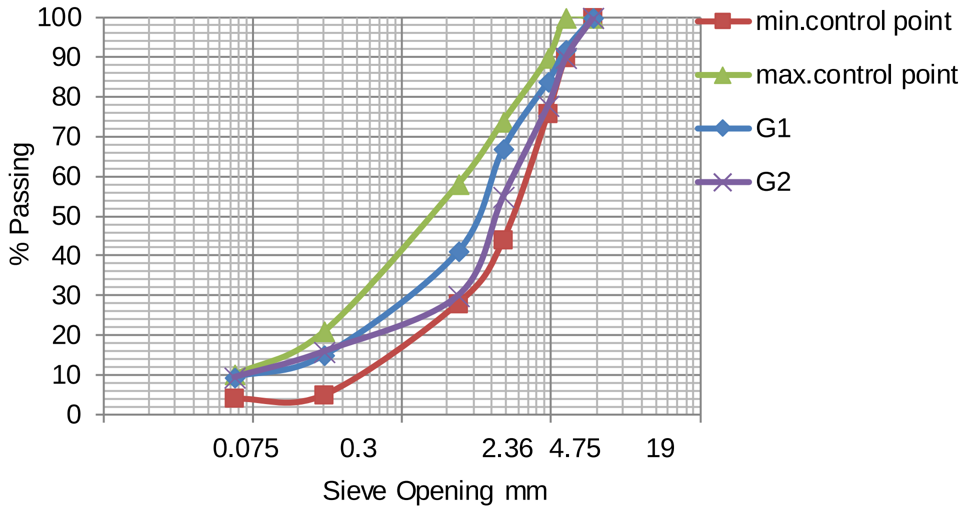

Figure 1 Selected Gradation, according to SCRB

3.3 Mineral Filler

Ordinary Portland cement was used as filler material, which passes sieve No. 200. According to the aggregate gradation listed above, a percentage of 9.5% was used in the mixture. Portland cement is locally available in the market, and its properties are presented in Table 4.

Table 4 Filler Properties

Property	Results
Specific Gravity (g/cm^3)	3.12
% Passing sieve No.200	95

3.4 Polymer additives

Polymers are classified into two types: elastomers and plastomers. Elastomers enhance elasticity within the asphalt structure, while plastomers tend to make stiff structures within the asphalt [2]. Polymers can be a very cost-effective way to increase the performance of asphalt mixtures. Different types of polymers are available, but it is vital to select the right types. The chosen polymer must have a low cost and provide good adhesion and durability. Polymer resins used in this study are depicted in Figure 2 and are classified into three types:

1-Epoxy resin

Epoxy resins were introduced in 1949, and are widely used. Epoxy resins are a type of thermosetting resin and are characterized by excellent adhesion, chemical resistance, and toughness [10]. These resins are cured by internally generated heat. They are composed of two parts, namely, resin and hardener. When mixed together, a chemical reaction occurs, which causes hardening of the material. Epoxy resins are more viscous than polyester resins. They are also superior in strength, but generally higher in cost than polyester resins.

2-Polyester resin

Polyester resin is available with various formulations and has good PG properties [10]. Polyester resins, such as epoxy types, are two-component liquid systems (resin and harder) and can be formulated to have a wide range of physical properties.

3-Phenol resin

Phenol resins have been used in various fields in the woodworking industry. They are easier to use and less expensive than epoxy resins [11]. They are also characterized by good strength and stability at high temperatures. Phenol resin in powder form was used in this study. It has thermosetting properties and hardens with heating. Studies on phenolic resins, focusing on their application in modified asphalt, demonstrate that they influence the viscoelastic properties of the modified asphalt. Phenol resins provide a low-cost solution in comparison with other modifiers, and their application is a matter of further research. Table 5 presents some of the physical properties of various polymers.

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Table 5 Polymer Properties

Item	Epoxy Resin	Polyester Resin	Phenol Resin
Density	1.05 g/cm^3	1.15 g/cm^3	1.11 g/cm^3
Resin Form	Liquid	Liquid	Powder
Color	No color	Amber	Amber
Reaction Temperature			High 90–130 °C
Hardening Process	Hardening with the addition of hardener	Hardening with the addition of hardener	Hardening reaction with the addition of hexamethylene tetramine HMTA and by heating

a) b) c)
Figure 2 Types of Polymers; a) Epoxy Resin b) Polyester Resin c) Phenol Resin

4 PREPARATION OF MODIFIED ASPHALT MIXTURES

Three types of the modified binder were prepared, namely, pure asphalt added to phenol, epoxy, and polyester resin. Pure asphalt alone was also used for comparison. Three polymer resin concentrations were used in the study: 2%, 4%, and 6% by weight of pure asphalt for the three types of polymers. The amount of hardener added to the polymer resins was 2% by weight of polymer. Both polymer content and hardener were measured by weight in two separate containers to prepare a modified binder. Both parts were then blended with asphalt at 150°C and mixed thoroughly for 30 min to ensure a complete and homogeneous mixture. Then, the aggregate was added to the modified asphalt and mixed thoroughly. This step is essential to prevent separation of the polymer from the asphalt during mixing, because some polymers are incompatible with asphalt and hence, affect binder quality. Unmodified bitumen mixtures were prepared by the Marshall method. According to the Marshall mix design, the asphalt mixtures have an optimum asphalt content of 4.65% for mixtures with gradation G1 and 4.59% for mixtures with gradation G2. All modified asphalt mixtures were prepared at this optimum asphalt content, to observe the effect of polymers on mixture properties.

4.1 Asphalt Mixtures Types

Several asphalt mixture types were designed with one asphalt, two aggregate gradation, and three polymer modifier types. These mixes were coded as per Table 6.

Table 6 Asphalt Mixture Type Codes

Asphalt Mixture Code	Description
	Control Mix
G1	Control mix designed by aggregate gradation G1
G2	Control mix designed by aggregate gradation G2
	Modified Mix
G1 2%	Modified mix designed by aggregate gradation G1 and polymer additive 2%
G1 4%	Modified mix designed by aggregate gradation G1 and polymer additive 4%
G1 6%	Modified mix designed by aggregate gradation G1 and polymer additive 6%
G2 2%	Modified mix designed by aggregate gradation G2 and polymer additive 2%
G2 4%	Modified mix designed by aggregate gradation G2 and polymer additive 4%
G2 6%	Modified mix designed by aggregate gradation G2 and polymer additive 6%

5 CONVENTIONAL TESTS FOR POLYMER MODIFIED ASPHALT

Two standard softening point and penetration tests were implemented on the modified and unmodified asphalt. The softening points of pure asphalt and different modified asphalt samples were tested depending on ASTM D36 [12], and the penetration test was conducted at 25°C according to ASTM D5 [12]. All the types of modified asphalt used in these tests were produced by adding resins, in powder or liquid form, to melted pure asphalt at 150°C. The degree of modification depended on the base asphalt and the asphalt-polymer compatibility.

6 MODIFIED ASPHALT MIXTURE PERFORMANCE TESTS

To evaluate polymer modified asphalt mixtures, it is important to determine the desired performance properties. Tests should be conducted to study the polymer-modified asphalt mechanical properties, such as tensile strength, deformation, and temperature susceptibility. The Marshall Mix design was used to investigate the volumetric properties of the modified asphalt mix in comparison with that of pure asphalt mixes. Indirect tensile tests for the prediction of tensile strength were tested at three testing temperatures (15°C, 30°C, and 45°C), and were used to predict changes of the modified asphalt concrete with temperature. A creep test at 25°C was conducted to evaluate the permanent deformation of the modified asphalt mixtures.

6.1 Indirect Tensile Test

The indirect tensile test is an important test used to characterize mixtures for tensile strength and fatigue. Paving material was tested by loading a cylindrical sample along the vertical diametral. Uniform tensile stress is developed perpendicular to the direction of the applied load and along the vertical plane. This causes splitting and failure of the sample [13]. The test was conducted according to standard ASTM D3967, 2008 [12].

6.2 Creep Test

A second important test of asphalt mixture performance is to test the ability to elastically (deformation recovery). Asphalt mixtures are designed to be flexible so that they can quickly return to their original position after loading. Rutting, pushing and shoving are some examples of failure mechanisms associated with permanent deformation [14]. When asphalt is modified with polymers, the rheological properties of the asphalt are changed. Asphalt is a viscoelastic material, demonstrating both viscous and elastic behavior, depending on the temperature and duration of loading [15]. A creep test is a time-dependent test used to monitor recovery per unit time and is conducted depending on AASHTO T 322-07[16]. The static creep test was done at 25 °C, with an applied stress of 0.1 Mpa, to determine the resistance to permanent deformation of hot mix asphalt (HMA) at loads similar to those experienced in the field. During the test, the stiffness modulus was estimated at any loading time, and was equal to the applied stress divided by the irrecoverable axial strain. Axial deformation was measured during the test and as a function of time. The axial strain can be determined as long as the initial height of the specimen is known. Figure 3 depicts the measured creep properties in this test, including the initial strain, total strain, permanent strain, and recovered strain of the creep curve.

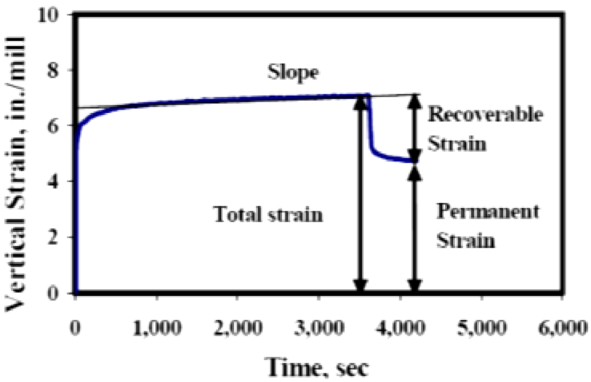


Figure 3 Creep Properties

7 TEST RESULTS AND DISCUSSION

7.1 Effect of Polymer Modified Asphalt on Penetration and Softening Point

The modified asphalt material was characterized according to conventional tests (penetration and softening point tests). Figure 4 illustrates the comparison of the properties of different modified asphalts with the unmodified pure asphalt. It is concluded that increasing phenol and epoxy resin content increases the softening point and decreases penetration. This is related to the harder consistency of polymer-modified asphalt, and this type of modified asphalt is therefore considered preferable in hot climates. The behavior is different when 2% of polyester resin is added, as the penetration increases and the softening point decreases. However, after that, the addition of polyester resin reduces the penetration and increases the softening point, as stated by Ahmedzade, P., & Yilmaz, M. [4]
Generally, polymer-modified asphalt exhibits a lower penetration value than unmodified asphalt. The penetration value typically decreases with increasing polymer content, and as expected, the modified asphalt exhibits a higher softening point. An increase in the softening point can improve the resistance under high temperature while maintaining a good asphalt performance. The polymer additives only alter the physical properties and do not change the chemical nature of the asphalt.

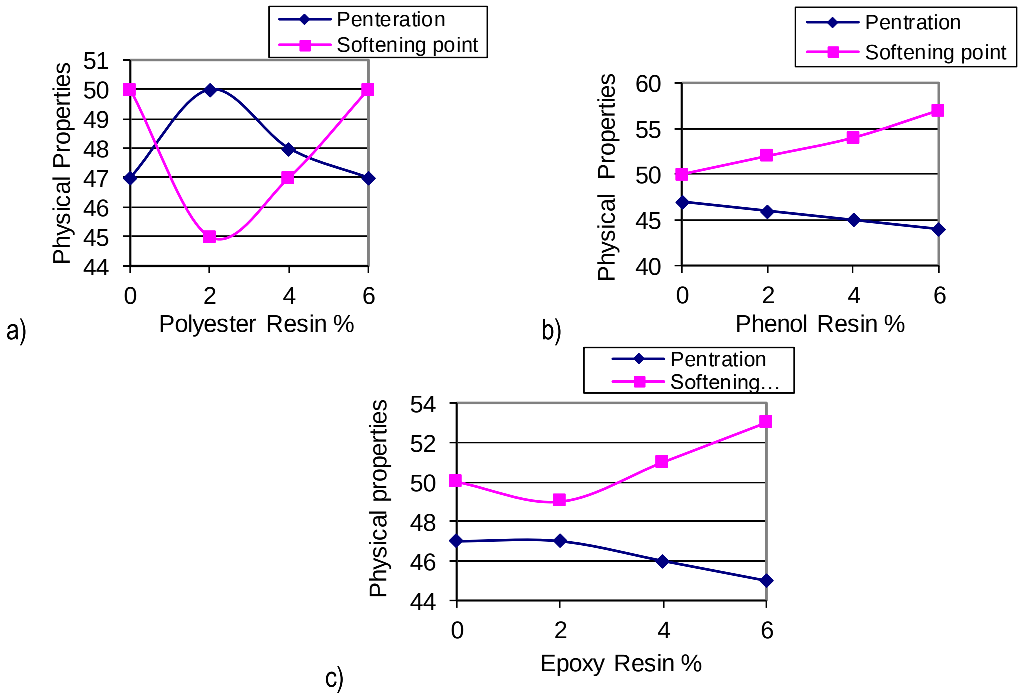


Figure 4 Physical properties of different modified asphalt; a) for Polyester additive, b) for Phenol additive, and c) for Epoxy additive

7.2 Effect of Polymer Modified Asphalt on the Volumetric Properties of HMA

The Marshall mix design was used for all mixes. The volumetric properties of air voids (VA), voids in mineral aggregates (VMA), voids filled with asphalt (VFA), and voids in the total mixture (VTM) were estimated for all modified and unmodified mixtures. Figures 5, 6, and 7 depict the effect of asphalt modification on volumetric properties. The density of mixture increased with 2% phenol resin, but when the content was increased to 4% or 6%, then the density decreased. An increase in polyester resin in the mixtures decreased the density; however, with epoxy mixtures, the density varied.

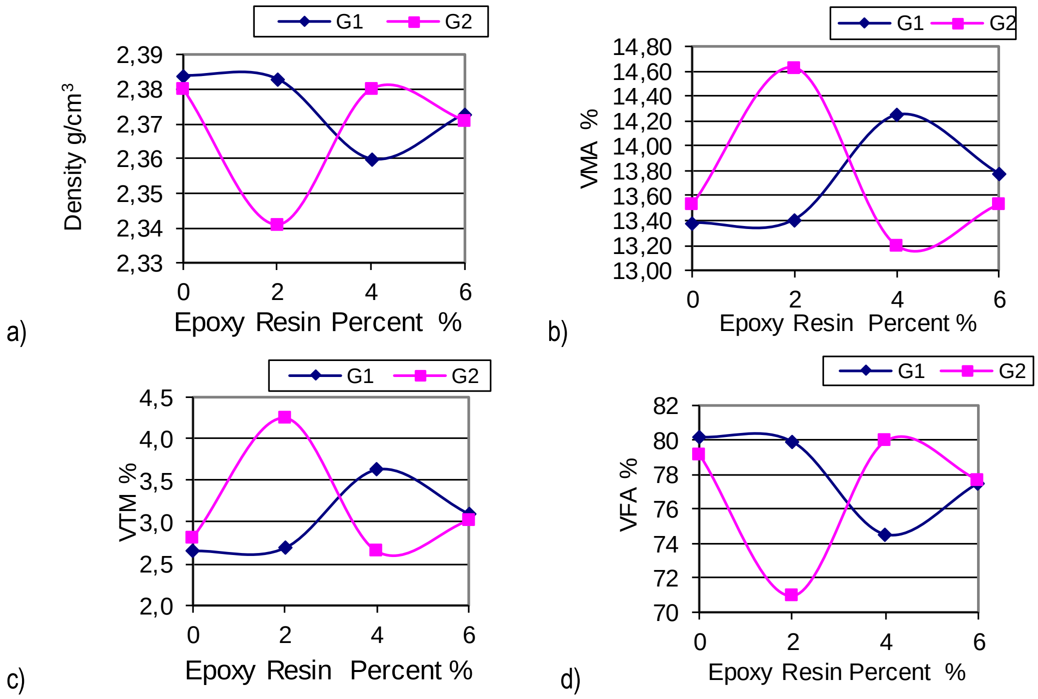


Figure 5 Effect of Epoxy asphalt modification on volumetric properties; a) density, b) VMA, c) VTM, d) VFA

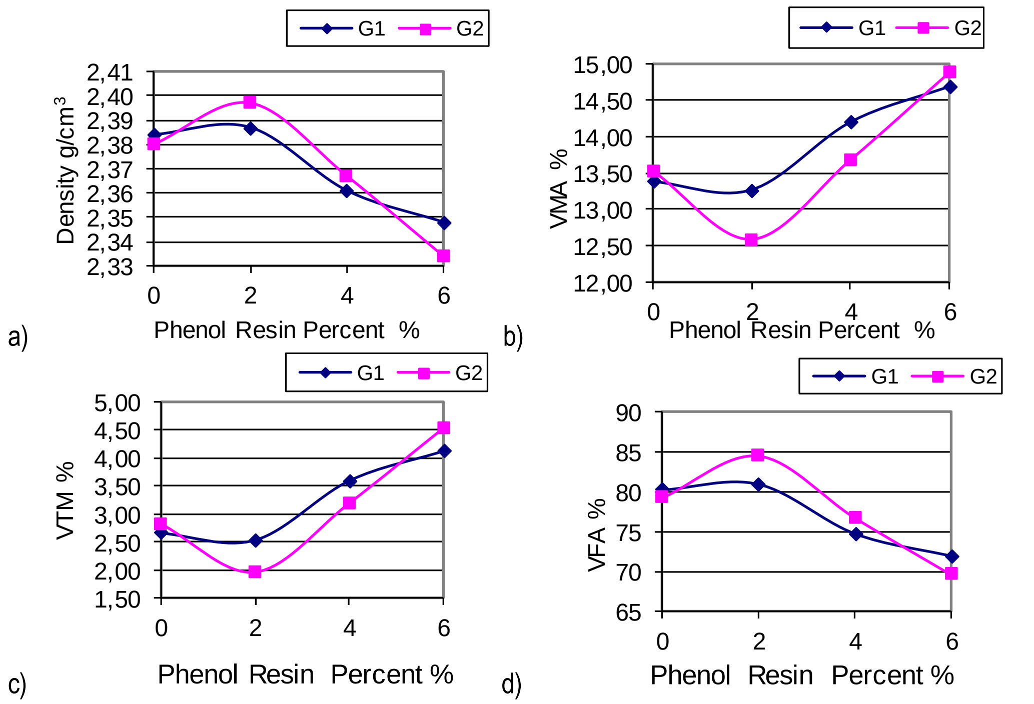


Figure 6 Effect of Phenol asphalt modification on volumetric properties; a) density, b) VMA, c) VTM, d) VFA

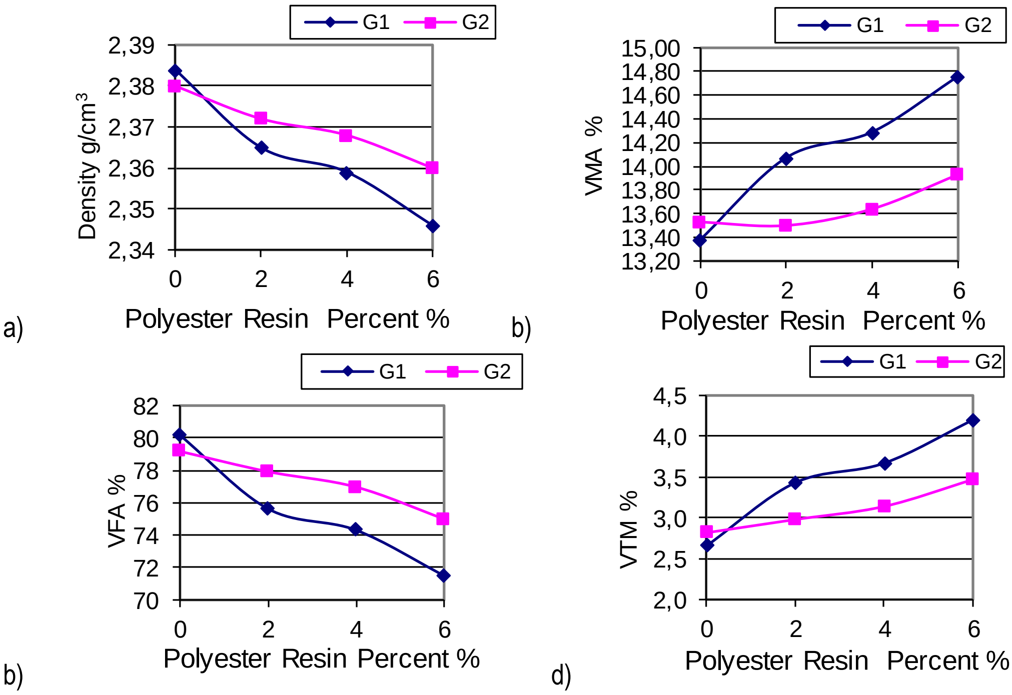


Figure 7 Effect of Polyester asphalt modification on volumetric properties; a) density, b) VMA, c) VFA, d) VTM

7.3 Influence of Asphalt Modification on the Performance of HMA

The tensile test is an important tool for observing changes in binder strength and for checking a mixture's susceptibility over the service temperature range. Figures 8, 9, and 10 depict the change in tensile strength value with modified asphalt mixtures, at three testing temperatures. According to the tensile test results, it is concluded that all types of the mix satisfy the tensile strength requirement; however, the modified specimen with epoxy polymer exhibits the highest tensile strength. Indirect tensile values indicate that a small difference exists between the different types of mixtures, although the most pronounced effect on tensile properties is observed for asphalt modified with an epoxy polymer. Tensile stress at failure for the epoxy asphalt mixture is higher than for the control or other modified asphalt mixtures at all three tested temperatures. The change in tensile strength with temperature provides an indication of the temperature susceptibility of the modified mixtures. However, at 45 °C, the results indicate that modified specimens can resist permanent deformation.

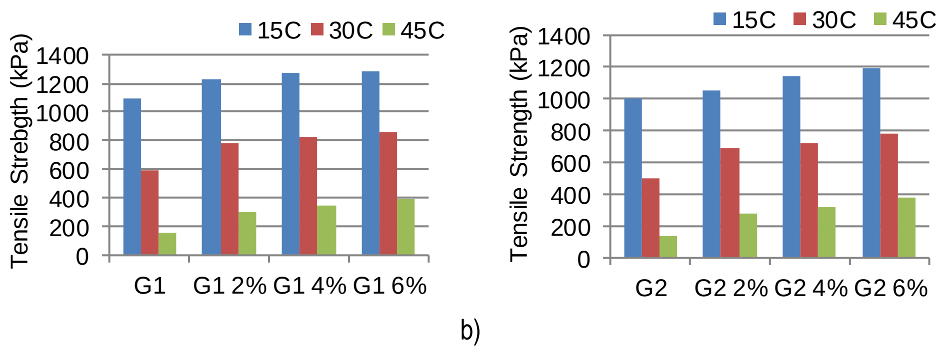
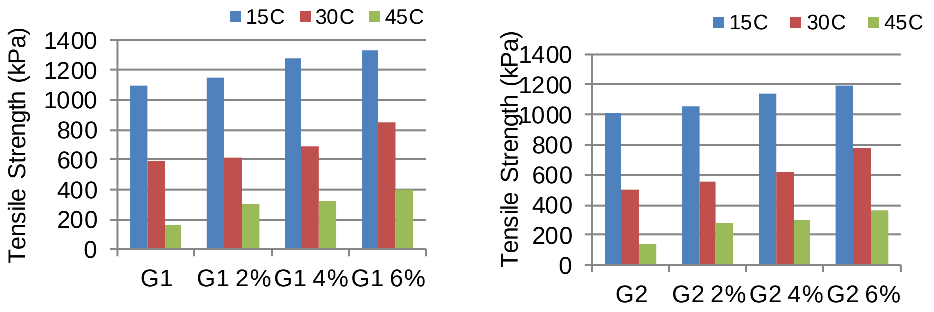
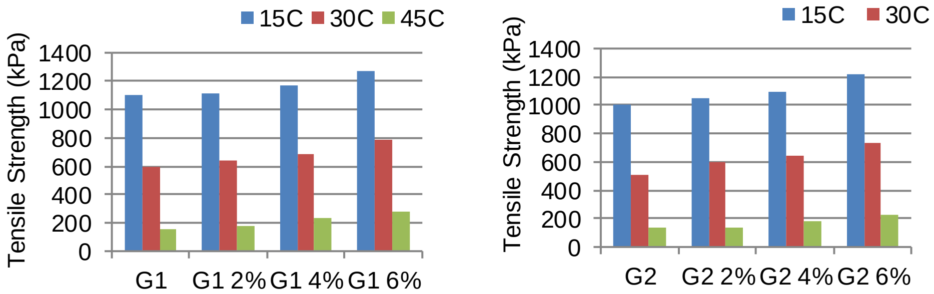


Figure 8 Evaluation of Tensile Strength of Epoxy asphalt mixtures; a) for aggregate gradation G1, b) for aggregate gradation G2



a) b)

Figure 9 Evaluation of Tensile Strength of Phenol asphalt mixtures; a) for aggregate gradation G1, b) for aggregate gradation G2



a) b)

Figure 10 Evaluation of Tensile Strength of Polyester asphalt mixtures; a) for aggregate gradation G1, b) for aggregate gradation G2

The rheological properties of modified asphalt differ substantially from those of unmodified asphalt [17]. The creep test results are depicted in Figures 11, 12, and 13, and are illustrated in the form of strain time curves for various mixes.

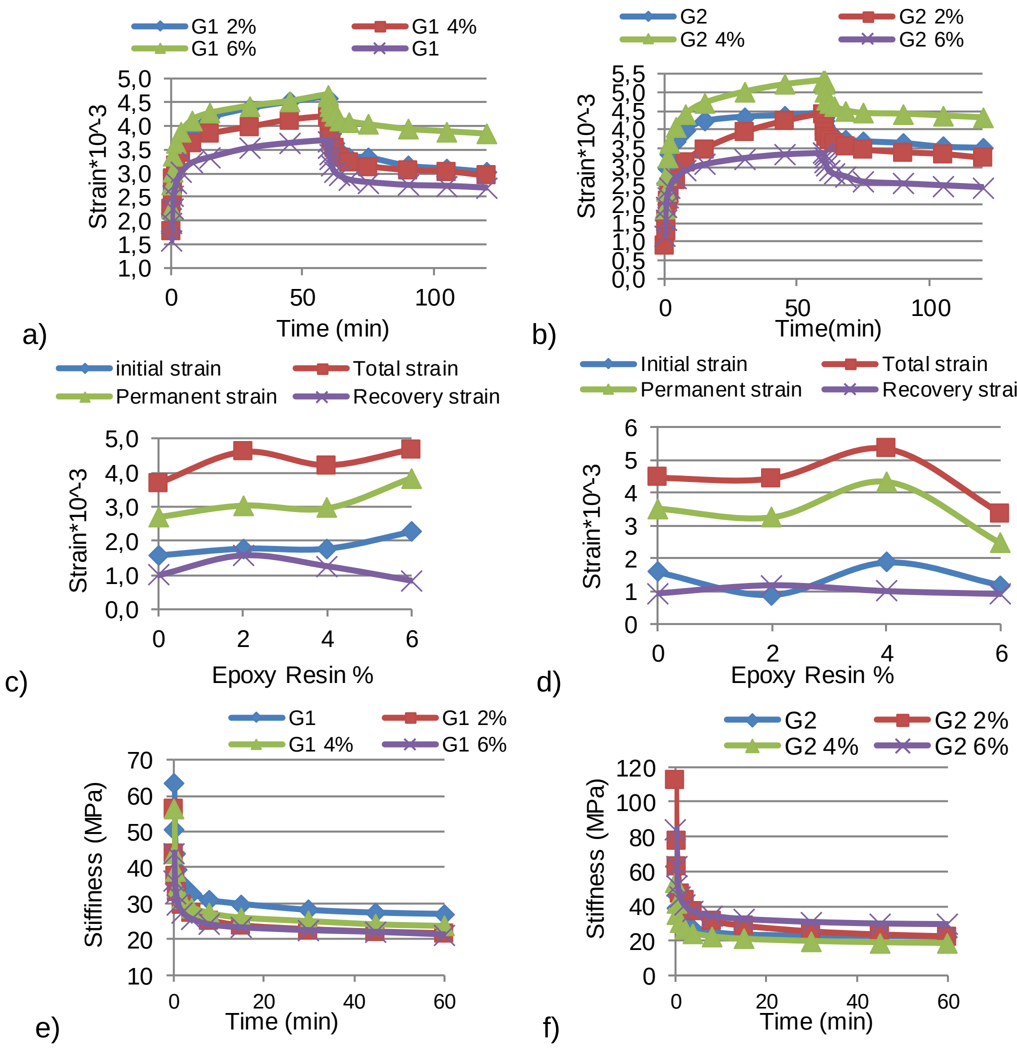


Figure 11 Creep test results; a and b) Strain-Time relationship of Epoxy asphalt mixtures, c and d) creep properties, e) and f) stiffness

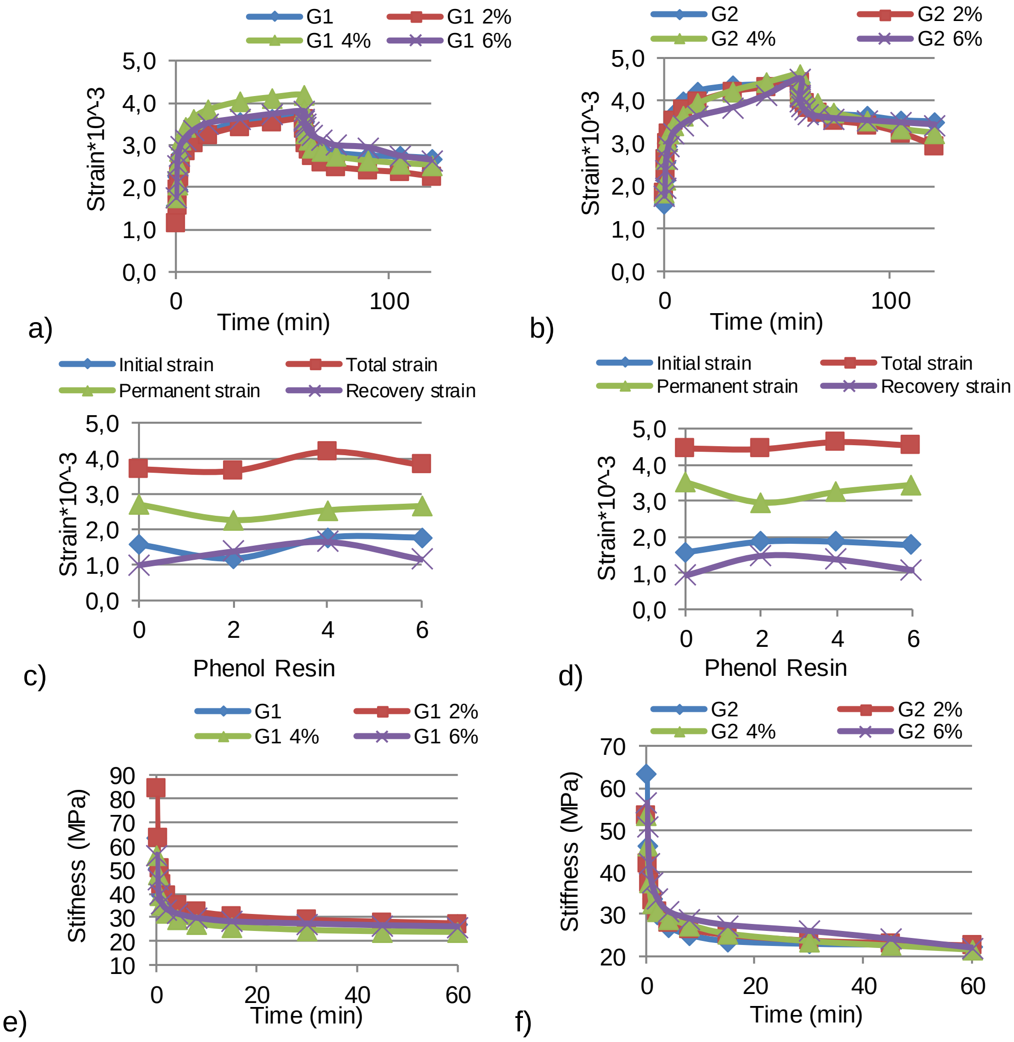


Figure 12 Creep test results; a and b) Strain-Time relationship of Phenol asphalt mixtures, c and d) creep properties, e) and f) stiffness

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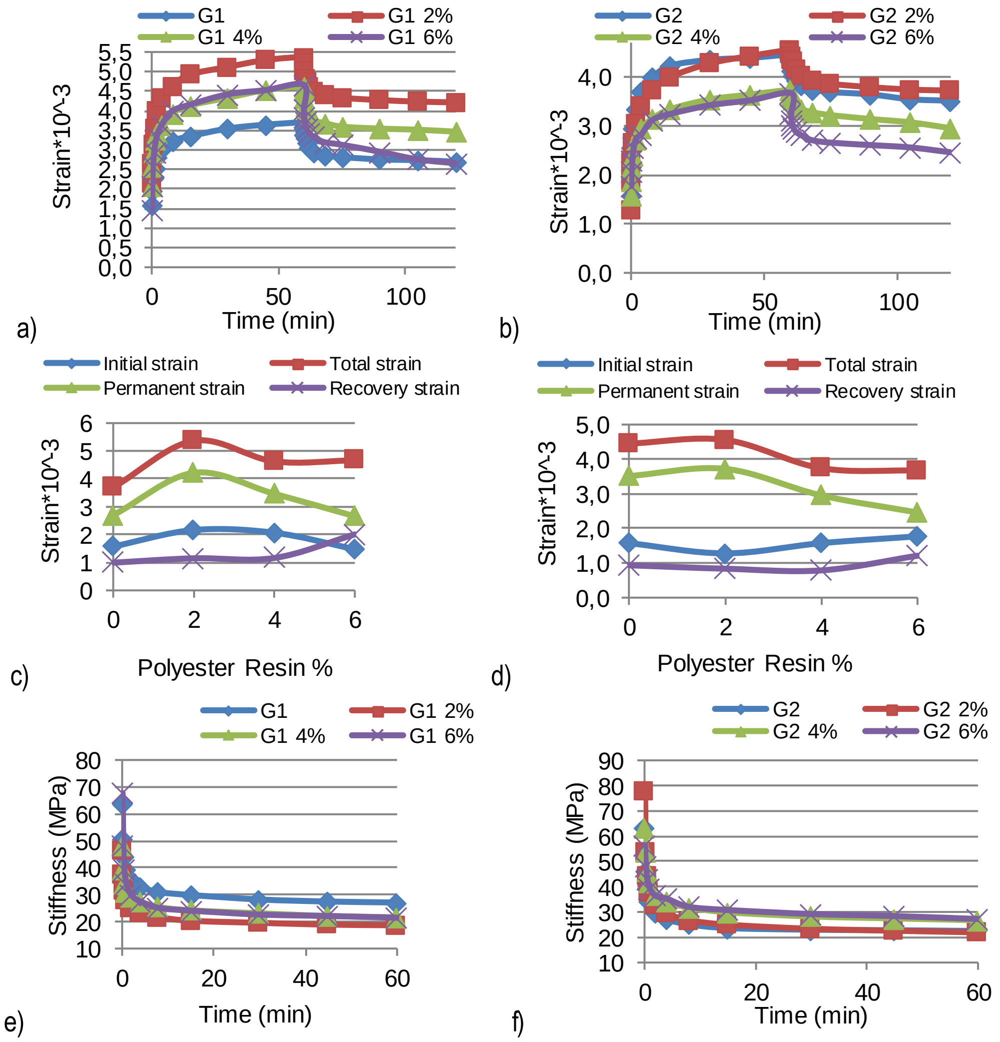

Figure 13 Creep test results: a and b) Strain-Time relationship of Polyester asphalt mixtures, c and d) creep properties, e) and f) stiffness

Improving the mechanical properties of modified asphalt can reduce permanent deformation. The figures indicate that the mixtures with polyester modification exhibit decreased permanent deformation and increased recovery. Adding 2% polyester increases the permanent strain; however, after increasing the content to 4% and 6%, the permanent strain is lower than the strain of the unmodified control mix. Mixtures with 2% phenol exhibit decreased permanent strain; however, after increasing the content to 4% and 6%, the permanent strain is approximately equal to the permanent strain of the control mix. This implies that the phenol mixtures have a higher recoverable strain, the least accumulated strain, and thus, the highest creep stiffness. After adding the proper amount of phenol resin, advantages, like high strength, high temperature resistance, and rutting resistance, can be realized. For mixtures with epoxy resin, the behavior is unclear. Indications are that, with epoxy asphalt modification, increasing epoxy content lowers the recoverable strain. Permanent strain, total strain, and initial strain are different and are related to the homogeneousness of the epoxy mixtures.

8 CONCLUSION

This study mainly aimed to modify asphalt cement properties with the use of polymers, focusing on achieving the best performance and long-lasting materials. Three types of polymers were used to modify asphalt cement, along with the behavior of asphalt with different percentages of these polymers. Physical tests were conducted to determine the penetration and softening point. In addition, asphalt mixtures modified by polymers were tested for performance via tensile and creep tests. From the results, it is concluded that a modified asphalt mixture with 2% of phenol increases the resistance to deformation when being used in the construction of the wearing course and exposed to various traffic loadings and climate conditions. Additionally, polyester resin improves recovery properties and reduces permanent strain in comparison with other modifiers. However, although epoxy modified asphalt mixes provide high strength, they cannot be used to reduce rutting. Moreover, they have drawbacks with respect to the homogeneousness of mixtures, performance, and cost.

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